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THE ADDED VALUE OF COPPER AND SILVER METAL FROM PRINTED CIRCUIT BOARDS WASTE USING DAVIS TUBE WITH VARIATIONS OF SIZE AND MAGNETIC INTENSITY

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Abstract

The widespread use of electronic devices has led to a significant increase in electronic waste, including PCB (printed circuit board) waste. PCBs contain valuable metals like copper and silver, which can be reclaimed and reused. Recently, there has been a growing demand for urban mining processes to extract electronic waste PCB Flame Retardant-2 (FR-2) from laptops and computers. During the urban mining process, PCB FR-2 waste undergoes various physical treatments such as dismantling, crushing, and concentration processes. One of the concentration processes involves magnetic separation using a Davis tube. This study aims to investigate the effects of size and magnetic intensity variations on the recovery of copper and silver levels in FR-2 PCB waste. The magnetic concentration process was carried out using different size ranges (-63+100#, -100+150#, -150#) and magnetic intensities (1000 G, 2000 G, 3000 G). The results indicated that the most effective size for separating copper and silver is -63+100# and the optimal magnetic intensity is 1000 G. This resulted in copper and silver content of 45.66% and 0.162%, with recoveries of 80.135% and 62.505% respectively.

Keywords: *Davis tube, electronic waste, magnetic separation, PCB FR-2, recovery*

1. INTRODUCTION

Advances in technology have led to an increase in the need for electronic equipment among the public so the production process of electronic devices is continuously in demand. However, this electronic equipment has a usage time limit which can cause e-waste to increase [1]. In 2016, global production of e-waste reached around 44.7 tons, while in 2021 the number increased by 17%, which is around 52.2 million tons and it can be estimated that by the end of 2030, total e-waste in the world could reach 74.7 million tons [2]-[3]. Things that can be done to take advantage of the ever-increasing amount of electronic waste can be reprocessing or urban mining. Many studies have been carried out to treat electronic waste, to obtain valuable metals contained in it such as gold and silver [2]. One part of an electronic device that contributes about 3% of all electronic waste is PCB (printed circuit board). PCB is a circuit board in a variety of electronic devices such as cell phones, computers, and televisions. The components on the PCB are made of polymer, metal, ceramic, and glass-based materials. PCB contains about 40% metal in all its components. Based on this, PCB is considered to have high economic value, so it is considered for reprocessing [2]. PCBs were included in electronic waste which contains the metal elements of Cu by 10-14.3% and Fe by 4.5-28% [4].

The three main stages applied to the process of extracting precious metals from PCBs are dismantling concentration, and purification. Magnetic separation was the commonly employed concentration process. Magnetic separation is carried out with two variables, i.e.,

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particle size and gauss/magnetic intensity. The use of the magnetic concentration method (magnetic separation) was effective in the process of extracting precious metals from PCBs because magnets can separate metals with different magnetic properties [5]. Particle size is critical in PCB waste treatment, influencing the distribution of metal content across various size fractions [4]. The finer the PCB sample size used, the higher the valuable metal content obtained.

2. MATERIALS AND METHODS

The material used in this research was FR-2 PCB (printed circuit board) waste from computers and laptops. In this study, the dismantling was carried out which was then followed by comminution and magnetic separation. In the dismantling process, the electrical components were separated manually using a screwdriver, pliers, and a hammer. Furthermore, the comminution process consists of two stages, crushing and grinding to reduce PCB size. In the crushing process, a hammer mill was used up to 18# PCB size. In the grinding process, a pulverizer mill was used to reduce the PCB size. Then the sieving process is carried out with sizes -63+150#, -100+150#, and -150#. The XRD (x-ray diffraction) and XRF (x-ray fluorescence) analyses were also carried out for initial sample characterization. The next process was magnetic separation using a Davis tube with a magnetic intensity of 1000 G, 2000 G, and 3000 G and variations in size -63+100#, -100+150#, and -150#. The recovered samples from the Davis tube were further analyzed by XRF.

3. RESULT AND DISCUSSION

3.1 Sieve Analysis of FR-2 PCB Waste

Sieve analysis was conducted in a dry state, and a graph in Fig. 1 shows the relationship between particle size in micrometers and the cumulative percentage pass. This sieve analysis aims to ensure that 80% of the passing particles are of the desired size.

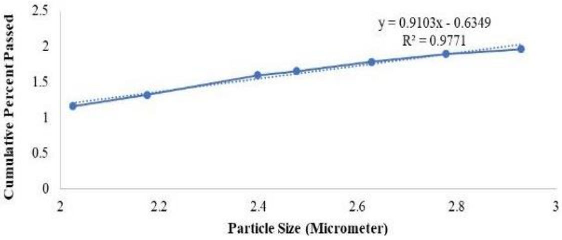

Figure 1. Graph of particle size against cumulative passage

Based on the graph, it appears that 80% of the initial samples did not pass through the 63#, 100#, and 150# sieves. Therefore, it is necessary to regrind the samples using a pulverizer mill.

3.2 XRD Characterization

The FR-2 PCB (printed circuit board) sample was tested using XRD (x-ray diffraction) characterization, and the results were obtained in Fig. 2. In Figure 2, it can be seen, that the dominant phases in the PCB used consist of copper and tin. The result is also supported by Anshu Priya's 2018 research which identified copper as the dominant metal element in PCB FR-2 [6]. On the other hand, tin is the main metal in the soldering process on PCBs, so the Sn content is also high [7].

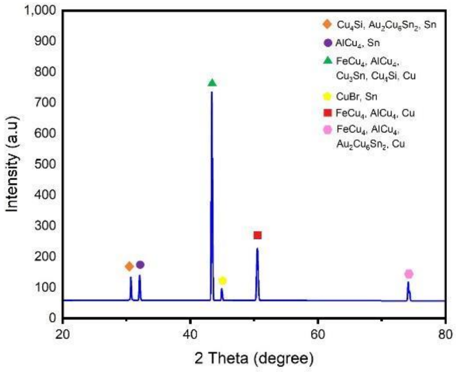

Figure 2. The constituents contained in PCBs

3.3 XRF Characterization

The results of the XRF (x-ray fluorescence) characterization test can be seen in Table 1 which depicts the highest elements content, such as copper, silicon, bromine, calcium, and aluminum.

Table 1. XRF characterization result of FR-2 PCB waste

Component	**Grade (%)**	**Component**	**Grade (%)**
Cu	54.03	Pb	0.71
Si	17.83	S	0.44
Br	8.57	Ag	0.24
Ca	7.44	Zn	0.17
Al	6.38	Ni	0.07
Sn	2.77	Sr	0.02
Fe	1.07	Sb	0.02

Copper l is the most dominant metal in PCBs because it has good electrical conductivity [8]. While silicon and calcium are non-metallic elements found in PCBs. Both elements were used as fiberglass materials for PCB parts [9]. Bromine was an element used in PCB boards such as paint, rubber, or PVC electrical insulation. Bromine has the function of reducing the flammability of PCB boards [8]. Silver and tin were used in solder to suppress the use of toxic lead [8]. Iron and nickel were used as construction elements for contact transformer magnetic cores [8].

3.4 Effect of Size Variation on Copper Content in Non-Magnetic Materials

The particle size is one of the factors that can affect the concentration in the magnetic separation process [10]. Figure 3 shows the effect of sample size on copper and silver content. The copper content is increased when it reaches the size of -100+150# at the magnetic intensity of 2000 and 3000 G. However, at this size, the copper content decreased at 1000 G. According to Wills, the finer the materials, the easier to separate them from impurities [10]. Deviations from expected results observed at size fractions between -100+150# under 1000 G, particularly in the context of decreased copper content, might be attributed to suboptimal release efficiencies caused by copper adhesion to the solder holding layer. The solder holding layer on the PCB is a permanent epoxy resin-based coating applied to the PCB shaping process. The copper was still attached or locked with other materials (gangue) which can only be separated with further comminution [11]. These results were also supported by Otsuki et al, who stated that on PCB boards there was a high probability of metal bonding with other materials such as metal, plastic, fiberglass, or resin in different particle sizes. In coarser sizes, metals are prone to bonding with other materials, whereas in finer sizes, the possibility of a metal still bonding with other materials is low [12]. Further comminution is also needed because based on the ductile nature of copper, it shows low grind-ability [13]. Therefore, to liberate copper with other components and increase its levels, it is necessary to carry out further comminution.

Table 2. Copper and silver content in magnetic materials

Magnet Intensity (G)	Particle Size (#)	Copper (%)	Silver (%)
2000	-150	36.97	0.144
3000		47.89	0.133

The reduction in copper content at a specific size during the magnetic concentration process using a Davis tube is influenced by various factors. These include the degree of release and forces such as magnetic intensity, gravity, and friction acting on the Davis tube. These forces can impact the outcome of the concentration process. [14]. The larger copper particles can get stuck in the magnetic material at the center of the tube, causing them to be trapped among the magnetic elements. Svoboda [15] suggests that at higher concentrations, fluid forces are less effective for larger copper particles, so they cannot push the copper to the non-magnetic output. The metal content was increased at -150# with conditions of 1000 and 2000 G, whereas at this size with a magnetic intensity of 3000 G, the content was decreased. The increase of copper content at -150# is supported by Wills, that fine-size samples will get higher levels [10]. The finer particles can cause a degree of liberation increase and the valuable minerals will be easily separated from the impurities [10]. The size reduction process carried out to be a finer size can optimize the degree of liberation of copper from impurities (gangue) such as epoxy resin [11]. The increase in copper content at fine sizes can also be affected by the fluid flow during this magnetic separation. The finer the particle size, can cause the fluid push to become stronger than the working magnetic force [15]. In finer size, copper is easily carried away by fluid flow. During the concentration process, small metal particles were carried by the fluid flow and deposited into a non-magnetic container. Anomalous findings at size -150# under a 3000 G magnetic intensity condition may result from copper becoming trapped by the magnet and entering the magnetic output due to the strong magnetic intensity. This is further confirmed by the significant copper content in the magnetic output, as indicated in Table 2, at 47.89%.

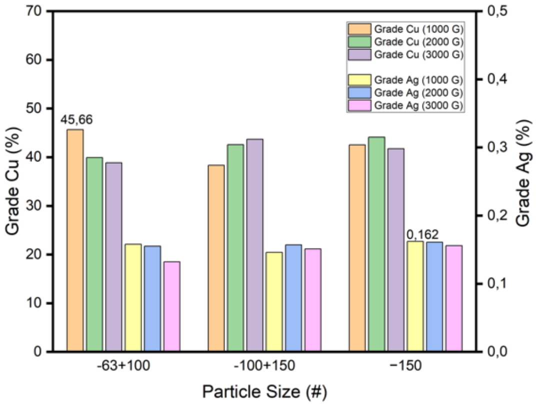

Figure 3. Effect of particle size on copper and silver metal content in non-magnetic materials

3.5 Effect of Size Variation on Silver Metal Content in Non-Magnetic Materials

The silver content obtained from this study can be seen in Fig. 3. The silver content continues to increase with the finer particles. The research by Wills [10] stated that the finer the size, the more valuable minerals will be free from impurities. The increased content of silver at a fine size was also caused by silver on the PCB board which is in the form of a thin layer [16]. Apart from this, the low content of silver facilitates the process of reducing the size of silver in PCB FR-2 waste [13]. The results of this study can be caused by the influence of the fluid used during the wet magnetic separation process. The fine size can cause the fluid force to be greater than the working magnetic force [15]. This is because silver with a smooth size and a flat shape on the PCB is easier to push by the fluid flow and not attracted by the intensity of the magnet which will then go to a non-magnetic material container.

3.6 Effect of Magnetic Intensity on Copper and Silver Content in Non-Magnetic Materials

In Figure 4 it can be seen the effect of the magnetic intensity on the levels of copper and silver. Copper and silver levels were concluded as fluctuating results. This is because the levels of copper and silver increase at a magnetic intensity of 2000 G and then decrease at a magnetic intensity of 3000 G. The increased levels of copper and silver in non-magnetic materials with a magnetic intensity of 2000 G can be caused by the dominance of low magnetic (diamagnetic) metals on FR-2 PCB waste samples. The dominance of low magnetic metals will cause impurities resulting from the magnetic concentration process. These impurities can be in the form of high-diamagnetic material at both outputs from the magnetic concentration process [10]. This is supported by the high levels of copper and silver in magnetic materials. The predominance of diamagnetic metals on FR-2 PCBs, for example, copper, tin, zinc, and silver, can be seen in Table 1.

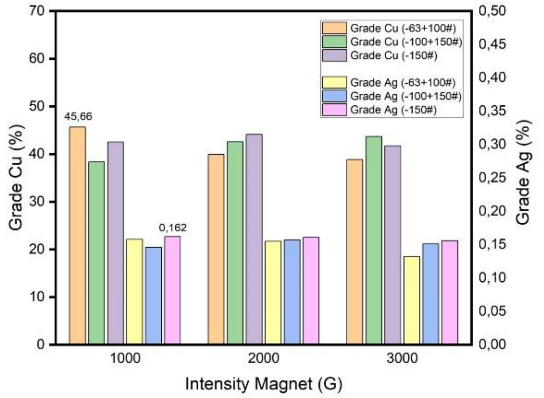

Figure 4. Effect of magnetic intensity on copper and silver content in non-magnetic materials

The decreased levels of copper and silver at a magnetic intensity of 3000 G can be caused by a high magnetic intensity. The high intensity of the magnet can increase the strength of the magnet to attract materials with low magnetic properties into the magnetic material output. This causes a decrease in weakly magnetic metals in the output of non-magnetic materials [10]. In other words, it can be concluded that with a magnetic intensity of 3000 G, a lot of copper and silver are attracted to the magnet and become a magnetic material output. The following research by Yamato [17] that the higher the magnetic intensity used, the material with low magnetic properties will be carried over to the magnetic material output.

The varying levels of copper and silver obtained could be due to clumping during the concentration process. Clumping prevents the material from coming into contact with the magnet during the magnetic concentration process. Clumping may occur because the PCB FR-2 material is hydrophobic, causing it to clump when dissolved in water [18].

3.7 Copper and Silver Recovery in Non-Magnetic Materials Using Davis Tube

The highest recovery of copper (80.135%) and silver (62.505%) was achieved at a magnetic intensity of 1000 G. While the documented prevalence of these key elements in FR-2 PCBs, as highlighted by Anshu Priya [6], may indeed facilitate their recovery, it appears that an alternative mechanism is in operation in this context.

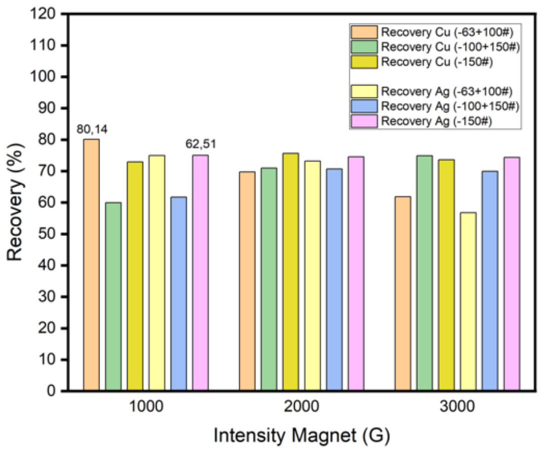

Figure 5. Copper and silver recovery in non-magnetic materials

Despite the hypothesis that strong magnetic attraction is needed to achieve high recovery of these weakly magnetic metals, the high recovery at 1000 G seems to be due to their repulsion from the magnet and subsequent settling in the non-magnetic container. This is consistent with the observation that high magnetic intensity can impede the recovery of non-magnetic materials [17].

The ideal magnetic intensity of 1000 G for the recovery of copper and silver is likely due to a balance between maximizing the capture of the main elements in the PCB and minimizing the repulsive effects of the magnet on these weak magnetic metals. Although this intensity is close to achieving the theoretical maximum recovery of 100% [19], further research is necessary to fully comprehend the connection between magnetic intensity, metal properties, and recovery efficiency in this separation process.

4. CONCLUSION

The size of particles influences how quickly valuable minerals are separated from impurities. During magnetic concentration, the highest levels of copper and silver were obtained at particle sizes of -63+100# and -150# respectively. The strength of the magnetic field affects the separation of materials based on their magnetic properties. The highest levels of copper and silver were found at a magnetic intensity of 1000 G, with levels of 45.66% and 0.162% respectively. The recovery of metals is impacted by the metal content and the mass of valuable minerals obtained. The best recoveries of copper and silver are 80.135% and 62.505% at a magnetic intensity of 1000 G.

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