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Conference Paper

Electric Discharge Destruction of Wasted Printed Electronic Boards for Extraction of Metals

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Abstract
The results of the electric discharge crushing of PCB (printed circuit boards) to millimeter-sized fractions suitable for separation of the metal from the dielectric are presented. The crushing was performed on a high-voltage repetitively pulsed generator with varying the number of pulses. It was determined the dependences of the fractional composition of crushing products on the number of pulses in the cycle. Crushing products were studied for definition separation of metal from the dielectric with optical microscope. The results of the work confirm the possibility of electric discharge crushing various types of PCB, including fiberglass PCB with four layers.

Keywords: high voltage fragmentation, waste printed circuit board, recycling

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1. Introduction

Intensive inculcation of electronics in all sectors of the economy has caused a rapid increase quantity of electronic waste. PCB (printed circuit boards) are an integral and very valuable part of this waste. Recycling PCB for reuse has high potential since the boards contain dozens of types of metals. Copper is the main metal in PCB in a volume of up to 20%. Also, PCB composition includes solder up to 4%, nickel up to 2%, and silver, gold, palladium and other in a much smaller amount [1, 2].

In world practice, the extraction of metals from electronic waste is carried out by means of mechanical processing, pyrometallurgy, hydrometallurgy, or a combination of these technologies. Combustion and melting, as well as hydrometallurgy processes, are characterized by high energy and material intensity and pose a danger to the environment. Also, the surface of materials could contaminate because of processing by metallurgical and chemical methods.

In the methods, based on the mechanical crushing of PCB, obtain disintegrated crushed material, which is further separated on a vibrating stand, in air, magnetic, electrostatic, and other separators [3–5]. Importantly, mechanically crushed material wasn‘t must over-crushed and be uniform in size of the fractions for effective separation. It is also important to ensure low energy consumption, as well as the fulfillment of environmental requirements by mechanical crushing methods.

The electric discharge method, in which the working tool is a discharge channel with a high energy concentration of about 100 kJ/cm^3, has justified prerequisites for efficient crushing of PCB. In particular, the method of electric discharge crushing was developed for aim to the task of extracting precious and rare metals from rocks [6–8]. The work results demonstrate high fracture selectivity, better recovery and lower content of finely dispersed inclusions in comparison with traditional mechanical methods. The selectivity of disintegration is achieved due to the difference in dielectric, strength, deformation and acoustic properties of the components.

PCBs have a complex multicomponent composition. Using the electric discharge method for PCB disintegration is interest because PCB have significant differences in density and electrical conductivity [9, 10].

The most common bases for the manufacture of printed circuit boards are foil-coated fiberglass (FR-4) and paper-based laminate (FR-2). As a rule, FR-4 is used in complex electronic devices, FR-2 - in simple home electronics. In addition to the base material, the boards can differ in the number of conductive copper layers. The material of the dielectric base and the number of layers determine the mechanical properties of the PCB and the energy consumption for crushing them. This paper presents the results of crushing by an electric discharge method of various types of the PCB with summary information on the fractional and structural composition of the resulting material.

2. Experiment Design

The experiments were performed with using generator with pulse charging of a high-voltage capacitive energy storage. The generator circuit and a photograph of the crushing chamber are shown in Figure 1. The primary capacitive energy storage C_1=244.4 μF is switched by the thyristor *VD* to the primary winding of the step-up pulse transformer *T* and charges the high-voltage energy storage C_2=8 nF to a voltage of 200–250 kV. Capacitive storage C_2 is switched by an uncontrolled gas spark switch *S* to the discharge gap of the crushing chamber. The impedance of the discharge circuit of a high-voltage energy storage device is about 10 Ohms. The pulse repetition rate is 5 Hz.

The crushing chamber uses a geometry with a sharply inhomogeneous electric field. The potential electrode is made in the form of a thin-walled cylinder with a diameter of 40 mm. A fragment of a PCB is placed on a grounded flat electrode. The volume of the crushing chamber is filled with water from the water supply network without additional processing. The specific resistance of water is ~10^4 Ohm·cm.

We studied the crushing of three common types of PCBs: single-layer board made of paper-based laminate, two-layer and four-layer boards made of fiberglass. The PCBs were cut into samples 60×60 mm^2 in size. Large components, such as radiators and electromechanical relays, were removed manually.

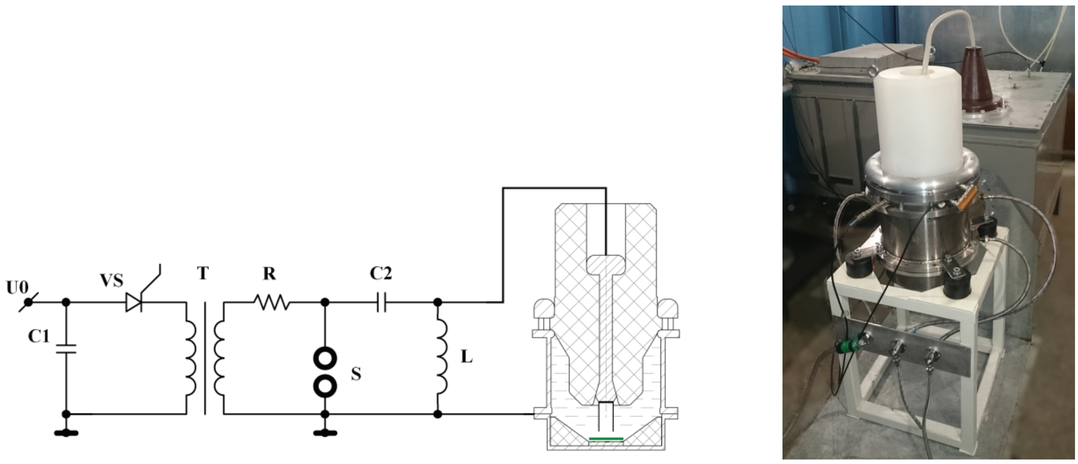

Figure 1: Generator circuit and a photograph of a chamber for electric discharge crushing.

Crushing was carried out in two stages. At the first stage, a regime was selected that ensured that the PCBs were cleaned of mounted electronic components. At the second stage, samples purified from electronic components were crushed. After a given number of pulses, the crushing products were successively sieved through a set of metal grids with different cell sizes and the separation of crushing products into fractions of +5 mm, +2.5-5 mm, +0.5-2.5 mm and -0.5 mm was obtained. It was investigated the effect of the number of pulses on the fractional composition. For this purpose, it was select four samples of each type of PCB with a similar configuration. Each sample was exposed to a different number of pulses. After then, the material was separated into fractions, dried and weighed. The separation of metal from the dielectric in fractions was studied using a Karl Zeiss optical microscope equipped with an AutoCam Hrc5 optical camera.

3. Experimental Results

Figure 2 shows the initial sample of a four-layer PCB and its appearance after 100 and 250 pulses. As can be seen from the figure, it is required about 250 pulses to completely clean such PCB from electronic components. With a further increase in pulses, the destruction of the PCB itself begins.

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Figure 3 shows the dependences of the fractional composition on the number of pulses for three types of PCBs. An example of the appearance of the fraction after electric discharge crushing is shown in Figure. 4.

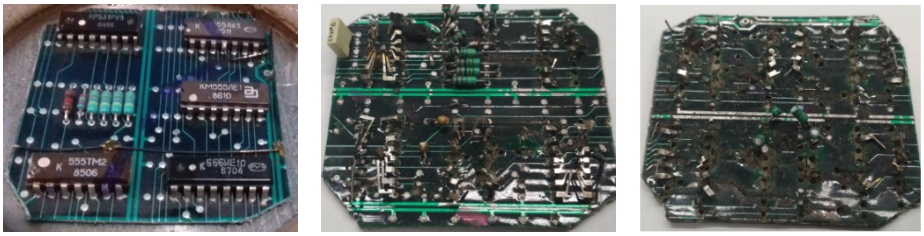


Figure 2: Photos of a four-layer PCB with attached components: initial, after 100 and after 250 pulses.

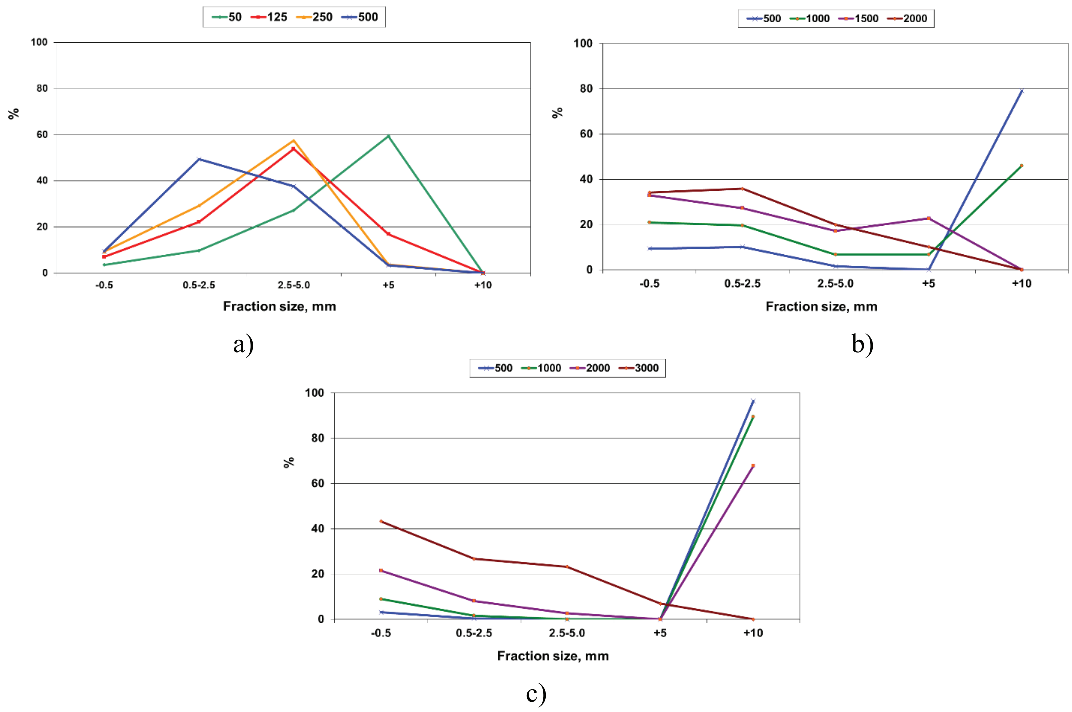


Figure 3: Diagrams of the dependence of the fractional composition on the number of pulses for single-layer PCB from paper-based laminate (a), two-layer (b) and four-layer PCBs (c) from fiberglass.

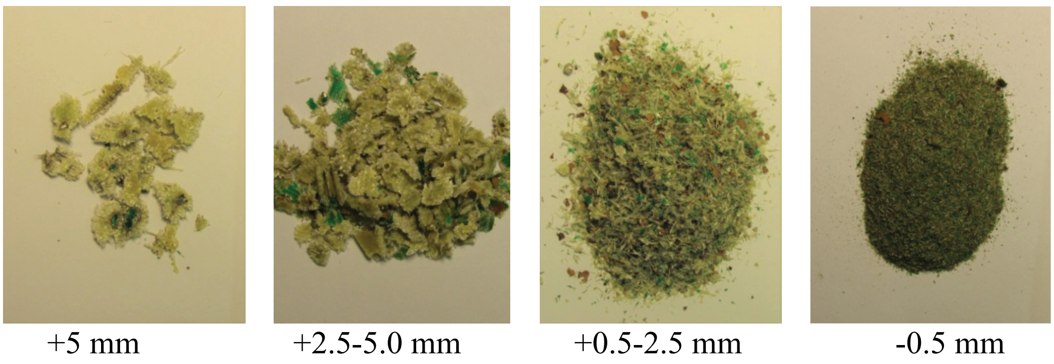
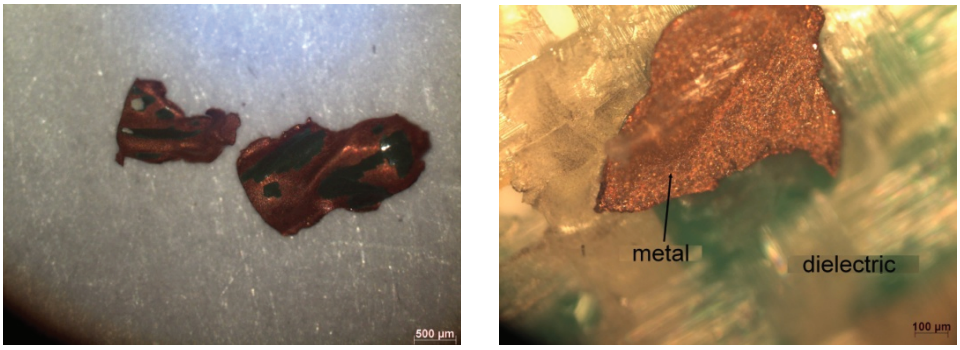


Figure 4: Photos of fractions obtained after crushing a four-layer PCB.

The crushing of single-layer paper-based laminate PCBs is significantly different from the crushing of fiberglass PCBs. The main difference is associated with significantly lower (at times) the mechanical strength of the paper-based laminate. In consequence of that, the resulting fractions generally have a size of less than 5 mm after 100 pulses already. In the case of crushing of two-layer fiberglass PCB, more than 1000 pulses are required to achieve a fractional composition with a predominant fraction size of -5 mm, and in the case of four-layer fiberglass PCBs, at least 3000 pulses. The crushing of the last type of PCBs by the electric discharge method is the most energy-consuming due to the internal copper supply layers.

Visually, the structure of fractions is not different for two-layer and four-layer fiberglass PCBs. The investigation showed that for fractions of +5 mm there is no separated copper from fiberglass and solder mask, but signs of peeling of metal layers in the form of curved edges are manifested. For fractions +2.5-5.0 mm, pure copper without mechanical impurities is observed (Figure 5a), as well as in dense intergrowth with fiberglass (Figure 5b). For fractions of +0.5-2.5 mm, the amount of copper without mechanical impurities increases. For the -0.5 mm fraction, pure copper in the form of plates and wire and solder in the form of balls are mainly observed (Figure 6). The results obtained are consistent with the data of [5, 11], according to which a fraction of less than 2.5 mm is required for separation of copper from the fiberglass, and less than 0.5 mm for separation from the ceramic.



a) b)

Figure 5: Photos of fractions +2.5-5.0 mm of pure copper (a) and in intergrowth with fiberglass (b).

4. Conclusion

The results of the work confirm the possibility of crushing of electronic PCBs of various types (including four-layer ones with a fiberglass base) by the electric discharge method. It was determined the dependences of the fractional composition of crushing products on the number of pulses in the cycle and the possibility of obtaining submillimeter-sized

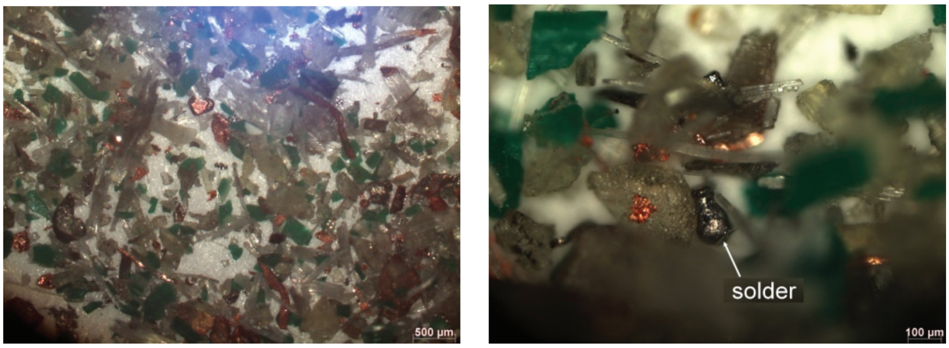


Figure 6: Photos of fractions -0.5 мм.

fractions is shown. The data obtained make it possible to select the number of pulses providing the maximum yield of the fraction of the required size for complete separation of the metal from the dielectric. Further work is associated with the optimization of the discharge gap and discharge parameters to increase the energy efficiency of the crushing process.

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