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Liberation characteristics after cryogenic modification and air table separation of discarded printed circuit boards

Cuihong Zhou[a,*], Yongtai Pan[b], Maxi Lu[b], Changshun Yang[a,c]

[a] Department of Environmental Engineering, Beijing Institute of Petrochemical Technology, Beijing 102617,PR China
[b] College of Chemical and Environmental Engineering, China University of Mining and Technology, Beijing 100038, PR China
[c] College of Mechanical and Electrical Engineering, Beijing University of Chemical Technology, Beijing 100029, PR China

HIGHLIGHTS

- The PCBs were preferably crushed by impact and bending means.
- The power consumption had a strong dependence on cooling temperature.
- Cryogenic grinding obtained fine size reduction and good liberation.
- Air table effectively separated 2.8–0.5 mm grade PCBs material.

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ABSTRACT

Liberating useful materials from printed circuit boards (PCBs) is challenging because PCBs are flexible and complex in terms of materials and components. In this study, the crushing of PCBs at low-temperature was investigated. The results indicated that when the temperature was decreased to approximately −20 °C, the strength of PCBs decreased and their brittleness increased, making them easier to crush. A double roll crusher was selected to crush the PCBs. The particle size distribution and power consumption were studied under different working conditions. The results showed that the particle size of most of the lumps was in the range 15 × 20–25 × 20 mm, and that power consumption was minimal when the frequency of the crusher was 40–50 Hz. A small shredder was used for cryogenic grinding, and it was found that its power consumption strongly depended on the cooling temperature. An orthogonal experiment was conducted, which revealed that a smaller cutter gap and higher rotational speed could achieve higher yield. Furthermore, the results indicated that the air table developed to liberate PCB materials could effectively separate 2.8–0.5 mm grade materials. Overall, the results of this study provide an experimental foundation for more effectively recycling discarded PCBs.

1. Introduction

With the continuing development of information and electronic technology, the amount of electrical and electronic waste has increased. The recovery of useful materials from PCBs has drawn considerable attention because the printed circuit boards (PCBs) in personal computers (PCs) and mobile phones contain valuable metals. These include precious metals such as gold, silver, palladium, and rhodium [1–5]. PCBs also contain major metals and alloys, such as ferromagnetic materials, aluminum, and copper, which are difficult to liberate from PCBs at normal temperature or by using general crushing technology [6–8]. Moreover, the treatment of PCBs is very challenging because PCBs are diverse and complex in terms of materials and components. Nowadays, new technological innovations continue to accelerate the replacement of electronic devices, leading to a significant increase in discarded PCBs [9–13].

The process for recovering useful materials from PCBs includes dismantling, crushing, and separation. Crushing is a crucial step for the subsequent treatment of PCBs [14–17]. There are three primary objectives for size reduction by crushing: 1) generation of particles that are more easily handled than bulky parts, 2) generation of uniformly sized and shaped particles that can be separated effectively in downstream processes, and 3) liberation of dissimilar materials from one another [18,19].

* Corresponding author at: Department of Environmental Engineering, Institute of Petrochemical Technology, Qingyuan North Road 19, Daxing, Beijing 102617, PR China.
E-mail addresses: tide_zhou@163.com, zhoucuihong@bipt.edu.cn (C. Zhou).

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Because traditional grinding is not suitable for PCB recovery, a wet impact crusher and shear hammer mills are generally used to obtain coarse size reduction and liberation of materials [10,20]. To develop a low-cost recycling process for treating PCBs from scrap electronics, selective grinding for ductile and stiff materials was investigated with a PC-assisted impact grinding system that can automatically control various operating conditions in real time [21,22].

The cryogenic grinding process has advantages, such as lower energy costs compared to traditional grinding, and can help realize a more uniform particle size. However, studies are required to ascertain the economic value of this process. This technology has been adopted for crushing rubber, thermoplastics, spices and other food products, pharmaceuticals, waxes, hot melt adhesives, pigments, powder coating materials, and electronic wastes [23–25].

Several studies have been conducted for embrittlement of materials by pretreatment at low temperatures (−20 °C or less) or high temperatures (250 °C) utilizing selective grinding in waste processing. [26–28]. The results show that the metal and nonmetal particles of PCBs dissociate completely at the crushing size of 0.6 mm and that metal is mainly enriched in four size fractions between 0.15 and 1.25 mm [29,30]. By using cryogenic grinding technology, the material properties are changed at low temperatures, so materials that cannot be ground finely at room temperature can be ground when brittle at lower temperatures.

Before the cryogenic modification experiment, we crushed the PCBs using a hammer mill, and the experiment failed. The materials did not disintegrate, the quantity of qualified material was small, and the separation requirements were not satisfied. Hence, we improved the crusher and adopted cryogenic technology. The objective of this study was to investigate the mechanical properties of discarded PCBs at low temperatures, including impact, bending, and shear strengths below a critical temperature. These results would be beneficial for the selection of effective crushers and grinders for use with waste PCBs. The influences of temperature and crushing time on the crushing characteristics and power consumption were also investigated. Finally, an air table was adopted, which uses air as a medium to separate metals and nonmetals through asymmetric reciprocating movement. The separation mechanism was analyzed, and the separation of PCB materials was demonstrated.

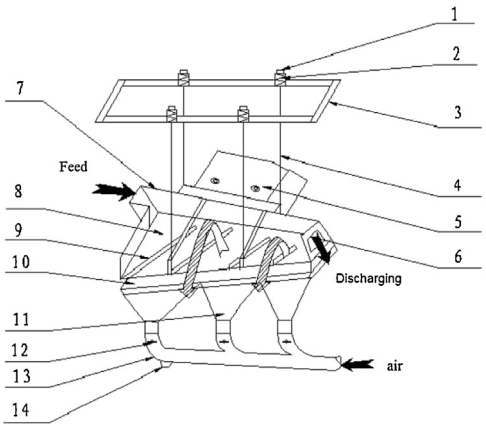

Fig. 1. Diagram of the air table. 1—Angle adjusting nut of table, 2—Damper spring, 3-Frame, 4—Steel wire rope, 5—Vibration motor, 6—Discharge port, 7—Backboard, 8—Bed, 9—Lattice bar, 10—Discharging Plate, 11—Air chamber, 12—Air valve, 13—Air hose, 14—Discharge port.

2. Experimental method

2.1. Materials and devices

The PCBs were collected from discarded electronics. Liquid nitrogen was selected as the refrigerating medium because it is a non-flammable and non-toxic inert gas. The double roll crusher used for the PCBs was improved by adding spirally arranged teeth. The particles are crushed by the relative motion of the two rollers as the grid rotates. The broken tooth space and the cutter gap of the top gear will determine the size of the crushing material,

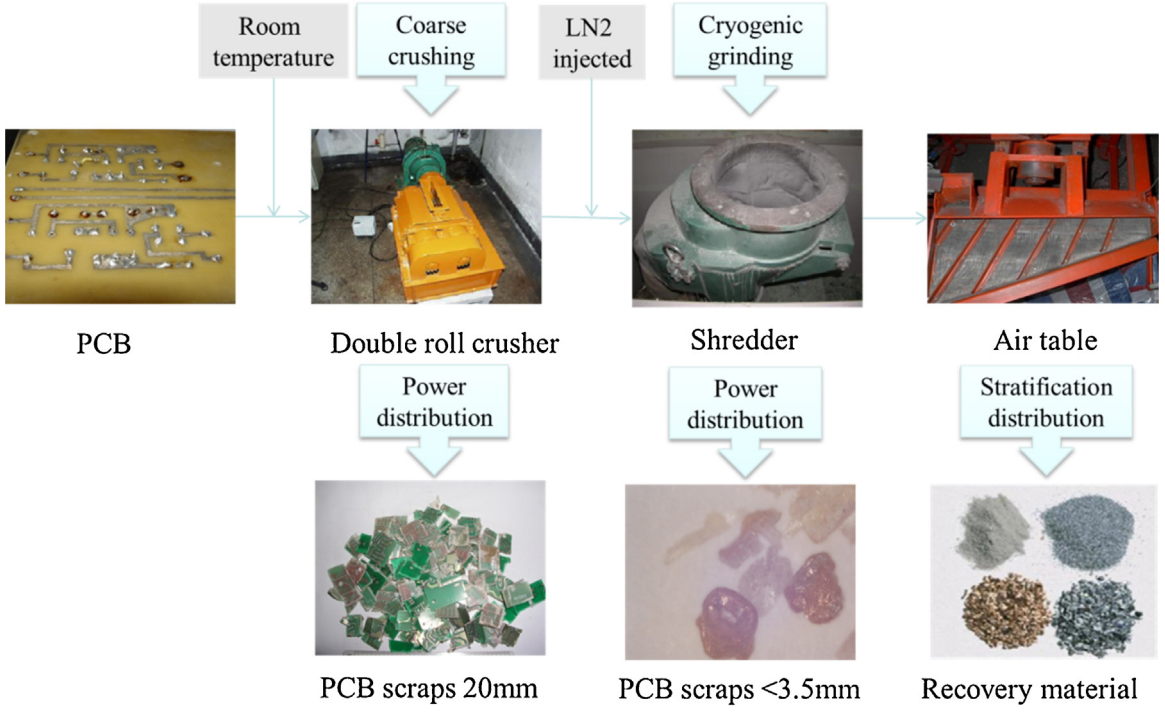

Fig. 2. Crushing and separation procedures.