Mass analysis of the components separated from printed circuit boards

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Methods of effective and ecological recycling of printed circuit boards (PCBs) are searched all over the world at this time. The material composition and temperature properties of PCB are necessary to be known for an optimal recycling technology. For this purpose we analyzed weight ratio of the electronic components moulded on the selected kinds of PCBs and next we formulated mathematic model of temperature field in PCB during a grinding process in that the metal layers are separated from the plastic elements. We present the obtained results in this paper.

Key words: *Mass analysis, printed circuit board, electronic components, recycling, model*

Introduction

Electronic waste proves a growing problem globally. Each European citizen currently produces between 17 and 20 kg of waste electric and electronic equipment (WEEE) per year [1]. The study of United Nations University predicts that across the European Union electronic waste will rise from 2.5 to 2.7 % per year - from 10.3 million tonnes generated in 2005 (about one-quarter of the world's total) to roughly 12.3 million tonnes per year by 2020 [2].

The printed circuit boards (PCBs) represent significant part of WEEE. They are components of all electronic equipments. PCBs are made from plastic boards covered by one or more metal layers with moulded electronic components. Material composition of PCBs is nonhomogeneous. They can contain precious metals (gold, silver and copper), plastics, ceramics, glass, toxic substances and carcinogenic substances (mercury, cadmium, arsenic and chromium), etc. Weight ratio of the above mentioned materials depends on kind of PCB. There can be as many as 120 – 150 kg of copper, 10 kg of gold, silver and slider, 10 – 15 kg of tin and lead in 1 tonne of PCB waste [3].

We find that the PCBs embody numerous materials which require quite large quantities of energy and other materials for manufacturing processes. Therefore it is necessary to deal with their recycling. There are many different processes for recycling of PCBs. Firstly the PCBs have to be sorted by type, i. e. on single-layer and multiply PCBs. Next, the small electronic components are removed.

After primary dismantling, high percentage of the plastic elements coated with one or more metal layers is obtained. For the following technological process, the metal and plastic elements have to be separated. The separation can be realized by the following processes:

- *Chemically* – metal and plastic are separated by the instrumentality of strong acids and bases.
- *Mechanically* (by disintegration) – by stamping or milling with following separation. In this process, different density of the separated materials is used.
- *Thermic* - by the instrumentality of temperature shock.

The obtained material is subsequently sorted and processed where necessary.

At this time, the separation of metal and plastic is one of the main problems of PCB recycling. The effective and environmental friendly recycling method depends on the material composition of PCBs. We deal with searching of the appropriate method of thermic separation of two-ply and multiply PCBs in order to divide the metal layer from the plastic elements. Consequently we would like to use the separated mixture of plastics for manufacturing of heat insulation and anti-noise panels with using of the special adhesive material.

In this paper we present results of the mass analysis of the electronic components moulded on selected kinds of PCBs. Next we formulate mathematic model of a grinding process in that metal layers are separated from plastic boards.

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Mass analysis of components separated from PCBs

We tested weight ratio of the electronic components in one-layer and multiply PCBs of electronic equipments used in eighties years of the twentieth century.

For this purpose we mechanically separated the electronic components from the tested PCBs and divided them into the following categories:

- PC components,
- CRT monitors and televisors,
- Analog circuits,
- Supply circuits.

Results of the analysis we show in the following Fig. 1.

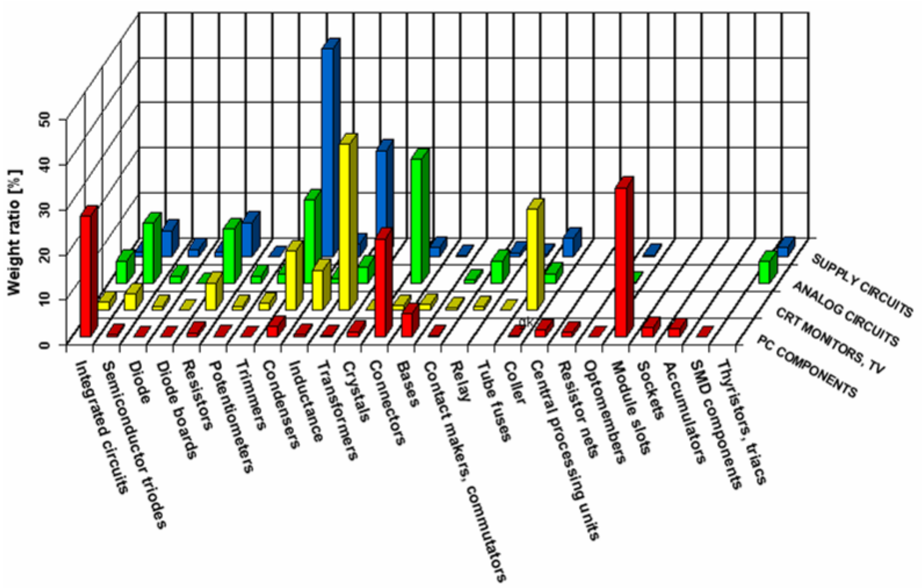

Fig. 1. Weight ratio of the separated electronic components in tested categories of PCBs.

It is evident that composition and weight ratio of separate electronic components depend on type of the PCB. Nevertheless, there are some common features between the tested PCB categories.

We found a significant weight ratio of condensers and transformers all tested categories. Furthermore, connectors occurred in a large ratio in PC components and analog circuits categories.

We find that the above mentioned electronic components are significant sources of materials such are metals, plastics, and ceramics and so on. Therefore, it is necessary to deal with the PCB recycling problem.

Modeling of temperature field in PCBs during a grinding process

As mentioned above, the separation of metal and plastic board is one of main problems of the PCB recycling at this time. A grinding process sounds like acceptable from the point of view of ecology.

The grinding process can be realized by using of an abrasive belt. In consequence of so much of heat generation during the process, the plastic material can agglomerate with metals, which complicate the process. Therefore it is necessary an optimal time course of grinding to find.

For this purpose we deal with the mathematic model of temperature course in PCB during the grinding process.

Symbol Meaning Unit

a - temperature conductivity, $a = \lambda/(\rho.c_p)$ [m^2.s^{-1}]
c_p - specific thermal capacity, [J.kg^{-1}.K^{-1}]
l - length of the ground surface, [m]
q - heat flow, [W.m^{-2}]
t - temperature, [°C]
x - position coordinate, [m]
λ - heat conductivity, [W.m^{-1}.K^{-1}]
ρ - density, [kg.m^{-3}]
τ - time, [s]

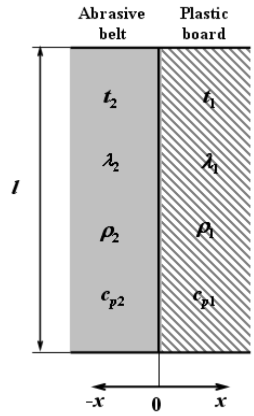

Fig. 2. Schematic model of grinding process.

Non-stationary temperature field in PCB and abrasive belt can be described by following Fourier-Krchhoff's equations (1), (2) with appropriate initial and boundary conditions (3) – (6)

$$\frac{\partial t_1(x,\tau)}{\partial \tau} = a_1 \frac{\partial^2 t_1(x,\tau)}{\partial x^2} \qquad \tau > 0, \quad 0 < x < \infty \tag{1}$$

$$\frac{\partial t_2(x,\tau)}{\partial \tau} = a_2 \frac{\partial^2 t_2(x,\tau)}{\partial x^2} \qquad -\infty < x < 0 \tag{2}$$

$$t_1(x,0) = t_2(x,0) = t_p \tag{3}$$

$$t_1(\infty,\tau) = t_2(-\infty,\tau) = t_p \tag{4}$$

$$q + \lambda_1 \frac{\partial t_1(0,\tau)}{\partial x} - \lambda_2 \frac{\partial t_2(0,\tau)}{\partial x} = 0 \tag{5}$$

$$\frac{\partial t_1(\infty,\tau)}{\partial x} = 0\,, \quad \frac{\partial t_2(\infty,\tau)}{\partial x} = 0 \tag{6}$$

We suppose that total heat flow divides equally among q_1 and q_2

$$q_1 = q_2 = 0.5q \tag{7}$$

Under these conditions, we obtained analytical solution given by temperature field $t_1(x,\tau)$ in plastic board

$$t_1(x,\tau) = \frac{2q}{\lambda_1}\sqrt{a_1\tau}\left[\frac{e^{-\frac{x^2}{4a_1\tau}}}{\pi} - \frac{x}{2a_1\tau}\cdot \operatorname{erfc}\left(\frac{x}{2a_1\tau}\right)\right] \tag{8}$$

We used mathematic software Maple for calculation and visualization of temperature field $t_1(x,\tau)$ in plastic board during grinding. We present an example of graphic output in following Fig. 3.

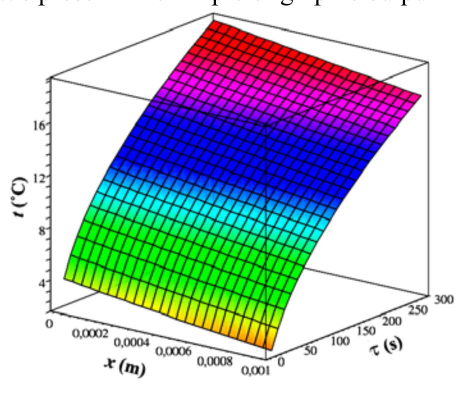

Fig. 3. Temperature field in plastic board during grinding *Parameters: q = 2000 W.m^{-2}, a =5.8.10^{-6} m^2.s^{-1}.*

It is clear that time course of grinding strongly depends on quantity of a supply heat which represents heat flow *q* (Fig. IV). Value *q* depends mainly on technological conditions of the grinding process and on physical properties of the ground board.

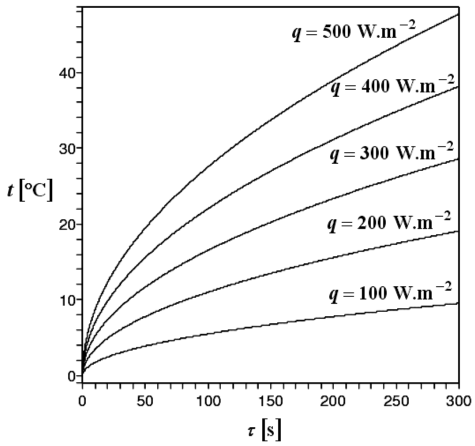

Fig. 4. Dependence of time course of grinding on quantity of supply heat Parameters: a $= 5.8.10^{-6}\ m^2.s^{-1}$, x = *0 m*.

Conclusion

In the paper we delt with the optimization of recycling process of PCBs. For this purpose we investigated weight ratio of the electronic components separated from PCBs of CRT monitors and televisors, PC components, analog circuits and supply circuits. The analysis proved a high occurrence of the components that are source of raw materials as are plastics, metals, ceramics etc. in the tested PCBs.

In the second part of our paper we formulated mathematic model of temperature course in PCBs during a grinding process. The obtained results can be used for finding of the effective and environmental friendly recycling method.

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