

Modeling of the ecological separation process of printed circuit boards

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Abstract. The content of this paper is the modeling of the stress in the printed circuit board due to the cyclic thermal stress for its ecological recycling. Cyclic thermal stresses result in separation of copper conduction paths and plastic plates due to different longitudinal expansion. For separation, it was important to determine the minimum temperature of the cyclical changes to separate the conductive copper paths and the plastic. We use mathematical modeling tools to describe the course of temperature fields in the PCB during heating and reheating. We conducted some simulation experiments in the Pro/ENGINEER programming environment to know the waveforms and stresses of the PCBs during the cyclic loading cycle. From experiments conducted in the laboratory, we have verified that the process of temperature separation is feasible for designing an eco-friendly way of recycling PCBs.

1 Introduction

With the development of new technologies that facilitate both the acceleration and acceleration of our lives, the production of electronic products grows proportionately. The basis of these products is mainly printed circuit boards. Just like the Internet that is becoming part of our lives, these electronic products are increasingly needed and desirable without which we cannot. These products have a certain lifetime and, when they are finished, they accumulate in landfills or are partially recycled. This diverse electronic waste is increasing, and according to studies, it is increasing several thousand tons a year.

Generally speaking, electronic waste is becoming more and more of a problem not only on a local scale but also on a global scale [1]. There is a wide range of recycling options by chemical processes where there is a risk of leakage of chemicals into groundwater and the occurrence of an environmental hazard. Another way to separate metal paths from plastics is grinding or crushing, magnetic separation, manual dismantling, etc.

Act No. 185/2001 Coll regulates the management of so-called electrical waste, On Wastes as amended, which was amended by Act No. 7/2005 Coll. (from now on referred to as "the Act") Moreover, is based on EU waste legislation 2002/96 / EC [1, 3]. These laws lay down the conditions for the disposal of waste electrical and electronic equipment, its separate collection and disposal from 13 August 2005. We have focused on the ecological separation of copper conductive paths from printed circuit boards due to thermal stress because it is separation based on a physical phenomenon.

2 DPS recycling options

From the study, we can identify the main ways and aspects of PCB recycling, which are the legislative solutions for disposal of waste electrical and electronic equipment including obtaining valuable materials and protecting the environment.

The law on the disposal of waste electrical and electronic waste includes recycling charges and their use for the treatment of waste electrical and electronic equipment.

The content of the article focuses on the environmental technology process when designing a new environmental separation method for recycling PCBs. Electronic waste contains many harmful substances that can be released into the environment during recycling. Some of these practices pose a potential environmental risk, such as chemical separation (precious metal extraction in lead melt) or waste plastic waste incineration. That is why we focused on the ecological separation of copper conductive paths from printed circuit boards by cyclic stresses due to temperature.

The printed circuit board includes surface wires, soldering points, and other conductive shape elements designed for assembly of components and mechanical parts, more recently called assembly and interconnection structures. The printed circuit board is an essential component of the assembly technology of all electronic units. It fulfills the function of the element carrier element, i.e., the mechanical function, ensures the loss of heat loss, acts as an electrical and, more recently, an optical interconnection between components and systems. PCBs must be reliable and affordable [2, 3]. It is a valuable asset to know the material composition of the waste. Reason? Waste hazard and recycling. PCBs are made up of metals, plastics, ceramics, glass,

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and halogens. The weights of individual materials depend primarily on the type of DPS. One ton of PCB waste can be 120-150 kg of copper, 10-15 kg of tin and lead and up to 10 kg of gold, silver, and platinum [4, 11].

2.1 Phenomena affecting the thermal separation of PCBs

2.1.1 Length thermal expansion of materials

When the solid body temperature changes, the body dimensions change. This is thermal expansion. For bodies that have a predominant length, we talk about thermal length expansion. Thermal expansion is a consequence of the distancing of mean distances between the particle of a substance due to its greater misalignment. The dependence of the elongation on the type of material is expressed using the temperature coefficient of the length expansion α . It is in physical tables, and the unit is K^{-1} [3, 6].

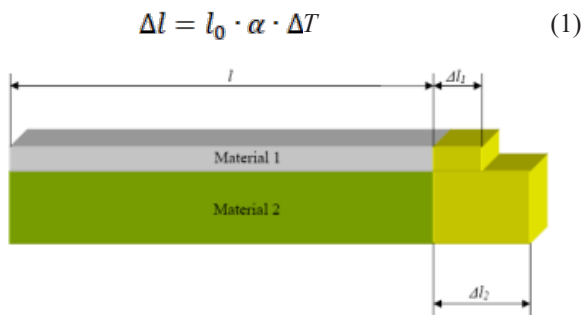


Fig. 1. Different longitudinal expansion of two materials.

The shear stress that is required to separate the two plates is described by Hook's law [2].

$$\sigma_1 = E_1 \cdot \varepsilon_1 \quad (2)$$

$$\sigma_2 = E_2 \cdot \varepsilon_2 \quad (3)$$

where:

- σ_1 is Resulting shear stress of the first material [Pa]
- σ_2 is Resulting shear stress of the second material [Pa]
- E_1 is Elastic modulus of the first material [Pa]
- E_2 is Elastic modulus of the second material [Pa]
- ε_1 is Relative elongation of the first material [1]
- ε_2 is Relative elongation of the second material [1]

2.2 Temperature field in PCB

For heat stressing of PCBs, it was also necessary to deal with the mathematical description of thermal fields in PCB during heating and cooling during cyclic loading. In the physical description of continuous heat sharing in a two-layer planar slab, we consider the semi-bounded massive in the interval due to intensive heating from the conductive paths. The analytical solution describing the temperature field in the first layer of the body $t_1(x, \tau)$ is shaped [2].

$$t_1 = \left[\sum_{n=0}^{\infty} h^n \left\{ \operatorname{erfc} \frac{(2n+1)b+x}{2\sqrt{a_1\tau}} - h \cdot \operatorname{erfc} \frac{(2n+1)b-x}{2\sqrt{a_1\tau}} \right\} \right] (t_o - t_p) + t_p \quad (4)$$

The temperature distribution in the second layer of the body $t_2(x, \tau)$ has the form [2, 6]:

$$\frac{t_2 - t_p}{t_o - t_p} = \frac{2K_\varepsilon}{1 + K_\varepsilon} \sum_{n=1}^{\infty} h^{n-1} \operatorname{erfc} \left(\frac{x - b + (2n-1)K_a^{-\frac{1}{2}} b}{2\sqrt{a_2\tau}} \right) \quad (5)$$

where:

- a is Thermal conductivity [$m^2 \cdot s^{-1}$]
- b is Thickness of the metal layer [m]
- $cp_{1,2}$ is Specific heat capacity [$J \cdot kg^{-1} \cdot K^{-1}$]
- λ is Coefficient of thermal conductivity [$W \cdot m^{-1} \cdot K^{-1}$]
- ρ is Density [$kg \cdot m^3$]
- t_1 is Temperature of metal [$^{\circ}C$]
- t_2 Temperature of plastic [$^{\circ}C$]
- t_o is Ambient temperature [$^{\circ}C$]
- t_p is Initial temperature [$^{\circ}C$]
- τ is Time [s],
- K_a is Specific constant [1]
- K_p is Rigidity [$N \cdot mm^{-3}$]
- K_ε is Similarity constant [1]
- erfc is Error function
- n is Number of members

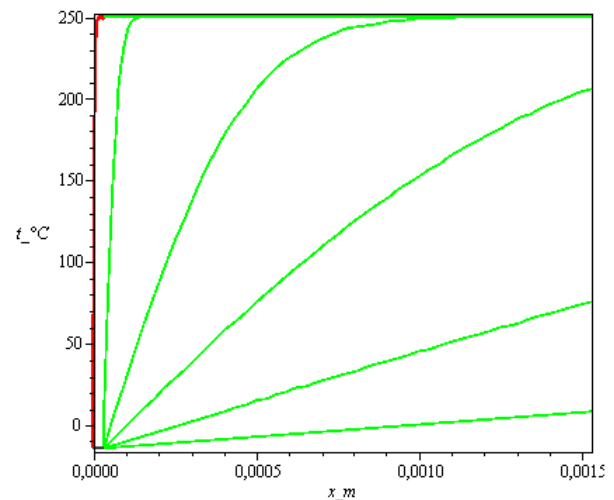


Fig. 2. Graphical display of calculated temperature curves in PCB – heating [2].

3 Modeling and simulation of PCBs

We focused on PCB modeling based on the real-world printed circuit board base to simulate temperature transitions and resulting shear stress on the computer directly for a specific sample and then compare it in the lab. Consideration was given to the PCB used, whether it is a single-layer or composite board and also used material. We used a library of materials that are part of SW [2, 5, 11].

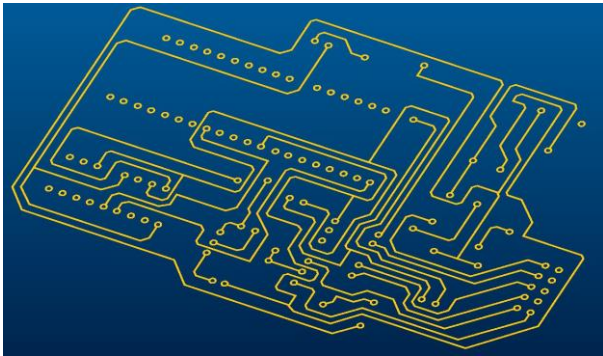


Fig. 3. PCB in SW Pro/ENGINEER.

3.2 Shear stress simulation process in PCB

In Pro/ENGINEER, We chose Pro / Mechanics. Then We picked material from the materials library and assigned geometry. The advantage of this process is that these materials already contain all the properties and physical quantities suitable for simulation. In the next step, We defined the heating at 260°C and boundary conditions. In this simulation, We were warming up the PCB. Once the temperature analysis was completed, We used the resulting temperature distribution for structural analysis [5, 7, 12]. Due to the different lengths of the material, the tension between the materials and the accompanying phenomenon - the shear stress - became apparent. The result of this analysis is presented in Fig. 4. The maximum strain occurred at a point shown red with an arrow. The value of this stress is 492 MPa.

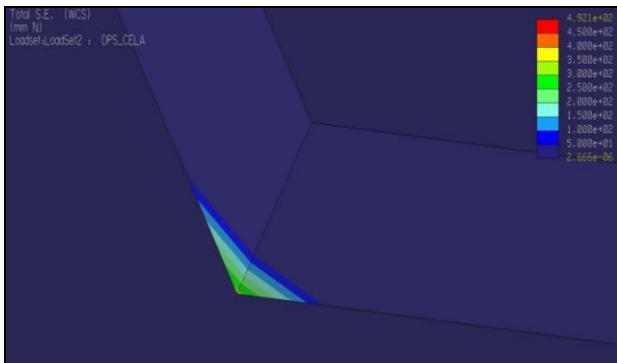


Fig. 4. The view maximum stress value 492 MPa.

The temperature distribution is shown in the figure (Fig. 5). The maximum heating temperature reached 225°C. It is also apparent from the figure that the resulting temperature at the heating point depends on the length of the copper conducting paths. During this simulation, the heat flow was gradually removed by the longer copper paths from the heated area and thereby cooled. The paths, which were short or directly ended in the heated area, warmed to a higher temperature [8, 9]. The direct influence of unheated copper paths heated by conductive copper paths. Where paths are too close, we can expect less stress than a place where the paths are far apart.

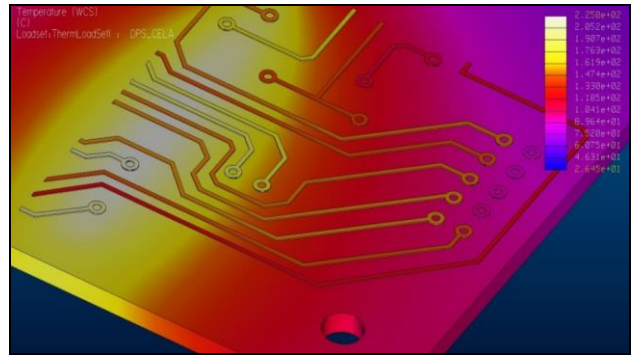


Fig. 5. The Final temperature distribution in PCB. Heating with power 100mW.

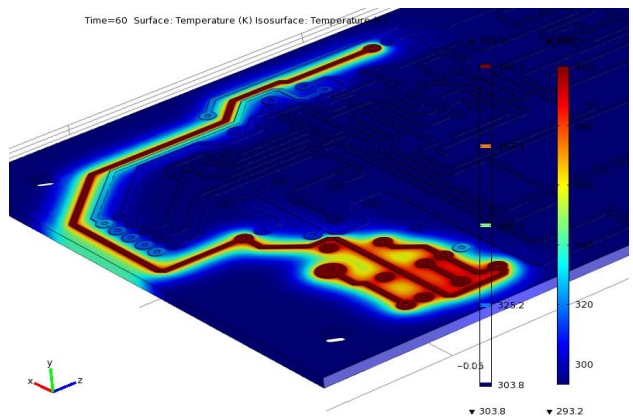


Fig. 6. A general view of the DPS with warmed paths at 400K for time 60 s.

One result is the stress distribution, which can we see in Figure 8, and further information is the PCD deformation due to stress, as can be seen from the Fig. 7.

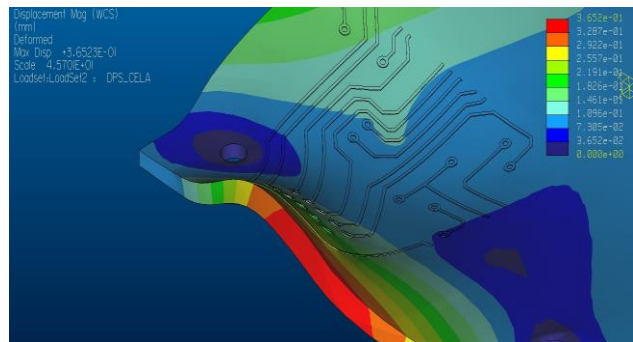


Fig. 7. PCB deformation due to stress.

The result of the simulation is shown in the bottom picture. It is a reflection of the PCB depending on temperature [10].

4 Results of the separation performed under laboratory conditions

Pictures of separating copper paths from PCBs at separation in the laboratory. Fig. 8 is an older type of PCB. The principle was to carry out cyclical thermal stresses, heating and hard-drying PCBs [2].

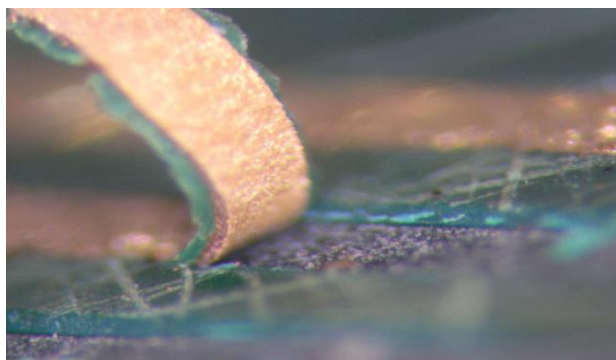


Fig. 8. Detailed view of the separated copper path under the microscope.

The required shear stress proceeds from the edge of the copper conductive path to its center. Images were taken using a stereomicroscope at a magnification of 5.6 times, and present the results of the tests performed in the laboratory. We see peeling conductive copper paths from PCBs. In our experiments, we have used several methods of heating of the PCB. Heating PCB at a press tempered at 200 °C, further microwave heating. Was the most effective heating with a heat gun to 350°C. This temperature is sufficient even for the separation of tin because the melting point of tin is 250 °C. After using mechanical separation, parts dropped away from the PCB. We used a mechanical separation for removal of conductive paths.

5 Conclusions

The results are interesting given the resulting shear stress between the copper path and the epoxy board. They confirm the calculated results. Exceeded shear stress is local and, according to defined conditions, occurs at the edges of copper paths. According to the color scale, it can be seen that it exceeds the calculated shear stress for the glued joints, and there is a risk of deformation and consequently the connection between the copper conductive path and the epoxy board. Although it appears only in several places, this is sufficient to continue the separation, for example by mechanical means. There is no need to use large forces to dump the conductive path from the PCB. A great influence on heat sharing and the rise of the temperature gradient (shock) has the density of the distribution of conductive copper paths on PCBs. Since older simulations performed with one or two conductive paths, the results were very interesting and comparable to the shear stress calculations required to tear the PCB conductive paths.

Now, for simulating multilayer conductive paths to PCBs, it is necessary to change the PCB mounting conditions. The reason is the different heat dissipation in the board and the interaction of the individual conductive copper paths. This influence is due to the minimum dimensions of the distance between conductive paths. In the DSP stress modeling, we will continue to apply the different mounting conditions and heating modes. With the simulations, we can easily detect under what conditions the stress is ineffective, and the PCB is only

twisted, and the shear stress is not overcome. Based on the calculations, we will try to determine the lowest possible temperature difference to minimize the financial costs of the process associated with environmental protection and the effort to minimize the number of harmful substances released from the PCB into the environment. In our work, we greatly help simulation of temperature and shear stress in DSP using the Pro/ENGINEER software environment.

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