Separation of Printed Circuit Board by Temperature Shock

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Abstract: - In this contribution we are dealing with the possibility of electronic waste separation by temperature effect. It gives a possible direction how to solve the problem of increasing with electronic waste not only in Czech Republic, but also throughout the world. Further, we are dealing with of heat transfer inside the printed circuit boards (PCB) and with thermal longitudinal expansion of used material in the FEMLAB software environment. The problem is modelled also in other programs, which offer the view of the whole structure of used materials and subsequently their movement in dependence on the changes of the ambient temperature. With the use of the utilize experience from detail references background research and various software simulators we achieved the maximum analysis of the problem. The solving, which resulted from the calculations of shear stress of given materials was subsequently verified in laboratory. The development of new criteria for PCB recycling has opened new possibilities of treatment for used materials.

Key-Words: - Electronic waste, printed circuit boards (PCB), recycling, separation, heat transfer, shear stress

1 Introduction

In the last twenty years the problem of material recycling, especially the electronic waste has been focused on by specialists of electronics. The production and subsequent consumption parts is generally growing and after termination of their time life usually end up on dumps solid and for hazardous waste, because these products contain also the materials, which represent potential risk the for environment as well as for human health. For this reason we have to look for any possibility of recycling these materials.

Nowadays, the call for utilisation of the secondary raw materials has considerably increased, but the way of their recycling still remains very expensive.

It is assumed, that in the Czech Republic there are about 2.10^5 functioning personal computers. It means, that at average working life of 11 years there are about 1.8.104 personal computers yearly eliminated. This amount, at the average weight of a PC 24 kg, represents 432 tons of mostly recyclable materials . This situation will be getting worse, because he world human population is growing and so will be the call for new computers. Perhaps the most valuable raw materials, which can be obtained from computer, are precious metals. According to the analysis performed on different PCB types it is possible to determine their average content in the input material, which isn't small. Therefore, this material is worth recycling [6].

In this work we focused on possible separation of PCBs by the effect of thermal dilatation of the materials of which the boards are made. As the introduction of new technologies and the manufacturing processes have become is too expensive, the required production is worth being simulated with the use of computer realization environment. This method is less expensive, but time-consuming. It concerns especially the creation of a mathematical description of the given problem creation of the required model, which will describe and give a true characteristics of the material. We used two simulator programs - FEMLAB and OOFELIE. By combination of results from both simulations we can deduce the conclusions, which accurately describe the state and characteristics of the material loaded in thermal shock.

The development of new criteria opens new possibilities of PCBs recycling and it also represents a way to answer the brought up queries about the used of PCBs treatment.

2 Theory

A printed circuit board is the essential part of the assembling technology of all electronic wholes. Is serves as supporting element of parts, it has mechanical function, interlock it provides the lost heat exhaustion, functions as an electric and recently also as an optical connecting member between parts and systems [1].

It is commonplace for big producers to have their own system for proposals and developments of a new products. Nevertheless it is possible to say that in the first place they respond to existing state, they do not use of all possibilities of voluntary implements and they can be lacking in some valuable information. The producer determines not only how product penetrates into the market, but also the WEEE (waste electric and electronic equipment) .Proposal criteria for production electric arrangement from views life cycle and LCD, with a view to prevention rise waste, dispraise his quantity and inadvisability. Directions to EEE (electric and electronic equipment) and WEEE demand, that the products (with minor exemptions) do not contain free lead, mercury, cadmium, hexavalent chromium, polychlorinated biphenyls (PCB*) and polybrominated diphenyl ether (PBDE). Further the producer is demanded, to select product design, which would allow a repeated use of the product or its parts, would facilitate the WEEE and achieve the prescribed quotas for recycling [2].

Recycling technologies depends particularly on economic conditions in the individual countries or localities.

The original way of recycling was a basic magnetic separation after hand dismantling and coarse grinding. With the increasing demands for recycling and the call for the secondary raw materials, the technologies were improving till the maximum possible material yield with minimum of energy and personnel demands has been achieved. The basic materials for processing are particularly plastics and metals.

When recycling the information and communication devices, the main problem is a complex combination of different materials - metals, polymers and ceramic materials [3].

The most used polymer in electronics are particularly ABS, PMMA and PVC [4].

2.1 PCB materials

For surface assembly the PCB material should have approximately the same coefficient of linear expansion as the material of the used parts. For reason of different of heat dilatation PCB and parts, was growing the mechanical stress of soldered joint.

But at the same time, the magnitude of mechanical stress is given by the difference of the linear expansion coefficients. According to previous experiences, in common application of surface mount assembly on a glass-epoxide PCB (FR4) it is possible (with no risk of subsequent cracking of soldered joints) to mount miniature passive parts (resistors, ceramic capacitors) of the size up to 10 mm, integrated circuits in SO version, plastic microchip carriers, flat pack and quad pack circuits, TAB (Micropack) etc. At present time, the European producers provide boards of thicknesses varying from 0.8 to 3.2 mm, preferred thickness is 1.6 mm. Copper foils are produced in thicknesses 35 μm, 70 μm and 105 μm, possibly thicker. The FR4 materials are provided with copper foils of 18 μm, 9 μm or 5 μm in thickness. The thinnest foils are used for the softest joints, which is the case of some special surface mount assembly applications [5].

3 Computational part

The following figure shows the material state at a temperature change. It is obvious that the expansion of material 1 is much smaller than in material 2. It is caused by different coefficients of linear expansion of both materials. We used this feature to derive the final relation for the resulting shear stress, which is necessary for separation of conductive parts from plastic materials in PCB.

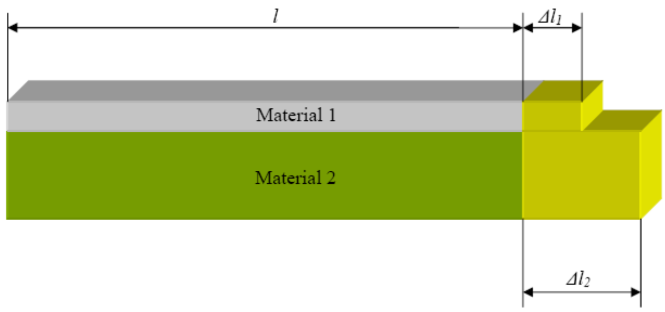

Figure 1: Linear expansion of materials.

The calculation of shear stress needed for division of two proceeded boards from Hook´s law.

$$\sigma = E \cdot \varepsilon \qquad (1)$$

where σ is the resulting shear stress [Pa]
E is modulus of elasticity [Pa]
ε is relative elongation

In the resulting quadratic equation it is necessary to include also the thermal linear expansion of solid bodies.

$$l = l_0 \cdot (\alpha \cdot \Delta T + 1) \qquad (2)$$

where α is coefficient linear expansion [K^{-1}]
ΔT is temperature difference [K]
l_0 is the original length of the material [m]

Rearrangement and the subsequent fusion both quadratic equations gives the following relation for calculation of shear stress of one board.

$$\sigma = E \cdot \alpha \cdot \Delta T \qquad (3)$$

Resulting force enumeration:

$$F_T = (\sigma_1 - \sigma_2) \cdot S_j \quad (4)$$

where F_T is resulting power [N]
σ_1 is the pulling stress in the first material [Pa]
σ_2 is the pulling stress in the second mater. [Pa]
S_j is the contacts surface of both material [m2]

This power must be greater than the allowed shear stress in the given materials. We obtain the following equation:

$$\frac{F_T}{S_j} > \tau_s \quad (5)$$

where τ_s is the maximum allowed shear stress of the material [MPa]

3.1 The concrete calculation

For this calculation we selected the combination of an epoxide resin and copper. In literature [1] we found the basic characteristics of the used materials needed for calculation (See Table 1). The calculation shows the value of depending force depending on temperature variation, which is necessary to divide the copper layer from the surface of epoxide resin.

Tab. 1: Mechanical properties of the material

	epoxide resin	**copper**
E **(Pa)**	$1{,}4 \cdot 10^{6}$	$13 \cdot 10^{10}$
α **(K⁻¹)**	$13 \cdot 10^{-6}$	$17 \cdot 10^{-6}$

Shear stress calculation for epoxide resin at temperature difference ΔT = 1K.

$$\begin{aligned} \sigma_2 &= E \cdot \alpha \cdot \Delta T \\ \sigma_2 &= 1{,}4 \cdot 10^{6} \cdot 13 \cdot 10^{-6} \cdot 1 \\ \sigma_2 &= \underline{\underline{18{,}2}}\ \text{Pa} \end{aligned} \quad (6)$$

Shear stress calculation for copper resin at temperature difference ΔT = 1K.

$$\begin{aligned} \sigma_1 &= E \cdot \alpha \cdot \Delta T \\ \sigma_1 &= 13 \cdot 10^{10} \cdot 17 \cdot 10^{6} \cdot 1 \\ \sigma_1 &= \underline{\underline{2{,}21}}\ \text{MPa} \end{aligned} \quad (7)$$

Resulting force enumeration relation:

$$\begin{aligned} F_T &= (\sigma_1 - \sigma_2) \cdot S_j \\ F_T &= (2210000 - 18{,}2) \cdot 10 \cdot 10^{-6} \\ F_T &= \underline{\underline{22{,}099}}\ \text{N} \end{aligned} \quad (8)$$

This force must be greater than allowed shear stress for the given materials. This results in the relation.

$$\begin{aligned} &\frac{F_T}{S_j} > \tau_s \\ &\frac{22{,}099}{10} > \tau_s \end{aligned} \quad (9)$$

The resulting shear stress is given in $N.mm^{-2}$. For brazing solders it is $t_s = 200\ N.mm^{-2}$ [5]. The calculation for other T showed, that the shear stress critical limit, $200\ N.mm^{-2}$ for $S_j = 10\ mm^2$ is exceeded at $\Delta T = 91K$ (see Table 2)

Table 2: Shear stress calculation

ΔT [K⁻¹]	Cu σ[Pa]	epoxide resin σ [Pa]	Surface [mm2]	Force [N]	τ of materials [N/mm2]
85	187850000	1547	10	1878,485	187,84
86	190060000	1565,2		1900,584	190,05
87	192270000	1583,4		1922,684	192,26
88	194480000	1601,6		1944,784	194,47
89	196690000	1619,8		1966,884	196,68
90	198900000	1638		1988,984	198,89
91	201110000	1656,2		2011,083	201,10
92	203320000	1674,4		2033,183	203,31
93	205530000	1692,6		2055,283	205,52
94	207740000	1710,8		2077,383	207,73
95	209950000	1729		2099,483	209,94
96	212160000	1747,2		2121,583	212,6
97	214370000	1765,4		2143,682	214,37
98	216580000	1783,6		2165,782	216,58
99	218790000	1801,8		2187,882	218,79
100	221000000	1820		2209,982	220,99
101	223210000	1838,2		2232,082	223,21
102	225420000	1856,4		2254,181	225,42
103	227630000	1874,6		2276,281	227,63
104	229840000	1892,8		2298,381	229,84
105	232050000	1911		2320,481	232,05

2.2 Computer simulation of PCB heating

In this chapter we deal with the heat transfer in PCB. It is important to know the time, in which the whole PCB heats up to the required temperature. To solve this problem we used the FEMLAB software. The ground is the creation of the required model with boundary conditions and properties of the used materials. The behaviour of individual simulations for given times are shown in the following figures.

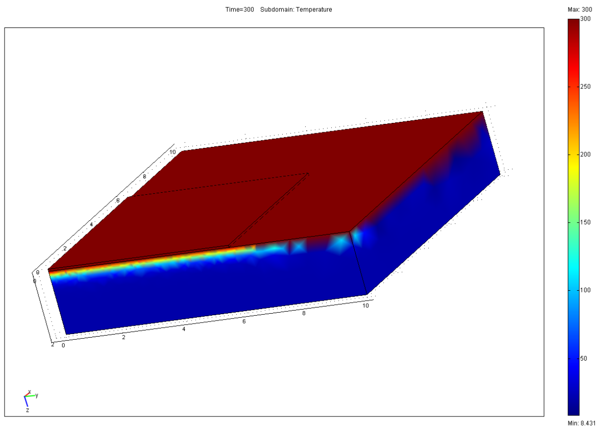

Figure 2: Heating of one side of the epoxide resin board during 300 s up to the temperature of 300 °C

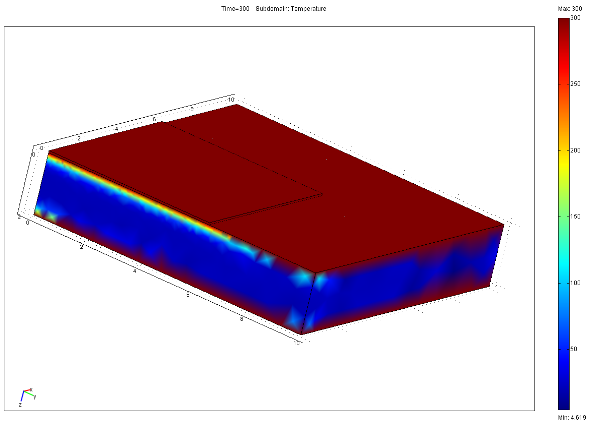

Figure 3: Heating of one both sides of PCB during 300 s up to the temperature of 300 °C

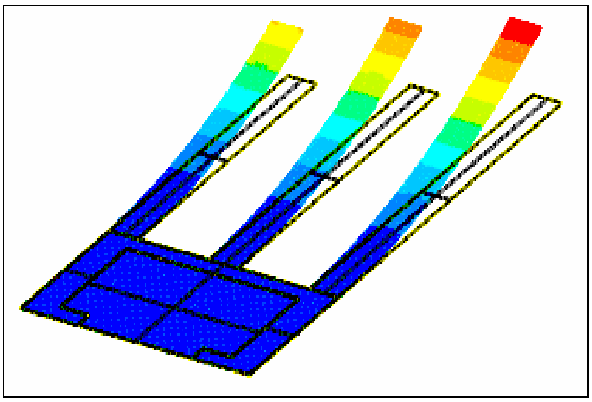

Figure 4: The conductive ways deformation by shear stress

4 Conclusion

We have worked out a study of PCB production, because it is necessary to know the manufacturing process to able to find the ways of recycling. We followed the PCB production from the beginning to the phase when it is ready for the market.

Further, we calculated the shear stress, which is needed to separation conductive copper ways from epoxide resin. We used several ways of PCB heating-up, for example heating-up the board in tempered press up to the temperature of 200°C. After, it was cooled in brine.

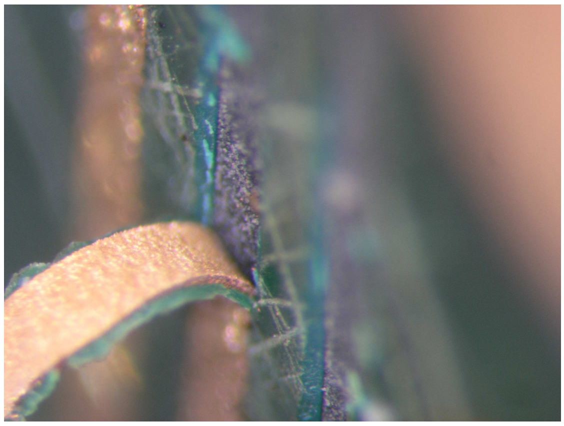

Figure 5: The laboratory separation of the conductive ways by temperature shock

Heating-up to 350°C by a proved to be the best approach. This temperature is sufficient also for the separation of tin, which the parts are soldered with the melting point of tin is 250°C. After using the mechanical separation, the fell off the PCB. We used the mechanical separation also to remove the conductive ways (See Fig.5). This case shows a resemblance with adhesive joints theory. However, laboratory test showed that the temperature difference must be much higher than shown in the calculation. It results from the fact that copper is very plastic and the calculated dilatation caused by the temperature difference is smaller. This way of recycling could lead to a possible industrial application and thereby to contribute to environment protection.

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