Abstract—The paper describes possibility to use recycled printing circuit boards plastic materials to manufacturing of thermo-insulating panels. It describes methods used for finding of an optimal composition of adhesive mixture made of hycol and crotonaldehyde as cross-linking agent. In the second part are presented results obtained by laboratory testing of thermo-insulating properties of panels made of plastic meal stucked together by the prepared adhesive mixture.

Keywords—Printed circuit boards waste, hycol, crotonaldehyde, thermo-insulating panels, thermal conductivity determination, cross-linking degree.

I. INTRODUCTION

The electronic waste recycling became a necessity with consumer electronics development in the recent years because the price reducing of electronics leads to its massive consumption and currently to reducing of its life time. The used up electronics usually ended at dumps of the solid and hazardous waste.

At our workplace we targeted the used up possibility of the electronic waste usage especially coming from computer technology as a source of valuable raw material because these products contain a lot of worth components so as materials which are malignant for environment. From this point of view, we deal with personal computer recycling.

From this account we deal with finding of an optimal method of separation of plastic boards from conductive ways of printed circuit boards which are basic parts of all computers [1], [2]. The separated plastic material we would like to use for manufacturing of thermo-insulating panels.

II. PREPARING OF ADHESIVE MIXTURE FOR STICKING OF PLASTIC MELT

Main aim of our research is to made panels which will be thermo-insulating and stable to climatic influences and will be not unhealthy. Furthermore manufacturing of the panels have to be economically advantageous.

On this account we have tested properties of hycol as an alternative adhesive of panels. Hycol is a protein hydrolysate. It is a recycling product of solid tanned waste treatment produced by enzymatic hydrolyze in leather industry. But the problem which we had to solve was its solubility in water. This disadvantageous of hycol we tried to eliminate by cross-linking by use crotonaldehyde as cross-linking agent [4]. The cross-linking process can be described by following chemical reactions [4]:
III. TESTING OF AN OPTIMAL COMPOSITION OF ADHESIVE MIXTURE BY DISSOLUTION IN WATER

The laboratory testing consisted in finding of an optimal weight ratio of crotonaldehyde in prepared adhesive mixture so the stucked together panels will be waterproof.

Preparing of tested mixtures

The tested samples were prepared from Hycol, crotonaldehyde and phthalic acid, which was used as stabilizer. The weight composition of the mixtures we show in Table 1.

Table 1. Material composition for tested adhesive mixtures

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>Weight ratio with regard to dry matter of hycol [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hycol (30 weight % of dry matter)</td>
<td>-</td>
</tr>
<tr>
<td>Phthalic acid</td>
<td>1</td>
</tr>
<tr>
<td>Crotonaldehyde</td>
<td>0 - 50</td>
</tr>
</tbody>
</table>

The prepared mixtures with various content of crotonaldehyde were dried to constant weight under laboratory conditions. After them they were put into the kiln at temperatures 180°C for 5 minutes, 8 minutes and 10 minutes. The cross-linked samples were put into distilled water and their dissolving for 24 hour was tested.

This method enables to determine dissipation factor, that is the ratio of the power loss in a dielectric material to the total power transmitted through the dielectric, the imperfection of the dielectric. Equal to the tangent of the loss angle [5]:

\[ D = \frac{\varepsilon' - \varepsilon''}{\varepsilon'} = \tan \delta = \frac{1}{2\pi f C_p R_p} \]

(1)

where

- \( f \) - frequency of applied voltage in cps,
- \( C_p \) - equivalent parallel capacity,
- \( R_p \) - equivalent parallel resistance,
- \( \delta \) - loss angle.

Aim of our testing was to verify an optimal time of cross-linking determined by above described method. We supposed that optimal time of cross-linking can be proved by change of dissipation factor of molecules of the tested mixtures.

The tested samples were prepared according the table 1. After them, they were dried to constant weight under laboratory. The measuring apparatus was prepared in conjunction of Department of Electronics and Measurements of Faculty of Applied Informatics at Tomas Bata University in Zlin. The measuring instrument was connected with software for evaluation of the measured data and with system of electrodes with tested sample (Fig. 4) [5].
First we searched an optimal temperature for cross-linking. For this purpose we put samples into the kiln at 25 °C and measured dissipation factor during heating to temperature 230 °C. The obtained results are depicted in Fig. 5. But the measured data were inaccurate. In most of tested samples, the maximal values of dissipation factor were at temperatures about 180°C and 230 °C and minimal values were at temperature about 180 °C. Therefore we choose temperatures 140°C and 180 °C for other testing of cross-linking process.

For testing of an optimal time of cross-linking, we put the electrodes with samples into the kiln for 1 hour. The Fig. 6 and Fig 7 show determined data at tested temperatures 140 °C and 180 °C. But the obtained results didn’t prove dependence between content of crotonaldehyde and optimal time of cross-linking. The measured data were inaccurate as
by previous testing of optimal temperature of cross-linking.

![Graph showing dissipation factor during cross-linking at temperature 140°C.](image)

**Fig. 6** Measuring of dissipation factor during cross-linking at temperature 140 °C. Mass ratios of crotonaldehyde in tested samples: 0%, 10%, 20%, 30%, 40%, 50%.

![Graph showing dissipation factor during cross-linking at temperature 180°C.](image)

**Fig. 7** Measuring of dissipation factor during cross-linking at temperature 180 °C. Mass ratios of crotonaldehyde in tested samples: 0%, 10%, 20%, 30%, 40%, 50%.

**IV. PREPARING OF THERMO-INSULATING PANEL SAMPLES**

With regard to above presented results, we prepared adhesive mixture of the composition:

- hycol with 30 weight % of dry matter,
- crotonaldehyde of weight ratio 30 % with regard to dry matter of hycol,
- Phthalic acid of weight ratio 30 % with regard to dry matter of hycol.

We compounded the mixtures with plastic melts with granularity until 0.5 mm to 3 mm. After them, we pressed the samples by laboratory press at temperature 150°C in specially prepared form (Fig 8 and Fig.9). The thermo-insulating panel samples after pressing are shown in Fig. 10.
V. THERMAL CONDUCTIVITY OF THERMO-INSULATING PANEL SAMPLES MEASURING

The thermal conductivity of prepared panels we measured by apparatus according to Fitch (Fig. 11). The principle was measuring of thermal conductivity by non-stationary method. By these method, temperature is scanned by modified modulus Control Web 2000 (Fig. 12). Data are transferred by transmission system ADAM 5 through the communication into the personal PC. The measured temperature increases to steady-state value. The obtained file can be evaluated by software NeReg02 (Fig. 13 and Fig. 14).

Mathematical model describing dependence of measuring roller temperature on time is based on thermal balance equation (2):

\[-K \frac{dt}{d\tau} = \frac{S\lambda(t-t_1)}{\delta} + B(t-t_1), \quad 0 < \tau < \tau_m\]  

(2)

Where

- $K$ – Thermal capacity of measuring roller, [J.K$^{-1}$];
- $S$ – Area of sample, [m$^2$];
- $\lambda$ – Thermal conductivity of material, [W.m$^{-1}$.K$^{-1}$];
- $t$ – Scanned temperature of measuring roller, [$^\circ$C];
- $t_1$ – Temperature of tempering board, [$^\circ$C];
- $\delta$ – Thickness of sample [m];
The heat loss coefficient \( B \) can be computed by equation (3):

\[
B = \alpha \cdot S
\]

Where
\( S \) – Area on which losses occur, \([\text{m}^2]\);
\( \alpha \) – Heat transfer coefficient, \([\text{W.m}^{-2}.\text{K}^{-1}]\).

Right side of the equation (2) describes heat flow through the sample of block into the measuring roller. It includes also heat loss caused by convention of air around the measuring equipment.

Left side of the equation (2) describes accumulation of heat in the measuring roller as time change of temperature.

Analytical solution of equation (2) is given by equation (4):

\[
t = t_1 - \left( t_1 - t_2(0) \right) \cdot e^{-(A_1 + A_2) \tau} 
\]

Where parameters \( A_1 \) and \( A_2 \) can be computed by equations (5) and (6):

\[
A_1 = \frac{S \lambda}{\delta K}
\]

\[
A_2 = \frac{B}{K}
\]

\[
A_3 = A_1 + A_2
\]

Where
\( A_1 \) – Parameter of measuring equipment, \([\text{s}^{-1}]\);
\( A_2 \) – Parameter describing heat loss into the surroundings, \([\text{s}^{-1}]\).

For data evaluation, as dependence of measuring roller temperature on time, we used above described mathematical model. Parameters \( a_1, a_2, a_3 \) we determined by non-linear regression

\[
t = a_1 + a_2 \cdot e^{a_3 \cdot \tau}
\]

Thermal conductivity can by obtain from parameter \( a_3 \):

\[
a_3 = -(A_1 + A_2) = -A_3
\]

Fig. 11 Scheme of apparatus according to Fitch

1 - Tempering temperature board for temperature \( t_1 \), 2 – Tempering temperature board for temperature \( t_2 \), 3 - Measuring roller, 4 –Thermocouple, 5 – System ADAM, 6 – Personal computer, 7 – Insulating cover of measuring roller, 8 – Stabilized direct-current generator, 9 – Measured sample, 10 – Thermostat
The measured data are shown in Table 2. The obtained results proved good thermo-insulating properties of the tested samples. The highest value of thermal conductivity was measured in samples of coarse melt. The samples by medium, fine and very fine granulity had approximately comparable thermal conductivity value.
Table 2 Determined values of thermal conductivity in the thermo-insulating panel samples

<table>
<thead>
<tr>
<th>Tested sample</th>
<th>Granularity of the sample [mm]</th>
<th>Average thickness of the sample [mm]</th>
<th>Temperature of measuring roller [°C]</th>
<th>Ambient temperature [°C]</th>
<th>Thermal conductivity [W.m⁻¹.K⁻¹]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse melt</td>
<td>3.0</td>
<td>6.72</td>
<td>41-30</td>
<td>27.9</td>
<td>0.14171</td>
</tr>
<tr>
<td>Medium melt</td>
<td>1.5</td>
<td>6.03</td>
<td>41-30</td>
<td>25.9</td>
<td>0.10723</td>
</tr>
<tr>
<td>Fine melt</td>
<td>1.0</td>
<td>6.09</td>
<td>41-30</td>
<td>27.3</td>
<td>0.11207</td>
</tr>
<tr>
<td>Very fine melt</td>
<td>0.5</td>
<td>5.98</td>
<td>41-30</td>
<td>29.2</td>
<td>0.10867</td>
</tr>
</tbody>
</table>

VI. CONCLUSION

In the paper we tested properties of adhesive mixture prepared for sticking of the plastic melt from printed circuit boards waste. The obtained results proved possibility to use hycol as an alternative adhesive. We eliminated its solubility in water by addition of crotonaldehyde. The optimal concentration of crotonaldehyde was 30 weight % with regard to dry matter of hycol.

The obtained results of thermal conductivity in prepared thermo-insulating panels proved good thermo-insulating properties. The highest value of thermal conductivity was measured in samples of coarse melt (about 14 W.m⁻¹.K⁻¹). The samples by medium, fine and very fine granularity had approximately comparable thermal conductivity value (about 11 W.m⁻¹.K⁻¹).

REFERENCES


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