ATLAS OF THERMAL ANALYSIS AND CHEMILUMINESCENCE MEASUREMENTS ON THE SET OF POLYMERS FROM POPART PROJECT
The graphical records that may be on the request complemented by the numerical data of thermal analysis and chemiluminescence (non-isothermal mode) from polymers involved in the resin kit (50 samples) and Smile polymers (35 polymers) represent here the original position for:

a) Identification of unknown plastic samples

b) Round robin test in thermal analysis

c) Characterization of subsequently aged samples aimed at the determination of their trajectory of life with applicability for museum plastics artefacts

The Atlas will be step-wisely complemented by experiments under different conditions as well as by characterization of other materials which might be independent continuation of the Popart project.

The Atlas is targeted for research scientists at the universities, academic and industrial institutions as well as for those who like to work with plastics in museums and galleries

Measurements and collection of data were performed by Jozef Rychlý, Lyda Rychlá, Ivica Janigová, Katarína Csomorová and Marta Malíková from PISAS Bratislava on following instruments:

Chemiluminescence - spectrometer Lumipol 3, product of PISAS Bratislava

DSC – Mettler Toledo DSC 821\(^{\circ}\) differential scanning calorimeter

Thermogravimetry - Mettler Toledo TGA/SDTA 851\(^{\circ}\)

Heats of combustion – IKA calorimetric bomb C 200

Bratislava, 07.3.2012
THERMAL ANALYSIS OF RESIN KIT POLYMERS
sample 1, polystyrene - general purpose

nitrogen, the rate of heating 5°C/min

403 °C
Sample 2 - polystyrene (medium impact)

DSC, mW

% of the mass

temperature, °C

the rate of heating
5°C/min

nitrogen

oxygen

418 °C

Sample 2 - polystyrene (medium impact)
DSC, mW
% of the mass
temperature, °C
the rate of heating 5°C/min nitrogen oxygen 418 °C
Sample 3 - polystyrene (high impact)

% of the mass

temperature, °C

the rate of heating, 5°C/min

nitrogen

oxygen

420 °C
Sample 4, styrene-acrylonitril copolymer, nitrogen

DSC, mW

% of the mass

temperature, °C

the rate of heating, 5°C/min

399 °C
sample 5, ABS transparent, nitrogen

the rate of heating, 5°C/min

408°C
Sample 6, ABS - medium impact, nitrogen

DSC, mW

% of the mass

temperature, °C

the rate of heating, 5°C/min

408 °C
Sample 7, ABS - high impact, nitrogen

the rate of heating, 5°C/min

410 °C

temperature, °C
% of the mass
DSC, mW
Sample 8, Styrene butadiene block copolymer, nitrogen

The rate of heating, 5°C/min

435 °C
Sample 9 - acrylic

% of the mass

temperature, °C

nitrogen

oxygen

the rate of heating, 5°C/min

370 °C

DSC, mW
Sample 10 - modified acrylic

DSC, mW

% of the mass

temperature, °C

nitrogen

oxygen

380 °C

the rate of heating,
5°C/min

DSC, mW

% of the mass

temperature, °C

nitrogen

oxygen

380 °C

the rate of heating,
5°C/min
Sample 11, cellulose acetate

nitrogen, the rate of heating 5 °C/min

350-358 °C
Sample 12, cellulose acetate butyrate

% of the mass of nitrogen, the rate of heating 5 °C/min

348 °C

DSC, mW

temperature, °C

% of the mass
Sample 13, cellulose acetate propionate

nitrogen, the rate of heating 5 °C/min

352 °C
Sample 14, nylon transparent

nitrogen, the rate of heating 5°C/min

167 °C

459 °C
Sample 15, nylon type 66

nitrogen, the rate of heating 5°C/min

DSC, mW

temperature, °C

% of the mass
Sample 16, Nylon, type 6

% of the mass

nitrogen, the rate of heating 5 °C/min

224 °C

434-438 °C

DSC, mW

temperature, °C

% of the mass
Sample 17, Thermoplastic polyester (PBT)
nitrogen, the rate of heating 5°C/min
226 °C
383 °C
% of the mass
DSC, mW
temperature, °C
Sample 18, Thermoplastic polyester (PETG) in nitrogen, the rate of heating 5°C/min.

Temperature, °C

DSC, mW

% of the mass

403 °C, 496 °C
Sample 19, polyphenylene oxide

DSC, mW

nephphere, 5 °C/min

temperature, °C

% of the mass

409 °C

nitrogen

oxygen
Sample 20, polycarbonate, the rate of heating 5°C/min.

Temperature, °C

% of the mass

Oxygen

Nitrogen

DTG

0,0000

-0,0005

-0,0010

-0,0015

-0,0020

0

10

20

30

40

50

60

70

80

90

100

110

0

100

200

300

400

500
The sample 21, polysulphone

nitrogen, the rate of heating 5 °C/min

The graph shows the mass % of the sample over temperature in °C. The DTG (Derivative Thermogravimetry) curve indicates significant changes in mass loss at certain temperatures.
Sample 22, Polybutylene

nitrogen, the rate of heating 5°C/min

434-437 °C
Sample 23, Ionomer

nitrogen, the rate of heating, 5°C/min

100 °C

447- 449 °C

% of the mass

DSC, mW

temperature, °C

% of the mass
Sample 24, polyethylene, low density

DSC, mW

nitrogen, the rate of heating 5°C/min

116 °C

459 °C

% of the mass

temperature, °C
Sample 25, Polyethylene (high density)

nitrogen, the rate of heating, 5 °C/min

130 °C
465-468 °C

% of the mass

DSC, mW

temperature, °C
The sample 26, polypropylene copolymer

% of the mass vs. temperature, °C

nitrogen
oxygen
Sample 27, polypropylene homopolymer

The rate of heating, 5°C/min

166 °C

435 °C

doxygen

nitrogen

% of the mass

DSC, mW

The graph shows the DSC (Differential Scanning Calorimetry) analysis of Sample 27, a polypropylene homopolymer. The analysis was performed with nitrogen and oxygen environments at a rate of 5°C/min. Key temperatures include 166 °C and 435 °C.
The sample 28, polypropylene, baryum sulphate reinforced nitroge, the rate of heating 5 °C/min
The sample 29, PVC flexible

nitrogen, the rate of heating
5 °C/min
The sample 30, PVC rigid

nitrogen, the rate of heating 5 °C/min
Sample 31, Acetal resin homopolymer

nitrogen, the rate of heating 5 °C/min

177 °C

350 °C

% of the mass

DSC, mW

temperature, °C

% of the mass
Sample 32, Acetal resin copolymer

nitrigen,
the rate of heating
5 °C/min

166 °C

352-365 °C

% of the mass

DSC, mW

temperature, °C
The sample 33, polyphenylene sulfide

The rate of heating 5°C/min

% of the mass

nitrogen

temperature, °C

DTG
Sample 34, Ethylene Vinyl Acetate (EVA) Copolymer

nitrigen, the rate of heating, 5°C/min

344 °C

447 °C

DSC, mW

% of the mass

temperature, °C
Sample 35, synthetic elastomer (styren block copolymer) in nitrogen, the rate of heating 5°C/min. The graph shows a temperature of 445°C.
Sample 36, polypropylene, glass filled

- 165-166 °C
- 442 °C

nitrogen, the rate of heating 5°C/min
Sample 37, Urethane elastomer, thermoplastic (TPU)

The rate of heating 5 °C/min

330 °C

% of the mass

DSC, mW

temperature, °C

oxygen

nitrogen

Temperature: 330 °C

Rate of heating: 5 °C/min
The sample 38, polypropylene flame retardant

nitrogen, the rate of heating 5 °C/min
Sample 39, polyester elastomer

nitrogen, the rate of heating 5 °C/min

210 °C

389 °C

% of the mass

DSC, mW

temperature, °C
The sample 40

nitrogen, the rate of heating 5 °C/min

% of the mass

temperature, °C

The sample 40

nitrogen, the rate of heating 5 °C/min
Sample 41, polyallomer

nitrogen, the rate of heating 5 °C/min

158 °C

436-438 °C/min

% of the mass

DSC, mW

temperature, °C

Sample 41, polyallomer

nitrogen, the rate of heating 5 °C/min

158 °C

436-438 °C/min

% of the mass

DSC, mW
Sample 42, styrenic terpolymer
nitrogen, the rate of heating 5° C/min
Sample 43, polymethyl pentene

233-235 °C

419 °C

nitrogen, the rate of heating 5 °C/min
Sample 44, polypropylene talc reinforced nitrogen, the rate of heating 5 °C/min

165 °C

405-410 °C
Sample 45, polypropylene calcium carbonate reinforced

nitrogen, 5°C/min

% of the mass

temperature, °C

DSC, mW
Sample 46 - polypropylene, mica reinforced

nitrogen, 5°C/min

DSC, mW
temperature, °C

% of the mass

165 °C

455 °C
Sample 47, nylon, type 66 - 33% of glass

DSC, mW vs. temperature, °C

nitrogen, 5 °C/min

264 °C

391 °C
Sample 48, thermoplastic rubber (TPV), nitrogen, the rate of heating, 5°C/min

DSC, mW
% of the mass

159 °C

452 °C

temperature, °C
Sample 49 - polyethylene medium density

130 °C

nitrogen, 5°C/min

447 °C

% of the mass

DSC, mW

DSC, mW

temperature, °C

% of the mass

DSC, mW

Sample 49 - polyethylene medium density

130 °C

nitrogen, 5°C/min

447 °C

% of the mass

DSC, mW

DSC, mW

temperature, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW

DSC, mW

climate, °C

% of the mass

DSC, mW
Sample 50 - ABS - nylon alloy

DSC, mW

temperature, °C

% of the mass

233 °C

449 °C

nitrogen, the rate of heating 5 °C/min

50 100 150 200 250 300 350 350 400 450 500 550

-18

-16

-14

-12

-10

-8

-6

-4

-2

0

20

40

60

80

100
Chemiluminescence from Resin Kit polymers

All chemiluminescence experiments were carried out in oxygen atmosphere and at the rate of heating 5 °C/min.
1- polystyrene, general purpose
2-polystyrene, medium impact
3-polystyrene, high impact

CL intensity, counts/s/1 mg

temperature, °C
5-acrylonitril, butadiene, styrene (ABS), transparent

4-styrene, acrylonitril (SAN)

8-styrene, butadiene block copolymer

6-acrylonitril, butadiene, styrene (ABS), medium impact

7-acrylonitril, butadiene, styrene (ABS), high impact

CL intensity, counts/s/1 mg

temperature, °C
14 - nylon (transparent)

15 - nylon (type 66)

16 - nylon (type 6)

47 - nylon (type 66-33% glass)

CL intensity, counts/s/1 mg

temperature, °C
30-polyvinyl chloride (PVC) rigid

29-polyvinyl chloride (PVC) flexible
34-ethylene-vinyl acetate (EVA)
35-synthetic elastomer (styrene block copolymer)
37-urethane elastomer termoplastic (TPU)
39-polyester elastomer

CL intensity, counts/s/1 mg

temperature, °C
CL intensity, counts/s/1 mg vs. temperature, °C

- 41-polyallomer
- 42-styrenic terpolymer
- 43-polymethyl pentene
- 40-acrylonitrile, butadiene, styrene (ABS) flame retardant
Chemiluminescence, DSC and thermogravimetry of Smile polymers supplied by Collin Williamson
the rate of heating 5 °C/min

residual weight

temperature, °C

CL intensity, counts/s/1 mg

irregular

oxygen

nitrogen
rate of heating 5°C/min

nitrogen

oxygen

residual weight, %
temperature, °C

CL intensity, counts/s/1 mg

temperature, °C
the rate of heating 5 °C/min

residual weight, %

temperature, °C

CL intensity, counts/s/1 mg

oxygen

nitrogen

0 20 40 60 80 100

0 2000 4000 6000 8000 10000 12000
rate of heating, 5 °C/min

residual weight, %
temperature, °C

chemiluminescence intensity, counts/s/1 mg
nitrogen
oxygen

0 100 200 300 400 500
0
10
20
30
40
50
60
70
80
90
100
110
0
100
200
300
400
500
600
700
800
900
1000
the rate of heating, 5°C/min

residual weight, %
temperature, °C

nitrogen
oxygen
the rate of heating 5 °C/min

nitrogen

oxygen

residual weight, %
temperature, °C

CL intensity, counts/s/1 mg
the rate of heating 5 °C/min

residual weight, %

temperature, °C

nitrogen

oxygen

CL intensity, counts/s/1 mg
the rate of heating 5 °C/min

residual weight, %

temperature, °C

CL intensity, counts/s/1 mg

nitrogen

oxygen
the rate of heating 5 °C/min
The rate of heating is 5 °C/min.

- Oxygen
- Nitrogen

Residual weight, %

Temperature, °C

CL intensity, counts/s/1 mg
the rate of heating 5 °C/min

residual mass, %
temperature, °C

nitrogen
oxygen
irregular
the rate of heating 5 °C/min

residual weight, %

temperature, °C

CL intensity, counts/s/1 mg

nitrogen

oxygen
The rate of heating 5°C/min

- Nitrogen
- Oxygen

Residual weight, %

Temperature, °C

CL intensity, counts/s/1 mg
the rate of heating 5°C/min

residual weight, %
temperature, °C

nitrogen

oxxygen

CL intensity, counts/s/1 mg
the rate of heating 5°C/min

residual weight, %

CL intensity, counts/s/1 mg

nitrogen

oxygen

15
the rate of heating 5°C/min

residual weight, %

temperature, °C

CL intensity, counts/s/1 mg

nitrogen

oxygen
the rate of heating 5°C/min

residual weight, %
temperature, °C

CL intensity, counts/s/1 mg

oxygen
nitrogen
the rate of heating 5°C/min

residual weight, %

temperature, °C

oxygen

nitrogen

CL intensity, counts/s/1 mg

18
the rate of heating 5°C/min

residual weight, %

nitrogen

oxygen

CL intensity, counts/s/1 mg

temperature, °C

100 200 300 400 500

0 20 40 60 80 100

0 2000 4000 6000 8000 10000
the rate of heating 5°C/min

nitrogen

oxygen

CL intensity, counts/s/1 mg

residual weight, %
temperature, °C
the rate of heating 5°C/min
oxygen
nitrogen
CL intensity, counts/s/1 mg
residual weight, %
temperature, °C
the rate of heating 5°C/min
irregular
nitrogen
oxygen
CL intensity, counts/s/1 mg
residual weight, %
temperature, °C
The rate of heating 5°C/min

Temperature, °C

Residual weight, %

CL intensity, counts/s/1 mg

Nitrogen

Oxygen

Irregular
the rate of heating 5°C/min

residual weight, %

CL intensity, counts/s/1 mg

nitrogen

oxygen

temperature, °C
the rate of heating 5°C/min

nitrogen

oxygen

CL intensity, counts/s/1 mg

residual weight, %
temperature, °C
the rate of heating, 5°C/min

residual weight, %
temperature, °C

oxygen

CL intensity, counts/s/1 mg

26

0 10 20 30 40 50 60 70 80 90 100 110
0 5000 10000 15000 20000 25000 30000 35000 40000
0 5000 10000 15000 20000 25000 30000 35000 40000

0 10 20 30 40 50 60 70 80 90 100 110
0 5000 10000 15000 20000 25000 30000 35000 40000
0 5000 10000 15000 20000 25000 30000 35000 40000
the rate of heating, 5°C/min

residual weight, %

temperature, °C

nitrogen

oxygen

CL intensity, counts/s/1 mg
the rate of heating, 5°C/min

nitrogen

oxygen

CL intensity, counts/s/1 mg

residual weight, %

temperature, °C
residual weight, %

temperature, °C

the rate of heating, 5°C/min

CL intensity, counts/s/1 mg

oxygen

nitrogen

31
the rate of heating, 5°C/min

residual weight, %
temperature, °C
the rate of heating, 5°C/min

nitrogen
oxygen
the rate of heating, $5^\circ$C/min

residual weight, %

nitrogen

oxygen

CL intensity, counts/s/1 mg

temperature, $^\circ$C

$33$
the rate of heating, 5°C/min

residual weight, %

temperature, °C

nitrogen

oxygen

CL intensity, counts/s/1 mg
the rate of heating, 5°C/min

nitrogen
oxygen

CL intensity, counts/s/1 mg
residual weight, %
temperature, °C
the rate of heating 5 °C/min

residual weight, %

temperature, °C

CL intensity, counts/s/1 mg

nitrogen

oxygen
Overview of chemiluminescence, DSC and thermogravimetry data useful for identification of originally unknown polymers

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Residue at 550 °C, nitrogen, %</th>
<th>Temperature of maximum release of volatiles, °C, nitrogen</th>
<th>Maximum rate of release of volatiles, nitrogen, rel.u./s</th>
<th>Heat of combustion, J/g</th>
<th>Temperature of DSC melting endotherm, °C</th>
<th>I$_{\text{max}}$ of CL, counts/s/1mg</th>
<th>Temperature of I$_{\text{max}}$, °C</th>
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<tbody>
<tr>
<td>1 PE</td>
<td>0.4-</td>
<td>464.3</td>
<td>0.00251</td>
<td>47 426</td>
<td>132.2</td>
<td>135 783</td>
<td>&gt;250</td>
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<td>2 HIPS</td>
<td>4.3&gt;</td>
<td>414.9</td>
<td>0.00251</td>
<td>41 325</td>
<td>1 075</td>
<td>&gt;250</td>
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<td>246.7</td>
<td>1.2e-4</td>
<td>27 767</td>
<td>8 240</td>
<td>&gt;250</td>
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</tr>
<tr>
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<td>0.00174</td>
<td>32 085</td>
<td>708</td>
<td>&gt;250</td>
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<td>5 PBT</td>
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<td>26 425</td>
<td>122 404</td>
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<td>0.00128</td>
<td>32 432</td>
<td>263.7</td>
<td>1 383 507</td>
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<td>PVC flexible</td>
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<td>266.7</td>
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<td>26 003</td>
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<td>364.1</td>
<td>7.3e-4</td>
<td>39 284</td>
<td>22 125</td>
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<tr>
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<td>CN</td>
<td>12.1</td>
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<td>72 735</td>
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<td>15</td>
<td>POM</td>
<td>0.04</td>
<td>369.5</td>
<td>0.00375</td>
<td>17 472</td>
<td>335 511</td>
<td>246.0</td>
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<tr>
<td>16</td>
<td>PA 6,6</td>
<td>4.0</td>
<td>421.5</td>
<td>0.00132</td>
<td>32 196</td>
<td>264.2</td>
<td>616 811</td>
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<td>17</td>
<td>POM homopolymer</td>
<td>0.7</td>
<td>376.1</td>
<td>0.00332</td>
<td>18 437</td>
<td>177.9</td>
<td>74 462</td>
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*Values in the table indicate the material type and properties. The table includes materials such as PUR ether and PUR ester, UF, MF, PF, PVC rigid, PS, SBS, UP, and Vulcanite. The values represent various properties, possibly related to viscosity or other material characteristics. The table also includes a column for concentration or other relevant metrics, with values ranging from 7.6e-5 to 1.7e-4. The table concludes with a column indicating concentrations greater than 250.
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*foam, -, > steady, decreasing value at 550 °C

Samples were identified as:
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*foam*
Acknowledgements

The present research has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under the grant agreement no. 212218 - Popart: Strategy for the preservation of plastic artefacts in museum collections.