Using the latest advancements in injection molded thermally conductive plastics
LATI

Compounding solutions

LATI is a family-owned independent compounder based in Italy. In thermoplastics since 1945.

LATI portfolio: reinforced, flame retardant and special purpose grades.
LATI

Main markets

- BUILDING AND FURNITURE (7%)
- TELECOMUNIC. (1%)
- MEDICAL (1%)
- ELECTRICAL (45%)
- INDUSTRIAL (7%)
- TRANSPORTS (20%)
- APPLIANCE (20%)

Export: >70% of LATI’s business
Thermally Conductive Compounds and heat management
Since 2003

*Thermally conductive compounds (TCCs)*

First industrial products: year **2003**

First industrial application: LED modular lamp, year **2005**

PA12 – 85% ceramic
21\textsuperscript{st} Century technical megatrends

Managing heat build-up

- Electronic miniaturization
- Weight reduction
- Function integration
- Complex design
- Cost reduction

Heat build-up

Reduce number of materials

Metal replacement

Smart design
Booming industrial sectors

*Dissipate heat, work better*

Reducing local temperature increases performance and expected lifespan of electronics.

LED market
2016 – 2 B€
2023 – 23 B€
Plastics vs. Metals

*Conduction, convection, radiation*

Metals offer higher thermal conductivity than plastics, but...

<table>
<thead>
<tr>
<th>Material</th>
<th>Density (g/cc)</th>
<th>k (W/mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>steel</td>
<td>7.8</td>
<td>16</td>
</tr>
<tr>
<td>aluminum</td>
<td>2.7</td>
<td>237</td>
</tr>
<tr>
<td>copper</td>
<td>8.7</td>
<td>400</td>
</tr>
<tr>
<td>ceramic</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>plastics</td>
<td>1-1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>LATICONTHER GR</td>
<td>1.5</td>
<td>15</td>
</tr>
</tbody>
</table>

...thermal conductivity above 10 W/mK can be **redundant** in case of natural convection/radiation.
Plastics vs. Metals

*TCCs manufacturing – a complex process*

- Base resin intrinsic limits
- Conductive fillers content
- Particle dispersion
- Property compromise
LATICONTHER CP
Ceramics

Ceramic based
- Thermal conductivity up to 10 W/mK
- Electrically insulative
- Excellent dimensional stability
- Flame retardant versions

- medical grades
- accepts inserts
- clean: no sloughing
- can be coloured

LATI Industria Termoplastici S.p.A.
Business Development Unit
LATICON THER GR

Graphite

Graphite based

Thermal conductivity up to 20 W/mK
Electrically conductive
Excellent price/performance ratio
Easy processing, good flowability

- fill tiny features
- accept inserts
- epoxy paintable
- can be machined
Plastics vs. Aluminium
Advantages of TCCs

- Less energy consumption, smaller carbon footprint
- Very low density
- No post-processing (painting, de-flashing, machining etc.)
- Complex design and function integration
- Colourable, chemical and corrosion resistant
Know your TCC
Learn by doing

Correct approach, winning solution

TCCs are not aluminum “drop-in”

Proper moulding requires some dedicated practice

Correct design requires specific knowledge
TCC fundamentals

*Fillers = thermal performance*

Ceramics show a rather low aspect ratio. TCC featuring **ceramic fillers** feature **isotropic** thermal behaviour.
TCC fundamentals
Fillers = thermal performance

Assuming one single value for thermal conductivity is an acceptable compromise

\[
\begin{array}{|l|c|c|}
\hline
\text{THERMAL PROPERTIES} & \text{STANDARD} & \text{SI UNITS} \\
\hline
\text{VICTAT - Softening point - 50 N (heating rate 50°C/h)} & \text{ISO 305} & 210°C \\
\hline
\text{HDT - Heat Deflection Temperature} & \text{ISO 75} & 220°C \\
\hline
0.45 MN/m² & \text{ISO 75} & 220°C \\
\hline
1.81 MN/m² & \text{ISO 75} & 200°C \\
\hline
\text{Thermal conductivity in plane (Kx - ky) - 1/8 in. thickness} & \text{LATI} & 1.4 \text{ W/m/K} \\
\hline
\text{Thermal conductivity through plane (Kz) - 1/8 in. thickness} & \text{LATI} & 1 \text{ W/m/K} \\
\hline
\end{array}
\]
TCC fundamentals
Fillers = performance

<table>
<thead>
<tr>
<th>Property</th>
<th>Hex-BN</th>
<th>Graphite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cc)</td>
<td>2,1</td>
<td>2,1</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>K (W/mK)</td>
<td>70-100</td>
<td>75</td>
</tr>
<tr>
<td>Electric properties</td>
<td>insulator</td>
<td>conductor</td>
</tr>
<tr>
<td>Natural colour</td>
<td>white</td>
<td>black</td>
</tr>
</tbody>
</table>

TCCs featuring **graphite or boron nitride** show strongly **anisotropic** thermal behaviour because of **orientation** of conductive flakes during cavity filling.
### TCC fundamentals

*Fillers = thermal performance*

<table>
<thead>
<tr>
<th>Thermal Properties</th>
<th>Standard</th>
<th>SI Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VICAT - Softening point - 50 N (heating rate 50°C/h)</td>
<td>ISO 306</td>
<td>200°C</td>
</tr>
<tr>
<td>HDT - Heat Deflection Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0,45 MN/m²</td>
<td>ISO 75</td>
<td>210 °C</td>
</tr>
<tr>
<td>1,81 MN/m²</td>
<td>ISO 75</td>
<td>205 °C</td>
</tr>
<tr>
<td>Thermal conductivity in plane (K_x - k_y) - 1/8 in. thickness</td>
<td>LATI</td>
<td>28 W/m/K</td>
</tr>
<tr>
<td>Thermal conductivity through plane (K_z) - 1/8 in. thickness</td>
<td>LATI</td>
<td>4 W/m/K</td>
</tr>
</tbody>
</table>

In plane vs. through plane ratio deserves accurate consideration when modelling.

in plane through plane $>> 1$
TCC fundamentals

*Fillers = performance*

TCC featuring flake-shaped fillers may require a better description of local thermal properties.
1 - Measuring conductivity

In plane \((k_{x,y})\) and through plane \((k_z)\) thermal conductivity have to be measured as per ASTM E1530 and E1461-92 standards.

Suitable specimen are prepared using injection moulded plates.

Values from TDS LATICONTHER 62 CP6/650-V0HF1

- ASTM E 1461–92
  - \(4 \text{ W/(m} \cdot \text{K)}\)
  - \(1.5 \text{ W/(m} \cdot \text{K)}\)
1 - Measuring conductivity
Effects of geometry and moulding

Particle orientation is affected by **wall thickness**. Effects of **moulding parameters** (e.g. packing pressure) are less relevant.
1 - Measuring conductivity
*Flakes: effects of geometry and moulding*

- Conductivity through plane increases with wall thickness;
- Conductivity in plane decreases with wall thickness;

In this case, \( k_x \approx k_y > k_z \)

\( k_{\text{in plane}} / k_{\text{through plane}} > 10 \)

Random orientation becomes more and more important above 4-5 mm thickness.
Designing with TCCs
Let’s try to evaluate temperature distribution on the heat sink of a **50W** COB LED lamp:

**LED projector**

2xLED COB, 25W each

*open air 25°C, free convection*

*Heat sink: 250x150x60 mm*

*Average thickness > 4mm*

*Material: PA6 50% graphite*
2 - Designing

Geometry

Step 1 – part geometry and **boundary conditions**:

- **Convection only**: $T_{\text{env}} = 25^\circ\text{C}$;
- **Convection and radiation**: $T_{\text{env}} = 25^\circ\text{C}$;
- **Heat applied**: Power = 50W, with spreader
2 - Designing

*Evaluating feasibility – adimensional numbers*

**Step 2:** use **adimensional numbers** according to heat transport physics to obtain an acceptable evaluation of geometry capabilities.

<table>
<thead>
<tr>
<th>Description Parameters - Base</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Width</td>
<td>$W_B$</td>
<td>0.176</td>
<td>m</td>
</tr>
<tr>
<td>Base Length</td>
<td>$L_B$</td>
<td>0.25</td>
<td>m</td>
</tr>
<tr>
<td>Base Thickness</td>
<td>$t_B$</td>
<td>0.008</td>
<td>m</td>
</tr>
<tr>
<td>Base Thermal Conductivity</td>
<td>$k_B$</td>
<td>8</td>
<td>W/mK</td>
</tr>
<tr>
<td>Base Emissivity</td>
<td>$\epsilon_B$</td>
<td>0.87</td>
<td>-</td>
</tr>
<tr>
<td>Base Max Temperature</td>
<td>$T_B$</td>
<td>80</td>
<td>°C</td>
</tr>
<tr>
<td>Power to dissipate</td>
<td>$Q_D$</td>
<td>50</td>
<td>W</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description Parameters - Fin / Pin</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fin Width (Thickness)</td>
<td>$W_F$</td>
<td>0.004</td>
<td>m</td>
</tr>
<tr>
<td>Fin Length = $L_B$</td>
<td>$L_F$</td>
<td>0.25</td>
<td>m</td>
</tr>
<tr>
<td>Fin Height</td>
<td>$H_F$</td>
<td>0.04</td>
<td>m</td>
</tr>
<tr>
<td>Number of Fins on Base Width</td>
<td>$N_F$</td>
<td>13</td>
<td>-</td>
</tr>
<tr>
<td>Fins Frozen Layer Guestimation</td>
<td>$T_{FL}$</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Distance between fins = $(W_B - W_F^2)/(N_F - 1)$</td>
<td></td>
<td>0.012</td>
<td>m</td>
</tr>
<tr>
<td>Fin Thermal Conductivity, Longitudinal</td>
<td>$k_{F,L}$</td>
<td>15</td>
<td>W/mK</td>
</tr>
<tr>
<td>Fin Thermal Conductivity, Transversal</td>
<td>$k_{F,T}$</td>
<td>1.2</td>
<td>W/mK</td>
</tr>
<tr>
<td>Fin Emissivity = $\epsilon_B$</td>
<td>$\epsilon_F$</td>
<td>0.87</td>
<td>-</td>
</tr>
<tr>
<td>Fin Efficiency (Viewfactor approximation)</td>
<td>$\eta_F$</td>
<td>0.07692</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description parameters - Environment (Fin Side)</th>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature</td>
<td>$T_A$</td>
<td>25</td>
<td>°C</td>
</tr>
</tbody>
</table>
2 - Designing

_Evaluating feasibility – adimensional numbers_

**Step 2:** calculate **heat transfer coefficient** $h_{\text{conv}}$ for convective regime.

### Derived Parameters - Environment

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h$</td>
<td>7.833</td>
<td>W/m²K</td>
</tr>
</tbody>
</table>

### Derived Parameters - Assembly

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Equation</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q_{\text{conv}, F}$</td>
<td>$A_{F,S} \times h \times (T_{\text{AVG}} - T_A)$</td>
<td>45.53</td>
<td>W</td>
</tr>
<tr>
<td>$Q_{\text{conv}, B}$</td>
<td>$A_B \times h \times (T_{\text{AVG}} - T_A)$</td>
<td>17.98</td>
<td>W</td>
</tr>
<tr>
<td>$Q_{\text{rad}, F}$</td>
<td>$\sigma \times \eta \times A_{F,S} \times \epsilon \times (T_{\text{AVG}}^4 - T_A^4)$ [T in K]</td>
<td>7.06</td>
<td>W</td>
</tr>
<tr>
<td>$Q_{\text{rad}, B}$</td>
<td>$\sigma \times ((A_B - A_{F,T}) \times \epsilon_B + A_{F,T} \times \epsilon_F) \times (T_{\text{AVG}}^4 - T_A^4)$</td>
<td>15.54</td>
<td>W</td>
</tr>
<tr>
<td>$Q_{\text{tot}}$</td>
<td>$Q_{\text{conv}} + Q_{\text{rad}}$</td>
<td>86.10</td>
<td>W</td>
</tr>
</tbody>
</table>

\[ Q_{\text{conv}} = h_{\text{conv}} A(T_p - T_{\text{amb}}) \]

\[ Q_{\text{rad}} = \epsilon \sigma A(T_p^4 - T_{\text{amb}}^4) \]
2 - Designing

*Evaluating feasibility - FEA*

**Step 3:** run **finite element analysis** to evaluate part performance in actual working conditions (environmental temperature etc.).

**Test A: homogeneous isotropic** thermal behaviour of TCC (10 W/mK).

An **aluminium spreader** can be introduced simulating heat sink – PCB interface.
2 - Designing

Evaluating feasibility - FEA

Step 3: results indicate temperature distribution (steady state).

Test A
Isotropic thermal conductivity, natural convection
2 - Designing

*Evaluating feasibility - radiation*

**Step 3: test B, run finite element analysis** introducing radiation as well.

Heat removal by radiation can be quite relevant (>50% total).

\[ Q_{\text{conv}} = h_{\text{conv}} A(T_p - T_{\text{amb}}) \]

\[ Q_{\text{rad}} = \varepsilon \sigma A(T_p^4 - T_{\text{amb}}^4) \]

Wall temperature  Room temperature
2 - Designing

Evaluating feasibility - radiation

Step 3: contribution of radiation can be remarkable, specially for those geometries offering favourable view factors (surface exposure to radiation).

Fins offer poor view factor, radiation contribution may be low here.

Free faces radiate.

Test b
Isotropic thermal conductivity, natural convection, radiation.
2 - Designing

Evaluating feasibility – introducing flakes

Step 4: simulating flake orientation and local thermal performance.

Flake orientation is obtained by fluid-dynamic FEA simulating mould filling.

Actual viscosity and PVT curves of PA6 50% graphite available in MOLDEX3D-LATI database
2 - Designing  
*Orientation matters*

Fibre orientation tensor is used to evaluate deformation of part geometry and local mechanical performance.

Isotropic mechanical behaviour would lead to wrong assumptions.

What about thermal properties?
2 - Designing

Evaluating feasibility – introducing flakes

Flakes orientation data are calculated on every element of the 3D mesh...

Flake: disk, diam./thick. = 10

Orientation parameters can be mathematically processed to obtain a rough but reliable indication of local thermal conductivity.
2 - Designing

*Evaluating feasibility – introducing flakes*

Flakes orientation details describe local behavior (section cut – orientation normal to plane).

- **Z direction shows strong in-plane orientation on the heat-sink base**
- **Y direction shows strong orientation along fins plane**
2 - Designing

Evaluating feasibility – introducing flakes

Flakes orientation data can be used to evaluate local thermal conductivity values.

*local thermal conductivity* is translated into a specific material identity card associated to each 3D mesh element.
2 - Designing

Evaluating feasibility – introducing flakes

Thermal FEA using **local conductivity** data provides a more accurate temperature distribution.
2 - Designing

*Evaluating feasibility – confronting results*

Temperature distribution, re-scaled range 40-52°C

**Test A**
*Isotropic* thermal conductivity, natural convection.

**Test C**
*Local* thermal conductivity, natural convection.
2 - Designing
Evaluating feasibility – confronting results

**Test A**
*Isotropic* thermal conductivity, natural convection.

**Test C**
*Local* thermal conductivity, natural convection.

*Contribution of fins*

~ 52°C

~ 49°C
2 - Designing

Evaluating feasibility – confronting results

Contribution of fins is evidenced in Test C. **Flake orientation** enhances heat distribution along fins.

**Evaluation of local thermal conductivity improves by far with mesh quality.**
2 - Designing

*Not only thermal performance*

3 – Other fundamental factors must be kept into consideration when designing TCC parts.

- Mould layout and draft angle
- Moulding equipment
- Geometric features
2 - Designing

*Not only thermal performance*

**Deformations** can be a major issue leading to **poor matching** between heat source and sink. Failure follows.

*Warpage due to major geometric flaws in fins layout.*
2 - Designing

Not only thermal performance

Sink marks are an often neglected issue leading to poor contact between heat source and sink. Failure follows as well.

Sink mark generated by wrong fins/base thickness ratio
2 - Designing

Not only thermal performance

TCCs as aluminum drop-in? No! Design should be optimized for TCCs...

This geometry features very thin walls and thicker fins.

This radiator features a thick base but fins may be too large and narrow.
2 - Designing

*Not only thermal performance*

*Pins can work better than fins once their aspect ratio and taper has been properly tuned*
3 - Conclusions

*Expanding application fields*

TCCs can today be used in **demanding** applications, but **accurate design** is mandatory.

The case study used in this presentation is similar to an actual industrial product available on the market.

*(CASTOR 2M by Electromagnetica)*
3 - Conclusions

Extended play

Proper simulation, design and moulding may allow dispersion of higher power (> 1kW).
Any Questions?...

Thanks for your attention!