Tough or Strong?
Short or Long?
Dialing in Mechanical Properties

Karl Hoppe
Senior Product Development Engineer
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS
Resin + Additives = Change in Properties
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Structural Additives: Foundation
In this Presentation

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Modifiers

Fillers
Polymer Blends
Impact Modifiers
ABS brings
- Improved flow
- Chemical resistance
- Cost reduction

PP brings
- Improved flow
- Chemical resistance
- Cost reduction

PBT brings
- Improved flow
- Chemical Resistance
PC / ABS

Nylon / PP

PC / PBT

PC brings
- Toughness
- Strength

Nylon brings
- Strength
- Stiffness

PC brings
- Toughness
- Dimensional stability
<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PC/ABS (RTP 2500 A)</th>
<th>ABS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.19</td>
<td>1.15</td>
<td>1.05</td>
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<tr>
<td>Tensile Strength</td>
<td>59 MPa</td>
<td>59 MPa</td>
<td>45 MPa</td>
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<tr>
<td>Notched Izod Impact</td>
<td>850 J/m</td>
<td>740 J/m</td>
<td>250 J/m</td>
</tr>
</tbody>
</table>
Application: Housing for Hearing Tester

Problem: Toughness and chemical resistance

Solution: Polycarbonate/ABS Alloy

Benefit: Strength and toughness of PC with the added chemical resistance of ABS
Impact Modifiers

Strength
Stiffness

Impact properties
<table>
<thead>
<tr>
<th>Property</th>
<th>PA 6/6</th>
<th>Impact Modified PA 6/6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.14</td>
<td>1.08</td>
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<tr>
<td>Notched Izod Impact</td>
<td>55 J/m</td>
<td>900 J/m</td>
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<tr>
<td>Tensile Strength</td>
<td>80 J/m</td>
<td>45 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>2.8 GPa</td>
<td>1.8 GPa</td>
</tr>
</tbody>
</table>
Application: Housing for Wireless Workstation

Problem: Toughness and abrasion resistance

Solution: Impact Modified PA 6/6

Benefit: Wear and abrasion resistance of Nylon 6/6 with added toughness from impact modifier
Limitations

Base resin

Environment

Lose Performance

Temperature

Chemical Resistance

UV Resistance
Stabilizers

• Protect from
  – UV
  – Heat aging
• Hindered Amine Light Stabilizers (HALS)
  – Protects polymer by stopping degradation reactions once they have started

• UV Absorbers
  – Protects polymer by absorbing harmful UV light before the degradation reaction has started
30% Long Fiber (VLF) PP

Tensile Strength Retention

UV Exposure - kJ/m²

HALS
HALS + Absorber
Heat stabilizers come in many forms

- Slow down the degradation reactions of the polymer caused by heat
- Can be for process stability or Long Term Heat Aging (LTHA)
# Heat Stabilization Data

40% VLF PP
1000 Hour Heat Aging

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Tensile Retention</th>
<th>Izod Impact Retention</th>
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</thead>
<tbody>
<tr>
<td>140°C</td>
<td>+5.7%</td>
<td>+9.9%</td>
</tr>
<tr>
<td>150°C</td>
<td>-4.7%</td>
<td>-11.3%</td>
</tr>
</tbody>
</table>

Typical Automotive requirements are ~+/- 25%
In this Presentation

Modifiers

Fillers
Beads (Glass)
(photo: Potters, Inc.)

Minerals (Talc)

Fibers (Glass)
Property change determined by:

\[
\text{Aspect Ratio} = \frac{L}{D}
\]

Aspect Ratio

Reinforcing
**Low Aspect Ratio**

Beads (Glass)
(photo: Potters, Inc.)

Aspect Ratio = 1

<table>
<thead>
<tr>
<th>Property</th>
<th>PC</th>
<th>PC + 10% Glass Beads</th>
<th>PC + 30% Glass Beads</th>
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</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.19</td>
<td>1.27</td>
<td>1.42</td>
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<tr>
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<td>59 MPa</td>
<td>55 MPa</td>
<td>48 MPa</td>
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<tr>
<td>Notched Izod Impact</td>
<td>850 J/m</td>
<td>100 J/m</td>
<td>80 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>2.4 GPa</td>
<td>2.6 GPa</td>
<td>3.4 GPa</td>
</tr>
</tbody>
</table>
Minerals (Talc)

Aspect Ratio = 2-50

<table>
<thead>
<tr>
<th></th>
<th>PP</th>
<th>PP + 20% Talc</th>
<th>PP + 40% Talc</th>
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</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.91</td>
<td>1.05</td>
<td>1.25</td>
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<tr>
<td>Tensile Strength</td>
<td>32 MPa</td>
<td>32 MPa</td>
<td>30 MPa</td>
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<tr>
<td>Notched Izod Impact</td>
<td>47 J/m</td>
<td>45 J/m</td>
<td>34 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>1.5 GPa</td>
<td>2.5 GPa</td>
<td>3.8 GPa</td>
</tr>
</tbody>
</table>
Warp Control

Shrink Rate $x = \text{Shrink Rate } y$ → Flat Part
Application: Reusable Handling Container
Problem: Dimensional stability
Solution: Mineral filled Polypropylene
Benefit: Low warpage
### High Aspect Ratio

**Fibers (Glass)**

**Aspect Ratio = 50-250**

<table>
<thead>
<tr>
<th></th>
<th>PC</th>
<th>PC + 30% Glass Beads</th>
<th>PC + 30% Glass Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Specific Gravity</strong></td>
<td>1.19</td>
<td>1.42</td>
<td>1.42</td>
</tr>
<tr>
<td><strong>Tensile Strength</strong></td>
<td>59 MPa</td>
<td>48 MPa</td>
<td>124 MPa</td>
</tr>
<tr>
<td><strong>Notched Izod Impact</strong></td>
<td>850 J/m</td>
<td>80 J/m</td>
<td>160 J/m</td>
</tr>
<tr>
<td><strong>Flexural Modulus</strong></td>
<td>2.4 GPa</td>
<td>3.4 GPa</td>
<td>7.6 GPa</td>
</tr>
</tbody>
</table>
## High Aspect Ratio

**YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS**

<table>
<thead>
<tr>
<th>Aspect Ratio</th>
<th>Fibers (Glass)</th>
<th>50-250</th>
</tr>
</thead>
</table>

**Properties**

<table>
<thead>
<tr>
<th>Property</th>
<th>PP</th>
<th>PP + 40% Talc</th>
<th>PP+ 40% Glass Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>0.91</td>
<td>1.25</td>
<td>1.22</td>
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<tr>
<td>Tensile Strength</td>
<td>32 MPa</td>
<td>30 MPa</td>
<td>85 MPa</td>
</tr>
<tr>
<td>Notched Izod Impact</td>
<td>47 J/m</td>
<td>34 J/m</td>
<td>108 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>1.5 GPa</td>
<td>3.8 GPa</td>
<td>6.9 GPa</td>
</tr>
</tbody>
</table>
Application: Surgery Drill Guide

Problem: Stiffness and dimensional stability

Solution: Glass fiber reinforced Polycarbonate

Benefit: Rigidity and tight tolerances
Non-Uniform Shrink = Warp

Shrinkage X1 & X2 ≠ X3  ➔ Warp
Shrinkage $X_1 = X_2 = X_3$ → Flat Part
VLF Manufacturing Process

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Fiber  Extruder/Die  Puller  Pelletizer
### Extreme Aspect Ratio

Your Global Compounder of Custom Engineered Thermoplastics

<table>
<thead>
<tr>
<th></th>
<th>PP+ 40% Short Glass</th>
<th>PP + 40% Long Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>85 MPa</td>
<td>118 MPa</td>
</tr>
<tr>
<td>Notched Izod Impact</td>
<td>108 J/m</td>
<td>228 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>6.9 GPa</td>
<td>7.7 GPa</td>
</tr>
</tbody>
</table>

**Long Glass Fiber**

Aspect Ratio = 300+
Extreme Aspect Ratio

YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

Short Fiber

Fiber Length

~ 1-2 mm

Long Fiber

Fiber Length

12 mm
Secret to Success: The Skeleton

PA 66 + 60% VLF
Seat Belt Tensioner Housing
Polyamide 6/6 – 40% Glass Fiber

Impact Strength
Notched IZOD, J/m

Flex Modulus
GPa

Tensile Modulus
GPa

Flex Strength
MPa

Tensile Strength
MPa

Long Fiber
Short Fiber, Impact-Modified
Short Fiber
### High Aspect Ratio

#### Carbon Fibers

Aspect Ratio = 50-250

<table>
<thead>
<tr>
<th></th>
<th>PEEK</th>
<th>PEEK + 40% Glass Fiber</th>
<th>PEEK + 40% Carbon Fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>1.30</td>
<td>1.61</td>
<td>1.45</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>93 MPa</td>
<td>186 MPa</td>
<td>265 MPa</td>
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<tr>
<td>Notched Izod Impact</td>
<td>53 J/m</td>
<td>133 J/m</td>
<td>91 J/m</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>3.8 GPa</td>
<td>13.8 GPa</td>
<td>30.3 GPa</td>
</tr>
</tbody>
</table>
**Application:** Brake Rotor Measuring Probe

**Problem:** Casting replacement

**Solution:** Carbon fiber reinforced PPA

**Benefit:** High strength and stiffness
YOUR GLOBAL COMPOUNDER OF CUSTOM ENGINEERED THERMOPLASTICS

High Temperature Polymers

Amorphous
- Polyetherimide (PEI)
- Polyethersulfone (PES)
- Polysulfone (PSU)
- Polycarbonate (PC)
- Acrylonitrile Butadiene Styrene (ABS)
- Styrene Acrylonitrile (SAN)
- Polystyrene (PS)
- High Impact Polystyrene (HIPS)
- Acrylic (PMMA)

Semi-Crystalline
- Polyetheretherketone (PEEK)
- Polyphenylene Sulfide (PPS)
- Polyphthalamide (PPA)
- Polyethylene Terephthalate (PET)
- Polybutylene Terephthalate (PBT)
- Polyamide (PA/Nylons)
- Acetal (POM)
- Polypropylene (PP)
- Polyethylene (HDPE, LDPE, LLDPE)

Thermal & Cost Increases

High Performance  Engineering  Commodity
**Polyethylene**

$T_g$ -5 °F

\[
\begin{array}{c}
C \\
C \\
C \\
C \\
C \\
\end{array}
\]$

**Polyimide**

$T_g$ 482 °F

\[
\begin{array}{c}
O \\
C \\
C \\
N \\
R \\
\end{array}
\]$

---

*Image of a pink scooter and a military tank are also present.*
Flexural Modulus Vs. Temperature

- **Flexural Modulus, MPa**
- **Temperature, °F**

- **Flexural Modulus** of 40% GF PSU, 40% GF PES, and 40% GF PEI are shown in the graph.

The graph depicts the decrease in flexural modulus with increasing temperature for each material.
Flexural Modulus Vs. Temperature

```
<table>
<thead>
<tr>
<th>Material</th>
<th>Flexural Modulus, MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>40% GF PPA</td>
<td>18000</td>
</tr>
<tr>
<td>40% GF HTN</td>
<td>16000</td>
</tr>
<tr>
<td>40% GF PEEK</td>
<td>14000</td>
</tr>
<tr>
<td>40% GF PPS</td>
<td>12000</td>
</tr>
<tr>
<td>40% GF TPI</td>
<td>10000</td>
</tr>
</tbody>
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```

Temperature, °F
Multiple Temperature Tensile Stress/Strain

40% Glass fiber filled Polypropylene

- Typical DAM @ -40 C
- Typical DAM @ 23 C
- Typical DAM @ 65 C
- Typical DAM @ 107 C

40% Glass fiber filled Nylon 6/6

- Typical DAM, -40 C
- Typical DAM, 23 C
- Typical DAM, 65 C
- Typical DAM, 121 C

40% Glass fiber filled PPA

- Typical DAM, -40 C
- Typical DAM, 23 C
- Typical DAM, 65 C
- Typical DAM, 176 C
Application: Copier Bushings

Problem: High temperature (>445°F)

Solution: Aramid fiber reinforced TPI

Benefit: Wear resistance
Flexural Modulus

<table>
<thead>
<tr>
<th>High Temp Resin</th>
<th>PEI</th>
<th>PPS</th>
<th>PPA</th>
<th>PEEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>15000</td>
<td>30000</td>
<td>20000</td>
<td>33000</td>
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<tr>
<td>50% GF</td>
<td>15000</td>
<td>25000</td>
<td>18000</td>
<td>22000</td>
</tr>
<tr>
<td>50% VLF</td>
<td>14000</td>
<td>24000</td>
<td>17000</td>
<td>21000</td>
</tr>
<tr>
<td>40% CF</td>
<td>13000</td>
<td>23000</td>
<td>16000</td>
<td>20000</td>
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</tbody>
</table>
Impact – Izod Notched

<table>
<thead>
<tr>
<th>High Temp Resin</th>
<th>PEI</th>
<th>PPS</th>
<th>PPA</th>
<th>PEEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% GF</td>
<td>100</td>
<td>75</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>50% VLF</td>
<td>150</td>
<td>125</td>
<td>350</td>
<td>225</td>
</tr>
<tr>
<td>40% CF</td>
<td>60</td>
<td>50</td>
<td>180</td>
<td>120</td>
</tr>
</tbody>
</table>
Application: Multiple Components on V-22 Osprey

Problem: Environment

Solution: Carbon fiber reinforced TPI and PEEK

Benefit: Flame retardant, temperature resistance, strength/stiffness
Tensile Strength

<table>
<thead>
<tr>
<th>High Temp Resin</th>
<th>PEI</th>
<th>PPS</th>
<th>PPA</th>
<th>PEEK</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% GF</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% VLF</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40% CF</td>
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</table>
Tensile Strength

High Temp Resins

- PEI
- PPS
- PPA
- PEEK

<table>
<thead>
<tr>
<th>Material</th>
<th>50% GF</th>
<th>50% VLF</th>
<th>40% CF</th>
<th>40% UP CF</th>
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<tbody>
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<td>PPS</td>
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<tr>
<td>PPA</td>
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</tr>
<tr>
<td>PEEK</td>
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</tr>
</tbody>
</table>

(Tensile Strength (MPa))
Summary

• Modifiers
  • **Polymer Blends**: overcome morphology deficiencies
  • **Impact Modifiers**: increase impact but reduction in strength/stiffness
  • **Stabilizers**: protect polymer

• Fillers
  – Performance driven by aspect ratio
  – **Very Long Fiber**: increases impact and retains stiffness/strength

• High Temperature
  – Wide range of polymers with varying performance
  – Understanding environment and stress levels is key to success
Questions?

Karl Hoppe
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