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From Carbon Fiber to Carbon Fiber Reinforced ThermoPlastics

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Content

- Carbon fiber with P-sizing
- Thermoplastics vs. Thermosets
- CFRTP Product Families
- TPU High TS & IM Fiber(s) (Standard & Intermediate Modulus)
- Thermoplastic Part Making with TPU
- TPCL PEEK-High TS Fiber (Standard Modulus)
- Thermoplastic Part Making with TPCL
- Conclusion
Carbon Fiber with P-sizing

- Current sizing cannot be used with most thermoplastics because they are processed at temperatures above the sizing thermal resistance (250°C).
  - Sizing is either not applied or removed (pyrolysis, solvent) from the fiber before impregnation with thermoplastic matrices.
- Toho Tenax developed the P-sizing which withstand temperature up to ~ 450°C without degradation.
  - can be applied to all kinds of fiber, with the same fiber mechanical properties
  - focus is on 3K, 12K, and 24K fibers, High TS and IM Fiber.
- P-sizing can be used with high temperature polymers (PEEK) but also low temperature polymers (PA6) and high temperature thermosets (BMI).
- P-sizing can be processed for UD-prepreg, fabric or pultrusion.

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Abrasion</th>
<th>Abrasion with 200cN</th>
</tr>
</thead>
<tbody>
<tr>
<td>High TS Fiber</td>
<td>ref</td>
<td>ref</td>
</tr>
<tr>
<td>High TS Fiber – P-sized</td>
<td>-21%</td>
<td>-98%</td>
</tr>
</tbody>
</table>

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## Thermoplastics vs. Thermosets

### Intrinsic Properties

<table>
<thead>
<tr>
<th>Thermoplastic</th>
<th>Thermoset</th>
</tr>
</thead>
<tbody>
<tr>
<td>- room temperature and long-term storage</td>
<td>- low temperature storage (1-component resin system)</td>
</tr>
<tr>
<td>(when protected from UV)</td>
<td>- room temperature storage (mixture of two or more components)</td>
</tr>
<tr>
<td>- no transport restriction</td>
<td>- special conditions for transport (cold)</td>
</tr>
<tr>
<td>- not REACH critical</td>
<td>- in some cases REACH critical (registration needed)</td>
</tr>
<tr>
<td>- high viscosity</td>
<td>- low viscosity</td>
</tr>
<tr>
<td>(high pressure needed for impregnation)</td>
<td>(easy impregnation of reinforcement)</td>
</tr>
<tr>
<td>- high melting temperature (&gt;200°C)</td>
<td>- low to medium curing temperature (&lt;200°C, EP)</td>
</tr>
<tr>
<td>- short process time (several minutes)</td>
<td>- long process time (several hours)</td>
</tr>
<tr>
<td>- several-ways use (melting &amp; cooling/solidification)</td>
<td>- one-way use (chemical reaction: curing)</td>
</tr>
<tr>
<td>- re-use / recycle possible (re-melting)</td>
<td>- limited recycling (burn-off, grinding)</td>
</tr>
</tbody>
</table>
CFRTP Product Families

Part geometry complexity

- Short Fiber
- Long-Fiber
- Stretch-broken fiber
- Co-mingled

Mechanical properties

- "unlimited" fiber length
- Limited fiber length
- Woven fabric
- Unidirectional

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CFRTP Product Families

- High TS Short Fiber
- Long-Fiber
- Stretch-broken fiber
- High TS Fiber TPCL
- Co-mingled
- Woven fabric
- High TS Fiber TPUD
- Unidirectional

Part geometry complexity

Mechanical properties

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ThermoPlastic UniDirectional (High TS & IM Fiber TPUD)
High TD Fiber TPUD

TPUD PEEK-High TS Fiber (Standard & IM Modulus)

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Reinforcement</th>
<th>FAW weight [g/m²]</th>
<th>Fiber</th>
<th>Matrix content [%wt.]</th>
<th>Matrix</th>
<th>Nominal thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPUD PEEK High TS – Standard Modulus</td>
<td>UD</td>
<td>145</td>
<td>High TS 12K with P-sizing</td>
<td>34</td>
<td>PEEK</td>
<td>0.136</td>
</tr>
<tr>
<td>TPUD PEEK – Intermediate Modulus Fiber</td>
<td>UD</td>
<td>145</td>
<td>Intermediate Modulus with P-sizing</td>
<td>34</td>
<td>PEEK</td>
<td>0.134</td>
</tr>
</tbody>
</table>

- High TS or IM fiber with tailored sizing for thermoplastics applications.
- Width: 6.35 mm (¼”) to 304.8 mm (12”)
- European source (production in Oberbruch)
- Aero and non-aero grade
TPUD PART MAKING

- Lay-up
  - Hand Lay-up + Local welding (HLY)
  - Automated Tape Lay-up (ATL)
  - Automated Fiber Placement (AFP)
- Vacuum bagging
- Autoclave
- Consolidation using heat & pressure
- Oven
- Static Press
- (Semi)-Continuous Press Forming (CPF)
- Filament Winding (FW)

Similar to Thermoset Prepreg
Without debulking (Time saving vs. TS)
5-30 min (Consolidation time)

- Automated process (ATL, AFP)
- Out of autoclave consolidation
- Short cycle time
- TP joining technologies (resistance, ultrasonic, induction)

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High TS Fiber ThermoPlastic Consolidated Laminate (TPCL)
High TS TPCL (PEEK)

Materials

<table>
<thead>
<tr>
<th>Tenax®-E</th>
<th>Reinforcement</th>
<th>FAW weight [g/m²]</th>
<th>Fiber</th>
<th>Matrix content [%wt.]</th>
<th>Matrix</th>
<th>Nominal thickness [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPCL PEEK</td>
<td>5HS fabric</td>
<td>285</td>
<td>High TS 3K</td>
<td>40</td>
<td>PEEK</td>
<td>0.31</td>
</tr>
</tbody>
</table>

- Laminate size: 800 (warp) x 1200 mm (0.96 m²)
- Thickness: typically from 1.86 to 4.96 mm (6 to 16 plies)
- Aero grade
- Glass/PEEK: surface layer for corrosion protection
- Bronze mesh/PEEK: surface layer for lightning strike protection  
  - Future development of nanotube l.s.p. fiber.
TPCL: Part making

TPCL → Blanket nesting/trimming → Heating → Thermoforming & Cooling → Trimming/Drilling

- Automated process (pick and place)
- Very short cycle time
- Complex part shape
- Joining technologies

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Conclusion

- Room temperature transportable and storable.
- High-performance mechanical properties.
- Good properties against fire, smoke and toxicity.
- Automated production.
- Short cycle time.
- Welding technologies.
- Opportunities for repair technique.
- Recyclable.
Thanks for your attention

Tenax® ThermoPlastics