Processing of High Performance Thermoplastic Composites

Spring Semester 2017
131-5048-00L Manufacturing of Polymer Composites

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Thermoplastic composites

Reorient your focus

Different material systems $\rightarrow$ different properties + different processing conditions
Outline

- Introduction to Thermoplastic Composites
- Thermoplastic Matrix Materials
- Basics of Thermoplastic Composite Processing
- Intermediate Materials for Thermoplastic Composites
- Processes for Thermoplastic Composites
- Welding
- Recycling
Basics of Processing of Thermoplastic composites

Processing temperatures

- High temperatures are required to reduce melt viscosity for easier processing
- **BUT**, high temperatures cause the polymers to degrade due to thermal oxidation
- **Strategy**: To heat material quickly and minimize time at high temperatures
## Comparison of different heating strategies

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Heat Convection</th>
<th>Heat Conduction</th>
<th>Heat radiation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hot gas (Air)</td>
<td>Hot gas (Inert)</td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Temperature distribution</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Controllability</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Compact setup</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Flexibility</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Costs</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
</tbody>
</table>

*Quelle: Schmidt, R.: Einsatz von Hochleistungslasern für die Fertigung von Faserverbundbauteilen mit thermoplastischer Matrix im Wickelverfahren; VDI-Verlag, Düsseldorf 1994*
## Selection of possible heating strategies

<table>
<thead>
<tr>
<th>Heating method</th>
<th>Observed effects</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact heating</td>
<td>Measures to avoid contamination and impurities are required (films)</td>
<td>Large heating systems with additional pressure application</td>
</tr>
<tr>
<td>Hot gas</td>
<td>Reduced oxidation risks by use of inert gases</td>
<td>Large temporal inertia of systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Constant processing speeds are desirable</td>
</tr>
<tr>
<td>Open flame</td>
<td>Oxidation effects due to open flame</td>
<td>Constant processing speeds must be observed</td>
</tr>
<tr>
<td>IR-radiation</td>
<td>Useful control only available using short-wave IR emitters</td>
<td>Problems with thick laminates</td>
</tr>
<tr>
<td>CO$_2$-Laser</td>
<td>Ideal energy source</td>
<td>Elaborate set up required</td>
</tr>
<tr>
<td></td>
<td>Suitable for all materials</td>
<td></td>
</tr>
<tr>
<td>Nd:Yag-Laser</td>
<td>High energy density</td>
<td>Possible to transmit radiation through optical fibre</td>
</tr>
<tr>
<td></td>
<td>Limited efficiency with transparent materials</td>
<td></td>
</tr>
</tbody>
</table>

Processing of Thermoplastic composites: Main steps

Consolidation mechanisms

Impregnation

Matrix permeation

Pressure

Fiber preform is compressed

Time (log)

Thickness

Compaction

Autohesion

Resin flow mechanisms

100% Contact

100% Autohesion

Fiber preform is compressed

\[ z^2 = -\frac{2K_p \rho dp}{\eta} \]

\[ K_p = \frac{r_f^2 (1 - \nu_f)^2}{4k \nu_f^2} \]
Coomingled yarns: Schematic of the consolidation process
Evolution of the void content as a function of the consolidation time

Flow mechanisms during forming

<table>
<thead>
<tr>
<th>Resin percolation</th>
<th>Transverse flow</th>
<th>Interply slip</th>
<th>Intraplay shearing</th>
<th>Rotatory sliding</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="" /></td>
<td><img src="image2" alt="" /></td>
<td><img src="image3" alt="" /></td>
<td><img src="image4" alt="" /></td>
<td><img src="image5" alt="" /></td>
</tr>
</tbody>
</table>

Quelle: Niedermeier, E.: Analyse des Diaphragmaformens kontinuierlich faserverstärkter Hochleistungsthermoplaste; VDI-Verlag, Düsseldorf 1995
Processing of Thermoplastic composites: Main steps

Solidification

Temperature [°C]

Endothermic heat flow -> [mW]

178°C

149°C
Surface consistency after solidification

- Fiber-reinforced thermoplastics show generally a bad surface quality.

- This occurs due to:
  - The difference in the thermal expansion coefficients between fibers and matrix.
  - The phase transformation of the matrix during solidification.
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Processing routes for high performance thermoplastic composites

Pre-impregnation techniques

- Hot-melt
- Solution

(Pseudo-Thermoplastics)

Post-impregnated product forms

- Film stacking
- Cowoven fabric
- Powder coating
- Commingling yarns (hybridisation)

U. Thomann, Direct Stamp Forming of Non-Consolidated Carbon/Thermoplastic Fibre Commingled Yarns, Diss. ETH No. 15302, Zurich, 2003
Post-impregnated product forms

Verstärkungsfasern → Commingling → Thermoplastfasern

Verstärkungsfaser       Thermoplastfaser

→ Vermischen

Coweaving (Hybridgewebe)

Kette - Verstärkungsfaser
Schluß - Thermoplastfaser

Hybridgarn

Verweben

Hybridgarn-gewebe

Cowrapping:
Herstellung von Mischgarn durch das
Umspinnen von Verstärkungsfasern

Thermoplastfaser
Verstärkungsfasern
Thermoplastfaser

Hybridgarn

Commingled yarn
Commingled yarn
Hybrid Yarns: Different consolidation stages
Dry Powder impregnation


CMAS Lab
FIT: Fibre Impregnated with Thermoplastics

Powder coated sheathed yarn
Need for **flexible, perfectly mingled** materials for thermoplastic composites.
Intermediate Materials for Thermoplastic Composites

- Intermediate materials are used to bring reinforcing fibres and matrix together to reduce the distances that the high viscosity melts need to flow to achieve complete impregnation and consolidation.

- Intermediate materials are available where the hybridization is on the level of the laminate, the textile, the yarn, and the fibres, as well as and fully consolidated.
Intermediate material of the future?