Large Scale Manufacturing of Thermoplastic Composite Parts

Prof. Dr.-Ing. Frank Henning

Fraunhofer Institute for Chemical Technology ICT
Joseph-von-Fraunhofer-Str. 7
76327 Pfinztal, Germany

Phone: +49721/ 4640-420
frank.henning@ict.fraunhofer.de

1 Fraunhofer Institute for Chemical Technology (ICT), Pfinztal
2 Karlsruhe Institute of Technology (KIT) – Institut für Vehicle System Technology (FAST), Karlsruhe
Outline

- Introduction Composites for Automotive
- Thermoplastic (TP) Composites
- Overview of Process Technologies for Discontinuous Fiber Reinforced Thermoplastics
- Overview of Process Technologies for Continuous Fiber Reinforced Thermoplastics
- Hybrid Thermoplastic Composites
- Recycling of Thermoplastic Composites
Composites in Automotive Manufacturing
Opportunities

Metal Solutions

Composites

New materials challenges and opportunities

Development of methods to fully utilize weight saving potential

Quelle: Audi, Porsche
Composites in Lightweight Design
Interdisciplinary Approach

Multidisciplinary collaboration required
Consideration of product life cycle
Hollistic composite solution by interdisciplinary approach

Part Performance

Process
Material
Methods
Composites in Lightweight Design
Interdisciplinary MMP-Approach

**Areas of Interaction**

- **MATERIALS**
- **METHODS**
- **PROCESSES**
- **COMPOSITE SOLUTION**
- **TIME**
- **QUALITY**
- **COSTS**

Part performance + Economy

MMP-Approach
### Polymer resin
#### Thermoplastics

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Higher elongation at break and toughness than thermosets</td>
<td>• High melt viscosity</td>
</tr>
<tr>
<td>• Less knowledge about the chemical reactions required</td>
<td>• Difficult fiber impregnation</td>
</tr>
<tr>
<td>• Semi-finished products can be stored indefinitely in a suitable environment</td>
<td>• Higher processing pressures necessary</td>
</tr>
<tr>
<td>• Easier and faster processing possible</td>
<td>• Adhesion between the matrix and fiber difficult</td>
</tr>
<tr>
<td>• Granulates less critical to use than the reaction components of thermosets</td>
<td>• Mechanical properties depend more on environmental influences</td>
</tr>
<tr>
<td>• Suitable for mass production</td>
<td>• Profitable for expensive tools and machines only at high volumes</td>
</tr>
<tr>
<td>• Often weldable</td>
<td>• Tendency to creep</td>
</tr>
<tr>
<td></td>
<td>• There is a lack of experience in many areas</td>
</tr>
<tr>
<td></td>
<td>• High temperatures problematic</td>
</tr>
<tr>
<td></td>
<td>• Temperature and chemical resistance varies greatly</td>
</tr>
</tbody>
</table>
Overview of Technologies

Thermoplastics

Thermoplastic matrix

Short fibers
Long fibers
Continuous fibers

Injection molding

Compression/injection molding
- GMT
- LFT/LFT-D
- LWRT

Compression molding
- Prepregs (woven fabrics, layups)

Pultrusion

Braiding*¹

Winding
Tape-/Fiber Placement

Braiding*¹

Injection processes
- BMC
- R-RIM

Thermoset matrix

Continuous fibers
Long fibers
Short fibers

Compression molding
- SMC
- Wet molding

Compression molding

Pultrusion

Winding
Tape-/Fiber Placement

Injection processes

- T-RTM (Insitu Polymerization)
- RTM

Process combinations

*¹Continuous-fiber preform
Composites in Automotive Manufacturing
Opportunities

High Performance Composites

- **Aim:** Affordable light weight structural solutions
- **SOTA:** Structural solutions in niche applications

Semi-structural discontinuous fiber reinforced composites

- **Aim:** Lowest weight possible with maximum functional integration
- **SOTA:** Cost effective integral parts

Quelle: Porsche
Quelle: M. Wanders, LANXESS, 4th CTI Conference
Overview of Process Technologies for TP Composites
Design – Performance - Costs

- Injection Molding
- Compression Molding
- Thermoforming

Unreinforced
Short fiber reinforced
Long fiber reinforced

Laminate/woven (orthotropic)
UD-Tape/-profile (unidirectional)

Source: BASF SE
Thermoplastic Processing – Discontinuous Fibers

Semi-structural applications

Thermoplastic composites with discontinuous fiber reinforcement are already a well-established engineering material for semi-structural applications with constant growing market share.

Processing technologies: Injection Molding, Compression Molding
Overview of Process Technologies for TP Composites

Injection Molding – High-Volume for Complex Parts

- Processing of short/long fiber-reinforced pellets
- Part characteristics
  - Compact to medium size
  - very high complexity achievable
- Typical cycle time: 30 to 90 s
- Annual quantity
  - approx. 10,000 to > 500,000
- Process variations
  - Foam injection molding, injection-compression molding, multi-component injection molding, etc.
Overview of Process Technologies for TP Composites
Injection Molding – Application Examples

BMW Mini – Frontend assembly
Picture source: Magna

Front end carrier of a passenger car
Picture source: Celanese

BMW 1 and 3 series – controllable air guides (approx. 600.000 parts/a)
Picture source: Röchling

Mechanical properties

**PP-GF30 (long fiber pellets)**
Young’s modulus: 6.4 GPa
Tensile strength: 100 MPa

**PA6-GF30 (short fiber pellets)**
Young’s modulus: 6.2 - 9.5 GPa (cond./dry)
Tensile strength: 115 - 185 MPa (cond./dry)

Source: Ticona, BASF
Overview of Process Technologies for TP Composites

Compression Molding – Basics

- Compression molding technologies are (besides injection molding) very well suited for high-volume part production
- Main differences between injection and compression molding
  - **Injection molding:**
    - High pressure inside the cavity, material is injected after mold closure (constant mold gap)
  - **Compression molding**
    - Pressure inside the cavity approx. \(\frac{1}{4}\) compared to injection molding, material is placed inside the open mold \(\rightarrow\) mold filling by squeezing of the material during mold closure
- Most important process technologies
  - Glass mat-reinforced thermoplastics (GMT)
  - Direct process for long fiber-reinforced thermoplastics (D-LFT)
  - Light Weight Reinforced Thermoplastics (LWRT)
Overview of Process Technologies for TP Composites

Compression Molding – GMT

- Semi-finished sheet product
- Part characteristics
  - Thin-walled parts possible
  - Medium to large surface area
  - High complexity achievable
- Typical cycle time: 30 to 60s
- Annual quantity
  - Approx. 50,000 to > 500,000
- Process variations
  - GMTex
    (combination of GMT and continuous fiber-reinforced material)

Picture source: Dieffenbacher

Picture source: Quadrant
Overview of Process Technologies for TP Composites
Compression Molding – LFT-D

- Direct compounding of LFT strands
- Part characteristics
  - Thin-walled parts possible
  - Medium to large surface area
  - High complexity achievable
- Typical cycle time: 30 to 60s
- Annual quantity
  - Approx. 50,000 to > 500,000
- Process variations
  - Only one double screw extruder to compound LFT material

Picture source: Dieffenbacher
Overview of Process Technologies for TP Composites

Compression Molding – LWRT

- LWRT = Low weight reinforced thermoplastics
  - Fleece consisting of glass- and PP-fibers
- Part characteristics
  - Varying wall thickness with constant areal mass possible
  - Parts with medium to large surface area
  - Medium complexity achievable
- Typical cycle time: 30 to 90s
- Annual quantity
  - Approx. 50,000 to > 500,000
- Process variations
  - Combination with film for high surface quality
Overview of Process Technologies for TP Composites
GMT, D-LFT, LWRT – Application Examples

**Mechanical properties**

**PP-GF25 (GMT)**
- Young's modulus: 4.0 GPa
- Tensile strength: 60 MPa

**PP-GF30 (D-LFT)**
- Young's modulus: 6.5 MPa
- Tensile strength: 100 MPa

Source: Quadrant, Fraunhofer ICT

LWRT – Underbody shielding of the BMW 5 and 6 series

Picture source: Röchling

GMT – Battery tray

Picture source: Quadrant

LFT-D – Underbody cover

Picture source: Fraunhofer ICT
Trends in Processing of Thermoplastic Composites
LFT-D Foam Injection Molding

- Direct compounding of LFT material
  - Foaming is realized by the mold opening stroke (gas-loaded melt)
- Part characteristics
  - Compact to large size
  - Medium part complexity
- Typical cycle time: 45 to 120 s
- Annual quantity
  - ---
- Process variations
  - Combination with continuous-fiber-reinforced materials to realize sandwich structures
Trends in Processing of Thermoplastic Composites
LFT-D Foam Injection Molding

SEM picture of foamed LFT-D

<table>
<thead>
<tr>
<th>H [mm]</th>
<th>3.6</th>
<th>4.0</th>
<th>4.4</th>
<th>4.9</th>
<th>5.35</th>
<th>5.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δρ [%]</td>
<td>0</td>
<td>10</td>
<td>17</td>
<td>25</td>
<td>31</td>
<td>37</td>
</tr>
</tbody>
</table>

Comparison of plaques with varying degree of foaming
Continuous Fiber-reinforced Thermoplastic
Types of Reinforcement

- UD-Strands
- UD-Tapes
- Coiled Structures
- Fabrics
- Non-woven Fabrics

Benefits of continuous fiber reinforcements

- Semi-finished products containing fiber volume contents of up to 60 - 70 %
- High mass-specific part properties achievable
- Part designs are optimized for specific load cases
- More stable mechanical performance at elevated temperatures
- Increased dimensional stability
- Reduced creep tendency (if loads are transferred into continuous fibers)

⇒ Application of thermoplastics in structural applications
Thermoplastic Prepregs – Continuous Fiber RP Organosheets

- Flat SFP-plates with numerous woven and non-woven fabric layers containing continuous fibers as structural reinforcement
- Fiber volume content usually around 35 – 60 %
- Material thickness mostly in between 0,5 – 6,0 mm
- SFPs are completely impregnated and consolidated
- Further processing is done by quick heating and subsequent pressing
  - Short cycle times possible (45 s – 3 min)
- Material is not chemically altered
  - Name is an analogy to steel sheets
- Fiber/matrix system adjustable
Thermoplastic Prepregs – Continuous Fiber RP
Thermoplastic Tape-Laying

Unidirectional Tapes

- Processing in the “tape-laying process”
  - More information about this process in Chapter 7 „Manufacturing processes“
- Fiber volume fraction of up to 70 %
- Material thickness usually from 0,15 mm (CF) to 0,3 mm (GF)
- UD tapes find primary application for the production of non-woven fabric organsheets

Source: Fiberforge
Trends in Processing of Thermoplastic Composites

Thermoplastic Tape-Laying

- Processing of UD-Tapes
- Parts characteristics
  - Medium to very large size
  - Low to medium complexity
  - Today: max. production rate of approx. 200 kg/h
- Annual quantity
  - Today: approx. < 2,000
- Process variations
  - Combination with short/long fiber-reinforced material

Tape-laying

[Picture source: Fraunhofer ICT/FIL]

Fiber Placement

[Picture source: MAG]

[Picture source: Fraunhofer ICT/FIL]

[Picture source: Coriolis Composites]

[Picture source: Fiberforge]
Trends in Processing of Thermoplastic Composites
Thermoplastic Tape-Laying – Application Examples

Mechanical properties

**PA6-CF60 (0°/90° laminate)**
Young’s modulus: 58 GPa
Tensile strength: 800 MPa

**PA6-CF60 (0° laminate)**
Young’s modulus: 112 GPa
Tensile strength: 1800 MPa
Continuous fiber-reinforced FRP – Tape laying

Example for Processing

- Fiberforge RELAY tape laying by Dieffenbacher
- Fast, automated laying of tapes on a flat surface
- Local welding of the tape layers with ultrasonic welding
- Consolidation and forming take place in a subsequent process step
Trends in Processing of Thermoplastic Composites
Challenges for Continuous Fibers

- Technical challenges
  - Continuous-fiber-reinforced semi-finished products such as wovens or laminates are formed into shell-like structures
  - Limited drapeability and flowability result in restrictions for freedom of design and part complexity

- Economical challenges
  - Target costs for monolithic continuous-fiber-reinforced parts are oftentimes hard to achieve in high-volume applications
Trends in Processing of Thermoplastic Composites
Combination of Established Process Technologies

Local reinforcements with continuous fibers
- Woven fabrics
- UD-tape laminates
- Coil & wound structures
- Profiles

Compression and injection molding

LFT-D or pellet material

Final composite parts
Trends in Processing of Thermoplastic Composites
Co-Injection Molding of Wound Loop Structures

- Continuous fibers positioned in the main load direction
- Even with low fiber content a significant increase in breaking force and fracture energy is achieved
- No visual damages in the matrix before roving failure → no peak loads in the supporting structure
Trends in Processing of Thermoplastic Composites
Hybrid Thermoplastic Composites – LFT and Tapes

- Significant improvement of impact properties
- Feasibility for compression molding of complex UD-Tape structures with D-LFT was proven
Trends in Processing of Thermoplastic Composites
One-Shot Sandwich with Continuous Fiber-reinforcement

- Large scale production of continuous-fiber-reinforced sandwiches in one shot
- Very high bending stiffness at a low areal mass
- Very high impact resistance

Process visualization

UD-Tape laminate facings
Self-reinforced sandwich with Curv®-fabric reinforced facings and a foamed PP core
Recycling of Thermoplastic Composites
Long-fiber reinforced materials

- The trigger for developing a direct process was the increasing pressure for costs reduction at the companies
- Component manufacturer = SFP manufacturer
- Combination of at least two process steps
- The extrudate is obtained as a fiber-matrix mixture
- Direct reuse of recyclate possible
- Trimmings or LFT-components are chopped and reused
Contact

Fraunhofer Institute for Chemical Technology

Prof. Dr.-Ing. Frank Henning
Joseph-von-Fraunhofer-Straße 7
76327 Pfinztal, Germany
Phone: +49 (721) 4640-711
Fax: +49 (721) 4640-730
http://www.ict.fraunhofer.de/

Karlsruhe Institute for Technology (KIT)
FAST Institute for Vehicle System Technology

Rintheimer-Querallee 2
76131 Karlsruhe
Germany
Phone: +49 (721) 608-45905
Fax: +49 (721) 608-945905
http://www.fast.kit.edu/