Use of Long Fiber Thermoplastic in Automotive Market

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Projected Material use in Automotive Industry

**Automotive Material Trends**

Medium / HSS, Al, Mg & Plastics usage will increase

- Mild Steel: 228 lbs per vehicle
- Iron: 68 lbs per vehicle
- Aluminum: 13 lbs per vehicle
- Magnesium: 29 lbs per vehicle

Mild steel & iron usage will decrease

Changes in N.A. Light Vehicle Material Content from 2005 to 2015
Regulations-Driving Change

- The United States, the European Union and Korea are re-establishing Green House Gas reduction targets for vehicle operation, which makes it increasingly challenging to find cost effective solutions.

**CAFE (U.S.A.)**
- '08: 35.5 mpg (15.1 km/l)
- '16: 35.5 mpg (15.1 km/l)
  - Passenger Vehicle: 39 mpg (16.6 km/l)
  - Light Truck: 30 mpg (12.8 km/l)

**CO₂ Regulation (EU)**
- '08: 147 g/km
- '12~'15 (Annual Phase-in): 130 g/km
  - Monetary penalty if unsatisfactory

**CAFE (Korea)**
- '08: 17.0 kpl
- '12~'15 (Annual Phase-in): 140 g/km
  - 2012: 30%, 2013: 60%, 2014: 80%, 2015: 100%
Motivation for Lightweight Design

- Weight increase of typical medium-class vehicle since 1970
- Implementation of CAFE regulation

**Goals:**

- Reduction of consumption and emissions through lighter structures
- Improvement of passive and active safety and product attractiveness through functional design
- Reliable and consistent technologies capable of economically viable, small and large production volumes
The LFT Market

• Long Fiber Thermoplastics annual growth 13% to 17% over 15 years.

• Growth projected at 13% per year through 2012.

• Offering solutions for metallic and structural applications.

• Credible engineering, design and processing database.
Global LFT Demand History & Forecast
Processing Technologies

- Classification according to matrix type and fiber length
Processing Technologies

Classification according to production volumes

- LFT-Injection molding
- GMT/LFT compr. Molding
- BMC injection molding
- SMC-Pressen
- R-RIM
- LFI
- S-RIM
- RTM
- Vakuum injection
- Deep drawing
- Fiber-spraying
- Autoclave
- Hand lamination

Quelle: in Anlehnung an Prof. Schemme
Processing Technologies

Classification according to fiber length:

1. Short fiber processes:
   - Based on injection moulding and injection-compression
     - Thermoplastics
     - Themosets

2. Long fiber processes:
   - Based on compression moulding
     - Thermoplastics
     - Themosets

3. Continuous fiber processes:
   - Thermoplastics
   - Themosets
Fiber Reinforced Thermoplastics

- Short
- Long
- Continuous
Fiber Reinforced Thermoplastics

- Property comparison of short and long 40wt% PP
Fiber Reinforced Thermoplastics

- Impact property comparison of short and long fibers of 30wt% and 50wt% nylon
Automotive LFT Application
Long Fiber Thermoplastics Technologies

- Injection molding
  - Based on semi-finished products
  - LFT-G
  - Direct process
  - IMC
  - XRI

- Compression molding
  - Based on semi-finished products
  - GMT
  - LFT-G
  - Continous f.

- Direct process
  - CPI
  - DIF
  - Fiberpreps
  - LFT-D
  - LFT-D-ILC
  - STC
  - TPF
  - XRE

- Infusion
  - T-RTM
  - pCBT-RTM

- Compression molding
  - Based on semi-finished products
  - GMT
  - GMTeX™

- Direct process
  - E-LFT
  - Tailored-LFT
  - Tape-laying
  - Pultrusion
  - Winding
  - Diaphragma

in cooperation with
Colorado Legacy Group LLC
Thermoplastic Composites Solutions
Long Fiber Thermoplastics—Technologies

– **Compression:**
  - High volume production
  - Very large, shell like parts
  - Most important processing technologies include LFT-G, LFT-D-ECM, GMT, GMTex, LWRT

– **Injection molding:**
  - High-volume production
  - Compact parts with complex geometry
  - LFT-G, LFT-D-ILC
Basics of processing

Mechanical properties of parts made from FRP are strongly dependent on processing parameters and material components

- Examples of processing parameters: Tool temperature, injection speed and pressure etc. Influence:
  - Orientations of molecular chains and fibers
  - Internal stresses and warpage
  - Crystallinity

- Molecular structure (molar mass and ist distribution)

- Fiber content, additives, fillers
Basics of processing

Basics for processing fiber reinforced thermoplastics

- Processing temperature
  - Thermoplastics → approx. 160 – 290 °C
  - High performance polymers require even higher temperatures (e.g. PPS at approx. 340 °C)

- Tool temperature
  - Thermoplastics: Tool is cooled → approx. 50 – 80 °C
  - Heat needs to be removed from the plastic.
  - By cooling the plastic, the tool heats up
Basics of processing

- Pressures needed to process:
  - Thermoplastics \( \rightarrow \) approx. 100 – 2.000 bar
    - Compression molding: 100 – 300 bar
    - Injection molding: 400 – 2.000 bar

- Achievable cycle times vary for the different material classes
  - Thermoplastics
    - Mostly dependent on wall thickness and cooling rate (tool temperature)
    - Usually approx. 20 s up to several minutes
Basics of processing

Orientations of molecular chains and fibers in a part are mostly determined by:

- Part geometry
- Type of gate and its position (injection molding)
- Injection speed (injection molding)
- Tool closing speed (compression molding)
- Tool temperature $\rightarrow$ cycle time
- Viscosity
- Fiber content
Basics of processing

– Internal stresses and warpage

• Stresses (due to processing) within a part are mostly determined by:
  – Part geometry (e.g. Symmetric shape)
  – Degree of orientation for molecules and fibers
  – Wall thickness distribution
  – Tool temperature → cycle time
  – Shrinkage
  – Fiber content
Basics of processing

- Internal stresses and warpage
  - Internal stresses due to tool temperature
  - Temperature distribution
    - Warm core, cold next to tool surface
    - After cooling: if all layers could contract independently
      » No internal stresses
    - After cooling: with real limitations regarding material contraction
      » Internal stresses
Long Fiber Thermoplastics Granules
LFT-G

**Short Glass Pellet**
Glass Length 1 mm
Pellet Length 3 mm

**Long Glass Pellet**
Length 9 to 15 mm
3 mm diameter
30 to 70% by weight Fiberglass
Fiberglass length = Pellet Length
LFT-G Pellet Manufacturing

- Pellet pultrusion processing
LFT Injection Moulding Processing

- LFT can easily and repeatedly be molded into quality structural parts
  - Requires minimal modification to most standard equipment
    - Requires a low shear screw
    - A free flow or ring check valve
    - Sprew Diameter minimum of ¼”
    - Runner Diameter minimum of ¼”
    - Slightly higher processing temperatures
    - Large Gates
    - Good Venting in the Mold
    - Low backpressure
    - Low to Medium Injection Pressure
LFT Injection Moulding Processing

• 30wt% Long glass polypropylene moulding profile

<table>
<thead>
<tr>
<th>Rear Zone: 390 °F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center Zone: 400 °F</td>
</tr>
<tr>
<td>Front Zone: 410 °F</td>
</tr>
<tr>
<td>400 °F Nozzle:</td>
</tr>
<tr>
<td>410 °F Melt:</td>
</tr>
<tr>
<td>150 °F Mold:</td>
</tr>
<tr>
<td>Injection Speed: 2 in/s</td>
</tr>
<tr>
<td>Injection Pressure: Low</td>
</tr>
<tr>
<td>Back Pressure: 30-50 psi</td>
</tr>
<tr>
<td>Screw Speed: 30-50 rpm</td>
</tr>
</tbody>
</table>

Screw: General Purpose Metering Screw
40% feed
40% transition
20% metering
L/D 18:1 to 22:1
Minimum recommended diameter of 45 mm
7.5 mm Feed Zone Channel Depth:
3.5 mm Metering Zone Depth:
1D Pitch:
LFT Injection Moulding Processing

- Suggested check valve design

100% "Free Flow" Design

AI components made from high quality, high purity tool steel.

- High Polish
- Precision ground mating surfaces for effective sealing

Passageways sized to provide smooth open melt flow.
LFT-G Injection Example

- Replacing Stamped Steel Part
- 30-40% PP LFT
- Done by LFT-G IM or LFT-D-ILC
- Weight and Cost Reduction
- Part Integration and Design Flexibility

Door Carrier Plate
LFT-G Injection Example

- 40% glass filled LFT PP
- Large part metal replacement
- Acoustic part (Noise reduction)
- Wet/dry interface to engine compartment
- Cost/weight reduction
- Multiple part integration
- Design freedom for further part consolidation
LFT-G Injection Example

**Older Application of PP LFT-G**
- Battery Tray and Enclosures since:
  - Acid Resistant
  - Heat Resistant

**Newer Application of PP LFT-G**
- Air Bag Retainer Box
- Replacing Zinc Die Cast Parts
Case Study LFT-D
CM Underbody Shield

- Stiffness
- Impact
- Corrosion & impact protection
- Cw & fuel economy
- Large series
- Low cost & weight

Graph showing fuel economy vs. velocity with and without UBS.
Drivers for LFT Parts

Example: Golf A2 and A3 Front End Assembly

- Weight Reduction
- Part reduction
- Reduced assembly procedures

<table>
<thead>
<tr>
<th></th>
<th>Golf A2</th>
<th>Golf A3</th>
<th>Golf A3 vs Golf A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>parts</td>
<td>12 to 15</td>
<td>1 to 2</td>
<td>-11 to 14</td>
</tr>
<tr>
<td>weight [kg]</td>
<td>6.4</td>
<td>4.4</td>
<td>-2.2 (40%)</td>
</tr>
<tr>
<td>screwing points</td>
<td>38</td>
<td>27</td>
<td>-11</td>
</tr>
<tr>
<td>welding spots</td>
<td>57</td>
<td>0</td>
<td>-57</td>
</tr>
</tbody>
</table>
LFT-Direct Technologies

LFT-Direct:
- Motivation for a direct LFT process is the more direct process chain
- LFT-D-ECM compression moulding
- LFT-D-ILM injection moulding
LFT-D-ECM

- **One machine technology**
  - Lower investment
  - Limited versatility
  - Shorter fiber length
  - Lower material throughput

- **Two machine technology**
  - Lower fiber damage due to optimized system
  - In-line compounding reduces cost and increases versatility
  - High material throughput with long resulting fibers
LFT-D-ECM Process Schematic

- Automation of the entire production line
- Conveyor belt for LFT plastificate
- Glass fiber rovings
- Compression moulding
- Dosing unit
- In-line Compounding
- Mixing extruder
- LFT extrusion die

Quelle: Rieter Automotive/ Fh ICT
LFT-D-ECM

- Requirements for compression molding process technologies

Gravimetric dosing of raw materials (1)
In-line Compounding (2)
Mixing extruder (4)

Continuous glass fiber rovings (3)
LFT plastificate (5)

Process requirements
Materials
Costs
Part
Environmental conditions
Quality requirements

Quelle: Dieffenbacher
Mold Filling
Process Requirements LFT-D-ECM

• General mold filling process for LFT

• Mold coverage 30-50%
• Material flow distance about 30 to 40 cm
• Long flow requires higher press capacity, pressure required 150-250 bar
• Filling of ribs and complex geometry are feasible
• Cycle times 20-50 seconds
Mold Filling
Process Requirements LFT-D-ECM

- Understanding the flow behaviour, fiber orientation and required pressing forces
- Approximation of these parameters can be done through mold filing studies which require following steps:
  - Closing the mold using a blocking - LFT will be cooled and flow behaviour studied
  - Varying the mold blocks to achieve mold filling pattern (next slide)
  - Analysing the flow distance and prediction of weld lines
  - Analysing the press force vs the mold gap allows calculation of total press force required
Mold Filling
Process Requirements LFT-D-ECM

• Varying the mold blocks to achieve mold filling pattern
Symmetrical and asymmetrical plastificate placement
- Parallel levelling system required
Mold Filling- Multiple Charges
Process Requirements LFT-D-ECM

- Placement of multiple LFT plastificates
  - For complex geometries, one piece of LFT plastificate is probably not sufficient to fill the mold properly
  - Solution: Placement of multiple pieces
  - Avoids asymmetric moments
  - Issue: Weld lines due to multiple LFT plastificates
Mold Filling- Multiple Charges
Process Requirements LFT-D-ECM

- Profiled plastificates to avoid weld lines
  - Results in less material flow i.e.
    - Reduced press force
    - Reduced fiber orientations in the part (less anisotropic)
LFT Parts

- Fiber orientation after the form filling process
LFT-D Application
Spare Wheel Cover - VW Touran

- Material: LFT-D 20 PP
- Weight: 2.3 kg
- Dimensions: 730 x 690 x 18 mm
- Visible grained surface
- Cycle time: 25 sec
- Hydraulic fast-closing press
- Extruder capacity: 480 kg/h
Multi-Material Concept

- Intelligent combination of different materials (MMD): “Join the best”
- Material substitution no longer effective - holistic approach required
- Suitable joining technologies or intelligent intrinsic hybridization required
Composite technologies and hybridization

- Utilization of established composite technologies with mass production potential

- Local hybridization, and functionalization of composites with reinforcements made of steel, UD or textile fiber reinforcements, foams
Interdisciplinary, holistic approach

- Holistic consideration of materials, production processes and methods leads to new construction methods in multi-material design
Continuous Fiber-Reinforced – Thermoplastic (T-LFT)

- Advantages of local continuous fiber reinforcements
  - High potential for lightweight design due to specific material properties
  - Low creep tendency
  - Optimized part reinforcement
  - Optimized, load dependent fiber orientations
  - Prepreg material → lower risk of voids in the final part
  - High fiber volume fraction of 50 – 60 %
Continuous fiber-reinforced – Thermoplastic (T-LFT)

- Load transfer into local continuous fiber-reinforcements
- Development of novel solutions for load transfer into molded, continuous-fiber-reinforced structures is important
- Maximizing effects of fiber-reinforcement
- Creating guidelines for proper part design
- Types of reinforcement:
  - Tapes
  - Organo sheets
  - Fabric
  - Filament wound structures

Metallic inserts (e.g. wound loops)

Composite inserts (e.g. thermoformed)
Continuous fiber-reinforced – Thermoplastic

- Tailored LFT (T-LFT)
Continuous fiber-reinforced – Thermoplastic (T-LFT)
Continuous Fiber Reinforced - Thermoplastic (T-LFT)

- Types of local continuous reinforcements:

  - Textile reinforcement
  - Unidirectional fibers
  - Continuous fibers
  - Metallic inserts
  - Metal components
  - Metallic inserts
  - Textile reinforcement
Continuous fiber-reinforced – Thermoplastic (T-LFT)

- Wound and UD reinforcements

Manufacturing of preimpregnated fibers
Handling and transfer of reinforcing structure
Processing to final part
Continuous Fiber Reinforcement—Thermoplastic

Back molding of textiles and decor foil

- Back molded material provided structural stability

1. Fix textile in tool and close tool
2. Inject material
3. Dwell time
4. Demolding

E.g. textile material

Skript: Konstruieren mit Kunststoffen, Bonten

Quelle: Fraunhofer ICT

in cooperation with Fraunhofer
Continuous fiber-reinforced Thermoplastics

Thermoplastic tape-placement

- Processing of unidirectional prepreg tapes
  - Manufacturing of shell-like parts for structural applications

- Most common machine types:
  - Gantry systems (Especially for very large structures)
  - Robot-based processes with tape-placement according to final geometry
  - Tape-placement on flat surface with subsequent forming

- Material throughput:
  - Most processes deliver approx. 5 – 20 kg/h
    - Hence especially interesting for lower volumes
  - For thermoset systems, curing time has to be taken into account
Continuous fiber-reinforced – Tape placement
Continuous fiber-reinforced – Tape placement

Advantages of unidirectional tape structures

- High fiber content of 50 – 60 Vol-%
- Nearly no limitation regarding polymer selection
- Completely impregnated fibers – lower risk of dry fiber spots
- Several suppliers
- No handling of chemicals (thermoplastic materials)
- Clean processing (especially thermoplastic materials)
Continuous Fiber-Reinforced FPR-Tape placement

- **Advantages of thermoplastic Tapes:**
  - Faster cycle times through faster curing of the matrix (cooling at Tg)
  - High Impact strength high compared to thermosets
  - Very clean environment and process control
  - Thermoplastic joining processes applicable (esp. Welding processes)
  - Unlimited storage
  - Subsequent curing is omitted, eg. No autoclaves

- **Advantages of thermoset Prepreg:**
  - Less problems regarding to heat distortion/resistance and partly on chemical resistance
  - Already established in aviation industry
Continuous fiber-reinforced FRP – Tapes

- Advantages of tape placement
  - Fiber orientations within the laminate is arbitrarily adjustable
  - Varying wall thickness
  - Minimized scrap
  - Hybrid laminates
    - Variation of fiber or matrix type, fiber volume fraction etc.
  - Automated process with high reproducibility and accuracy
Continuous fiber-reinforced FRP – Tape placement

- Benefits of **thermoplastic** UD-tapes
  - Short cycle times
  - High toughness compared to thermosets
  - Very clean processing
  - Recyclable
  - Thermoplastic joining technologies applicable (especially welding)
  - No limited storage time
Continuous fiber-reinforced FRP – Thermoplastic Tape placement

- Manufacturing of tape layups using Fiberforge’s RELAY process
  - Tape placement on flat surface
    - Plies are locally connected by ultrasonic welding
  - This stage is called unconsolidated tape layup
Continuous fiber-reinforced FRP – Thermoplastic Tape Placement

- Part manufacturing using unconsolidated tape layups
  - Stamp forming

1. Fixing of tape layup in the transfer system
2. Heating to processing temperature
3. Forming
Thank You