Long-Fiber Reinforced Thermoplastics Tailored for Structural Performance

ACCE
5th Automotive and Composites Conference
Troy, USA, 12.-14. September 2005

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Outline

- Introduction
- Advantages of Dieffenbacher LFT-D-ILC technology
- Continuous fiber reinforced LFT
- Tailored LFT – material development
- Conclusions
- Future Perspectives
- Presses & More - Teaming up in development
Why Long Fibers for Reinforcement?

- Short fiber reinforced plastics
- Long fiber reinforced plastics
- Particle filled plastics
- Non reinforced plastics
- Rubber

Tailored LFT's
Established Processing Techniques for LFT Semi Finished Products

**Glass Mat Thermoplastics**
- GMT (semi-finished product)
  - GMT oven
  - Hydraulic press
- Product – LFT part

**Long Fiber Thermoplastic Granules**
- LFT-G (semi-finished product)
  - Single screw extruder
  - Hydraulic press
- Product – LFT part
Growth of LFT in Europe

Quelle: AVK-TV 2005
Technologies for LFT Direct Processing

- Polymer resin
- Additive/modifier
- Fiberglass roving

Polymer compound

LFT/SG
Injection molding

LFI injection molding equipment

Product – LFT part

LFT-D
Compression molding

LFT-D extruder
+ Hydraulic press

Product – LFT part

In-Line Compounding

LFT-D-ILC
compression molding

LFT-D-ILC equipment
+ Hydraulic press

Product – LFT part
Advantages of Dieffenbacher LFT-D-ILC Technology (2 Extruders)

- Compounding extruder suitable for:
  - Blending
  - In-line Stabilization and Coupling
  - In-Line coloring
  - Engineering resins/polymers
  - In-line compounding of fillers or nanoparticles

- Mixing unit (twin-screw)
  - Extraordinarily low wear (screw/cylinder)
  - Incorporation of different continuous fibers
  - Incorporation of natural fiber mats
  - Incorporation of chopped fibers
  - Complete disintegration of fiber bundles

→ Dieffenbacher LFT-D-ILC technology basis for visible applications
→ Disintegration of fiber bundles and homogenous dispersion
→ Reduced anisotropy and therefore low warpage
Advantages of Dieffenbacher LFT-D-ILC Technology

- Advantages regarding material properties
  - Tailored LFT material → Choice of matrix resin, additives and fibers
  - Adjustable and reproducible fiber length distribution
  - Continuously adjustable glass fiber content
  - Excellent homogeneity of LFT strands
  - Co-molding of continuous reinforcements at low thickness and weight compared to injection molding possible
  - Single heat history
  - Excellent flow behavior → Improved surface appearance (vs. GMT processing)
  - Processing of recycled trimmings and even ELV material

- Advantages regarding economical facts
  - High productivity
  - Low wall thickness possible compared to injection molding (material savings 25%)
  - Low down time due to turnkey production cell
  - Significantly reduced expenses for total process energy consumption
  - High material output rates at constant and reproducible material properties
  - Extremely short cycle times (22 seconds for VW Golf V underbody shield)
  - Reduced mold and screw wear
LFT-D-ILC
Base Equipment

- Fully automated material handling
- Conveyor belt for LFT strand
- Provision of rovings
- In-line compounder
- Mixing extruder
- LFT die
- Hydraulic Press

AVK-TV
Innovationspreis 2001
What is Tailored LFT?

LFT combined with local reinforcement by fabrics or continuous fiber structures

Next Generation of Composites in Automotive
Development Path

▸ GMT  (Glass-mat reinforced thermoplastics)

▸ LFT  (Long fiber reinforced thermoplastics – pellets, granules)

▸ LFT-D  (LFT with direct incorporation of glass fibers)

▸ GMTex  (GMT with one/several layers of woven fabrics)

▸ Tailored LFT  (LFT-D-ILC with local continuous fiber placement – rovings, profiles, textiles or combination)

Alternative to metal or metal hybrids
Applications – Spare Wheel Tub

Source: Quadrant
GMTex – Field of Applications

Improved crash performance by combination of LFT and Fabrics

Source: Quadrant
GMTex – Tailored LFT - Field of Applications

new model:
GMTex + integrated brackets

previous model:
GMT + steel brackets

Source: Quadrant
Production Technologies – Compression Molding of GMTex

GMTex

**Advantage**
- Synergy of co-molding (no high precision molds no additional handling of textiles or organic sheets)
- Local reinforcements just in areas where required
- Reduced costs compared to the use of pure organic sheets

**Disadvantage**
- Dependency on one material supplier
- Costs of semi-finished products (incl. shipment and storage)
- Co molding of standard GMT required
- Fiber alignment is not optimal (0/90°)
- No structural incorporation of inserts possible

Source: Quadrant
Tailored LFT - Adjustment of Mechanical Properties by In-Line Assembly of Continuous Fiber Skeleton with LFT-D

Important parameters are:

- Fiber orientation of each layer (fabric and LFT)
- Volume ratio of fabric and LFT (thickness of each layer)
- Properties of each layer
- Process parameters (processing window)

simplified approximation:

Calculation of Modulus utilizing the rule of mixture:

$$E_C = E_G \cdot v_G + E_{LFT} \cdot v_{LFT}$$
Fabric Reinforced LFT – Adjustment of Mechanical Properties

The variation of fabrics and LFT materials offers a material tailored for each application.
Local Reinforcement Using TWINTEX Fabrics

Elongation of a TWINTEX laminate 45° (7 layers of Twintex P PP60 745 AF)
Textile Reinforcements - Tensile Strength PP/GF60 Laminates

Laminates of non crimped fabrics offer a high potential for energy absorption.
Advantages and Challenges of Local Textile Reinforcements

- Significant increase of Tensile Modulus and Strength
- Significant increase of impact and energy absorption
- Slight increase of flexural strength and modulus (low wall thickness!)

**but**

Material properties $\neq$ properties of the component

Warpage…+

…Penetration of the fabric by LFT…+

…Influence of geometry =

= have to be considered in the design phase!
Tailored LFT – Light-Weight Composite Parts Made of Long Fiber Reinforced and Continuous Fiber Reinforced Thermoplastics

- Customized unidirectional continuous fiber structures for significant increase of part specific strength (increase of some 100%).

- Transmission of forces by part specific continuous fiber structures - fiber structures work as an superior integrated joining technology.
Integration of Different Types of Local Reinforcements

- Filament wound reinforcement
- UD-profile reinforcement
- Fabric reinforcement
Fusion Bonding of LFT and Continuous Fiber Reinforcements

**Cohesion and Adhesion**

- **Fusion Bonding**
  - between
  - LFT and films

- **Cohesion force**
  - (equal join partners)
  - Interdiffusion at polymer-polymer-interface (LFT / Reinforcement)

- **Adhesion force**
  - (different join partners)
  - Form fit
  - (surface roughness)
Setup to Produce Co-molded LFT/Fabric Sample Plates

- Heating of the fabric in an infra-red oven
- Transfer of fabric to the open mold
- Two LFT-strands are positioned in the mold
- Compression molding of fabric and LFT-material
Temperature Curve at Non- Isothermal Bonding

Preheat temperature of reinforcement (important for handling)

Preimpregnated fabric: PP/GF60
LFT-D: PP/GF30

Example:
- $T_{LFT} = 230^\circ C$
- $T_{Interface} \approx 185^\circ C$
- $T_{Fabric} = 140^\circ C$
- $T_{Mold} = 60^\circ C$

Interface temperature exceeds the melt temperature for a short time (Process window)
Micrograph of the Interface LFT/ Reinforcement

Filaments crossing the polymer-polymer interface

Uneven polymer-polymer interface

→ Bond strength is based on interdiffusion, fiber bridging, and mechanical adhesion due to an uneven surface in the interface
Penetration of Fabrics with LFT-Material

Function integration on both sides of the fabric

Penetration in the demonstrator part (beam structure)

No penetration

Standard mold filling

Penetration, Mold-fill trough the fabric
Functional Integration in a Front-End Carrier (by Penetration)
X-ray Images of Penetrated Areas

Rib structure of demonstrator part (LFT PP/GF30)
1. Row no Penetration
2. Row penetrated areas

- highly oriented fibers
- Reduction of glass content from 29.9 wt.-% to 26.9 wt.-%

(Fabric: Twintex P PP60 935 BF 4/1)
Improvement of Torsional Strength by Local Reinforcement

- LFT-beam structure with continuous fiber reinforcement
- LFT-beam structure without continuous fiber reinforcement

Adding an roving reinforcement:
Beam weight increase by 4% compared to pure LFT-PPGF30
Loop Reinforcement Between Fixtures – Load Path

Metal insert

Filament wound roving reinforcement

LFT-part with co-molded reinforcement (with and without metal inserts)

Part dimensions: Length: 300 mm
Part weight: 150 g
Additional weight for UD-Reinforcement: 10 g
Mechanical Properties of a Co-molded Continuous Loop Structure

The part strength is improved by a factor of 10 in all three directions.

- Test in X-direction
- Test in Y-direction
- Test in Z-direction

Testing directions:

Number of layers (glass-roving) vs. Force at break [kN]

- Y
- Z
- X

Number of layer

Fraunhofer ICT Chemische Technologie
Production Concept for a Tailored LFT Composite Frontend Carrier

UD-reinforcement is preheated as a tailored Preform
LFT-material and UD-reinforcement are assembled in-line to the compression molding step
Process Development and Modification for Tailored LFT Prototype Manufacturing
Production Technology – Tailored LFT

Tailored LFT

Advantage
- Synergy of co-molding (no high precision molds no additional handling of textiles or organic sheets)
- Local reinforcements just in areas where required
- Reduced costs compared to the use of pure organic sheets
- Reduced costs compared to the use of semi-finished products (GMTex)
- Independency from material supplier
- Optimimum fiber alignment and structural integration of inserts
- Combination of geometrical stiffening (ribs) and material stiffening (continuous fiber)
- Improvement of impact by additional fabric possible if necessary (integrity after crash)

Disadvantage
- Higher degree of automation due to profile positioning / equipment (not cycle time relevant)
- New development – not state-of-the-art, some development necessary
Advancements of Tailored LFT

Advantages of automised local fiber placement:

- Reduced material cost
- Economical use of continuous fiber reinforcements
- Reinforcement is tailored to the specification
- High level of functional integration

Bumper Beam made of Tailored LFT
Conclusion

- LFT-D Technology avoids the use of semi-finished products
- LFT-D parts can be reinforced with continuous fiber reinforcements
- Wide processing window allows good bonding of LFT and reinforcement
- Co-molding combines high functional integration and the performance of continuous fiber reinforced composites
Future/Perspectives

Development of process technology, material and equipment for the use of:

- **LFTs with engineering plastics**
  Application of technical plastics (ABS, SAN, PA 6, PA 6.6, PBT, etc.)

- **LFTs with other fibers/filling materials**
  Application of natural fibers (Flax, Sisal, Hamp, etc.)
  Application of additional filling materials (Talc, hollow glass beads, etc.)

- **Exterior body panels - „LFTs and PFM“**
  Back compression molding of films (PFM – Paintless Film Molding)
Dieffenbacher „Engineering Area“

Equipment consisting of features that are close to real production and different ways of treatment:

- Hydraulic High Speed Press 36,000 kN (End 05) with an active parallel levelling system
- LFT-D Plant
- LFT-G Extruder for granules
- Conveyor and dosing plants for various plastics granules and recycles
- Adjustable die for tailored plastificates

Research and Development

- Development of new process technologies and modifications suitable for the processing of long fiber-reinforced thermoplastics and -sets
- Support for part design by Dieffenbacher Competence Team
- Simulation of Mold filling by Fraunhofer ICT
- Matching and prototype production
- Material development in cooperation with Fraunhofer ICT
Closing Words

The In-line Compounding-Compression Process is an established technology for long fiber reinforced components which offers a high development potential for future applications especially for structural and semistructural parts as well as for car body parts aiming at class „A“ surface quality.

www.dieffenbacher.de
www.ict.fraunhofer.de