Long-Fiber Reinforced Thermoplastics Tailored for Structural Performance

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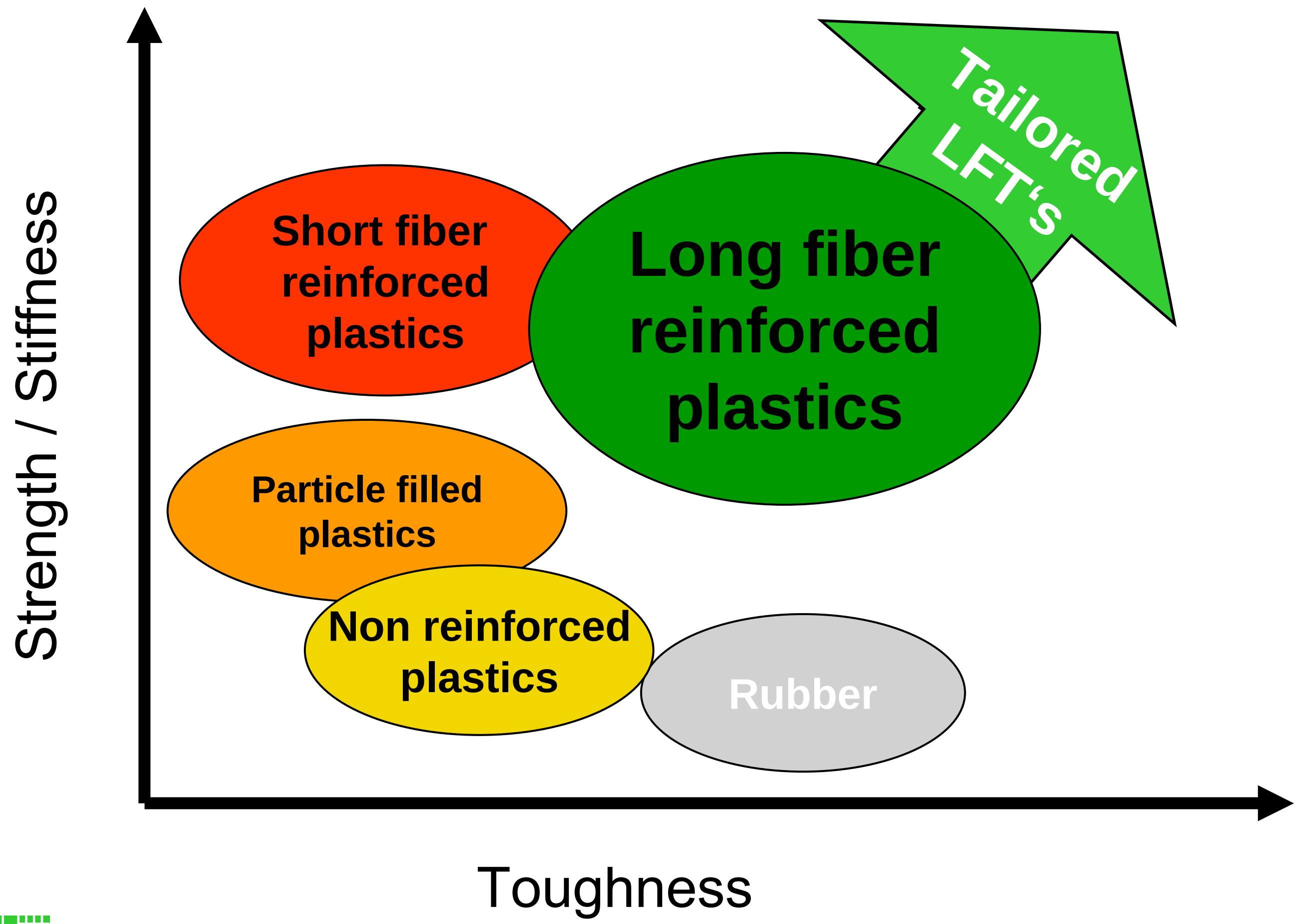
Outline

- 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 ?



Established Processing Techniques for LFT Semi Finished Products

Polymer resin | Additive/modifier | Fiberglass roving

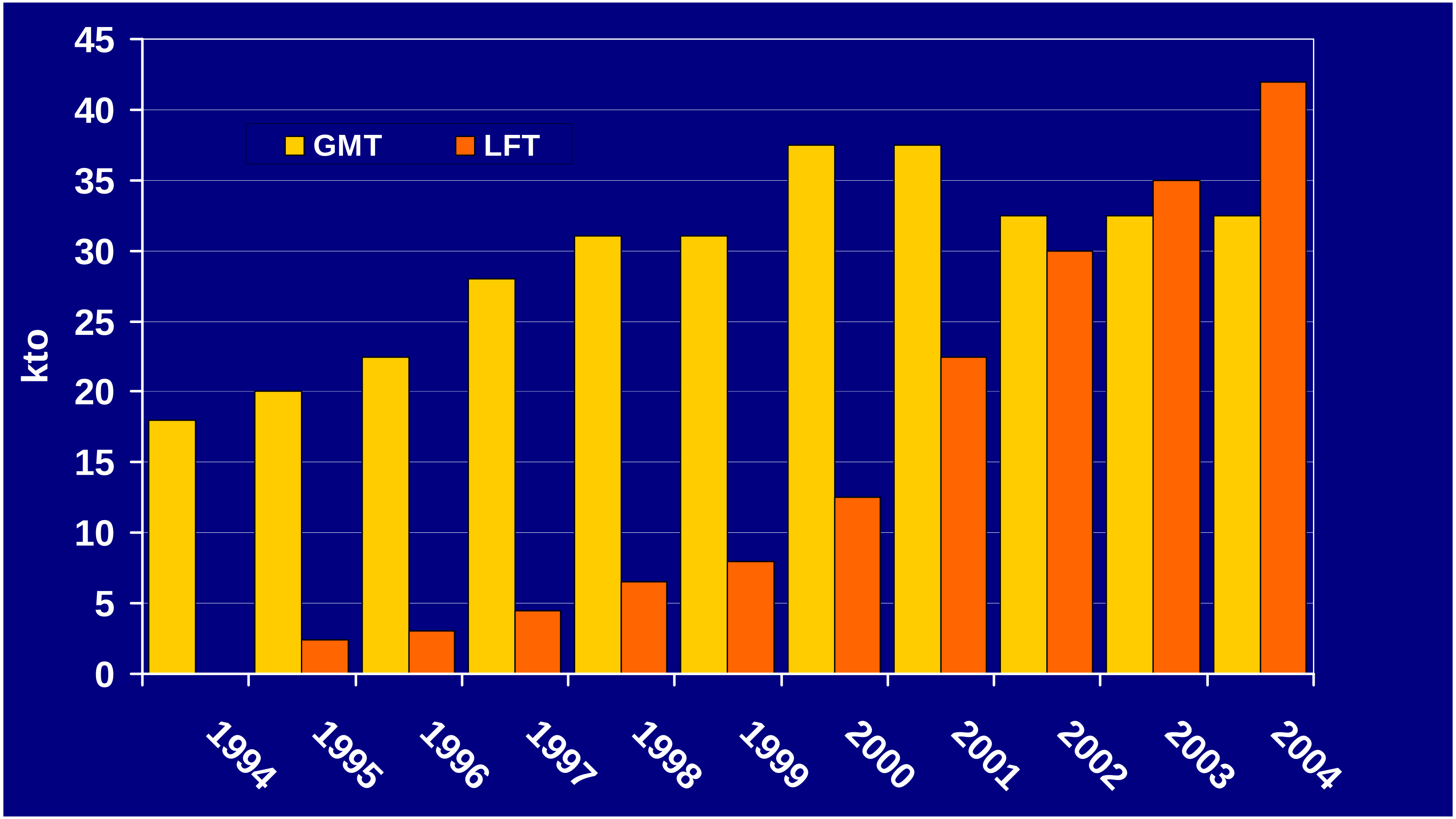
Glass Mat Thermoplastics (semi-finished product)

- **GMT** Compression molding → GMT oven + Hydraulic press → **Product – LFT part**

Long Fiber Thermoplastic Granules (semi-finished product)

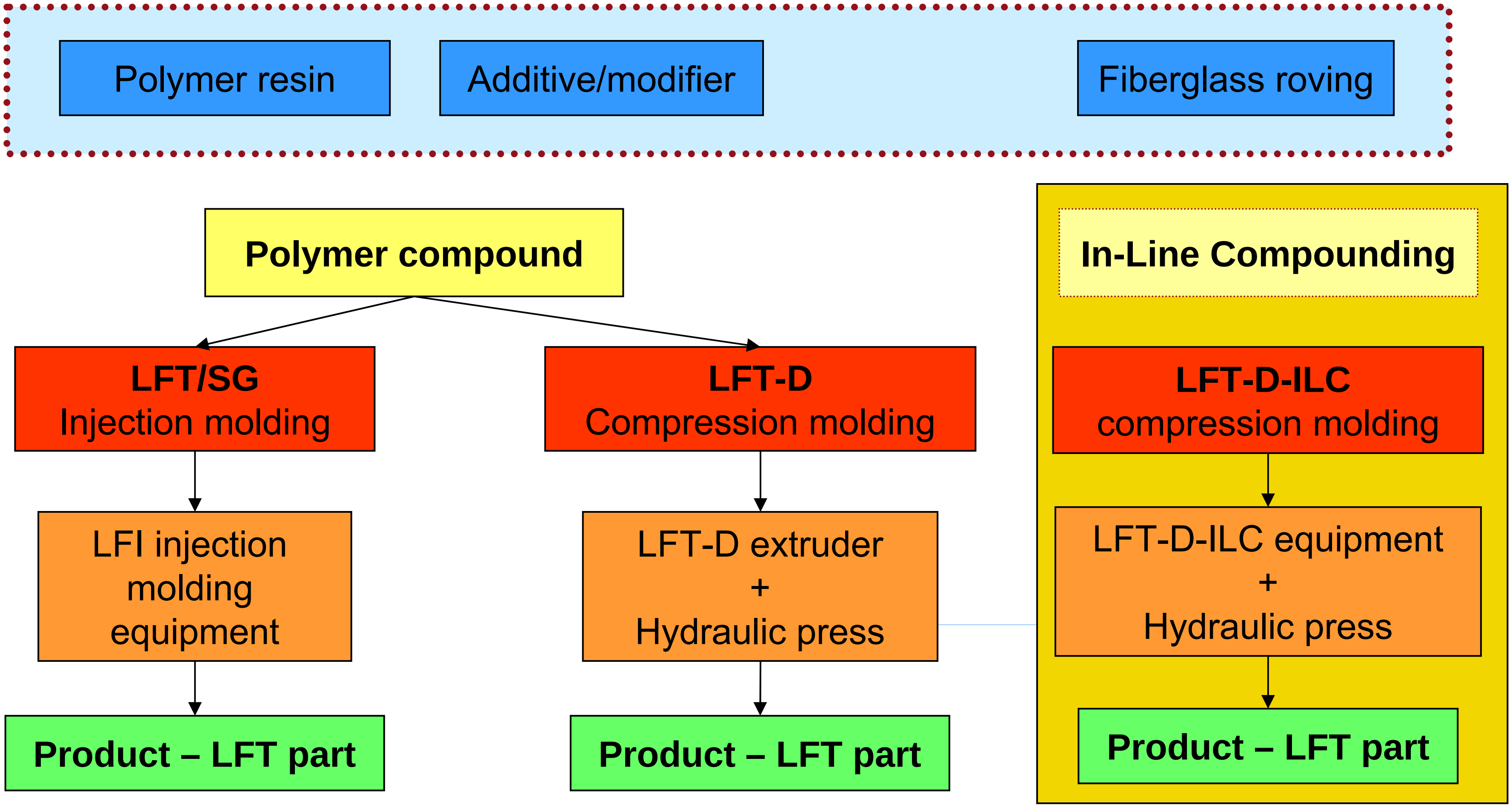
- **LFT-G** Compression molding → Single screw extruder + Hydraulic press → **Product – LFT part**
- **LFT-G** Injection molding → Injection molding machine → **Product – LFT part**

Growth of LFT in Europe



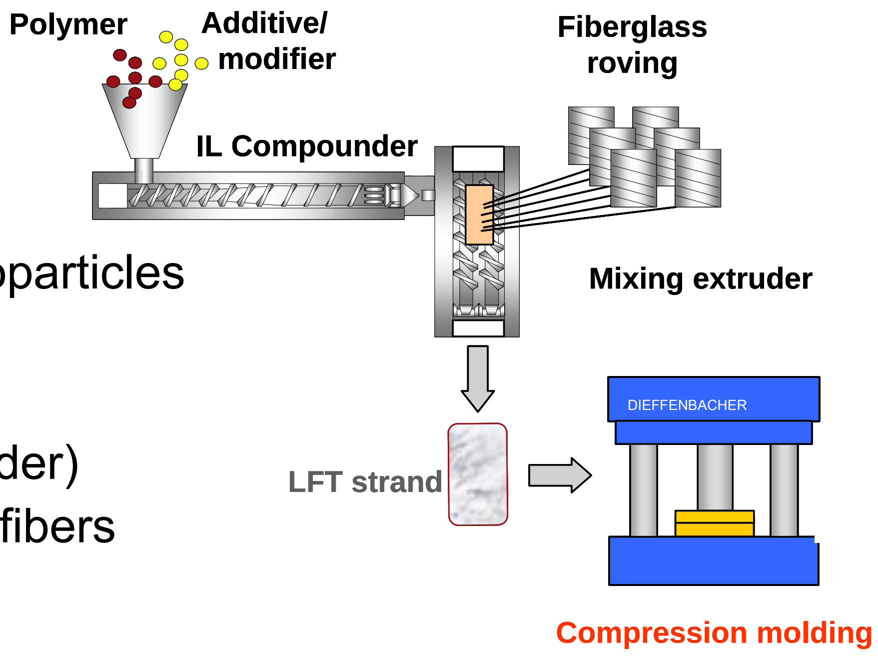
Quelle: AVK-TV 2005

Technologies for LFT Direct Processing



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

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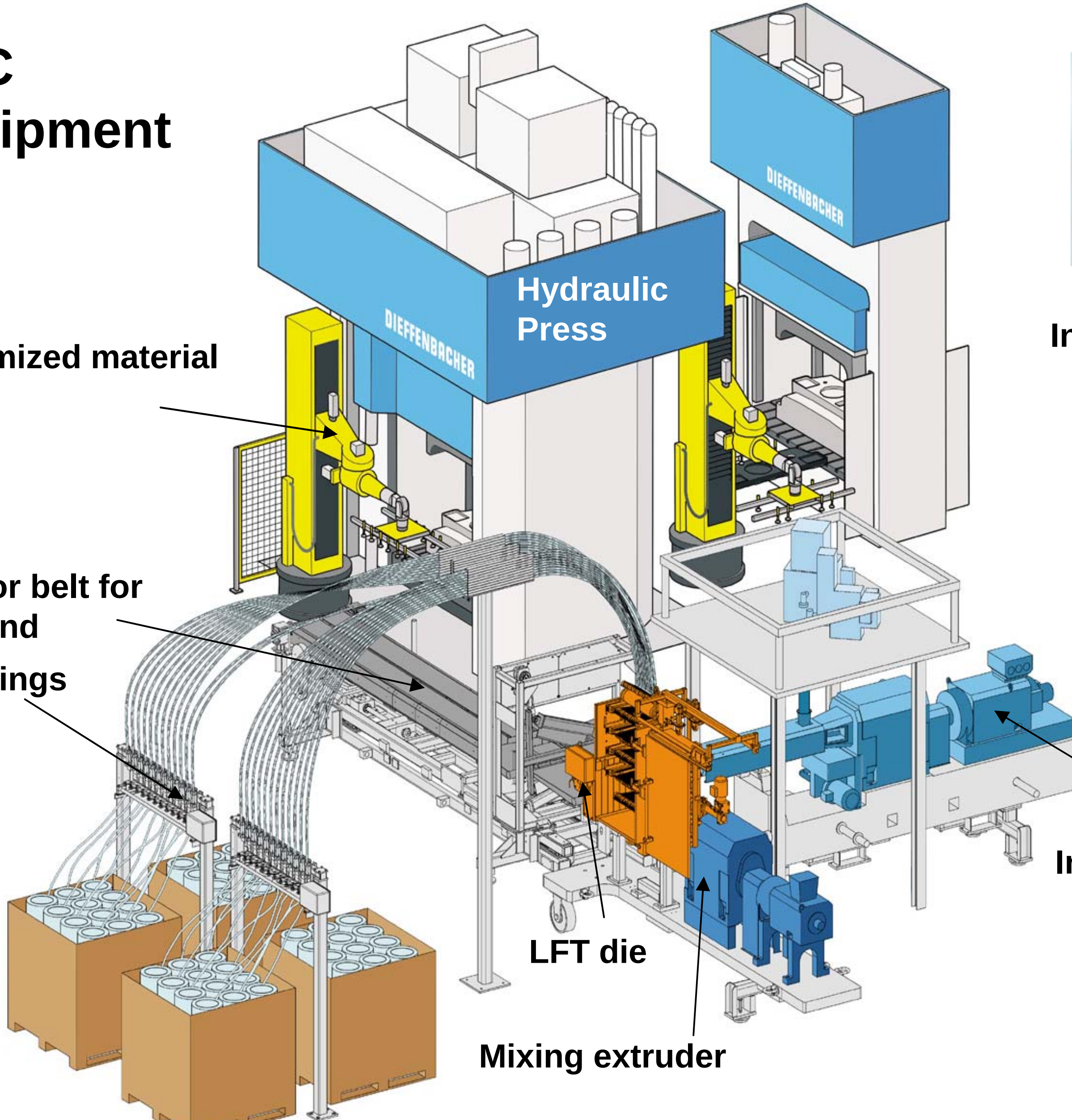
Advantages of Dieffenbacher LFT-D-ILC Technology

- **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



AVK-TV
Innovationspreis
2001

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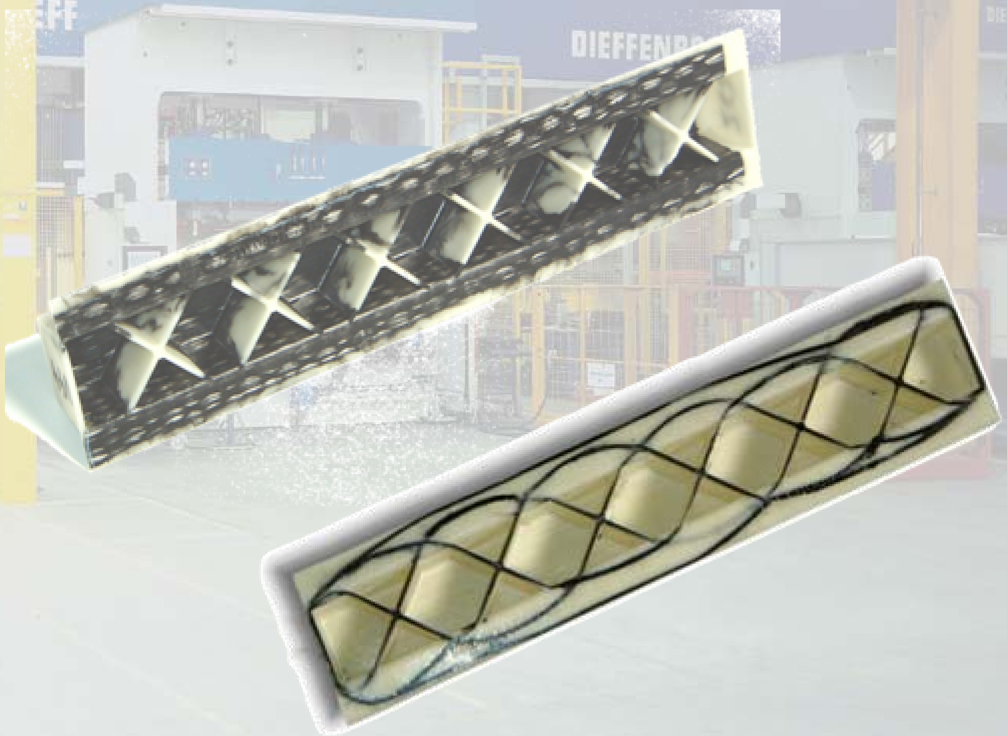
What is Tailored LFT ?

LFT combined with local reinforcement by fabrics or continuous fiber structures

Next Generation of Composites in Automotive



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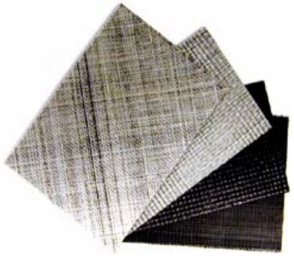
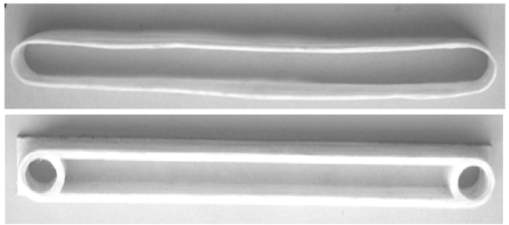
Development Path

- **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)

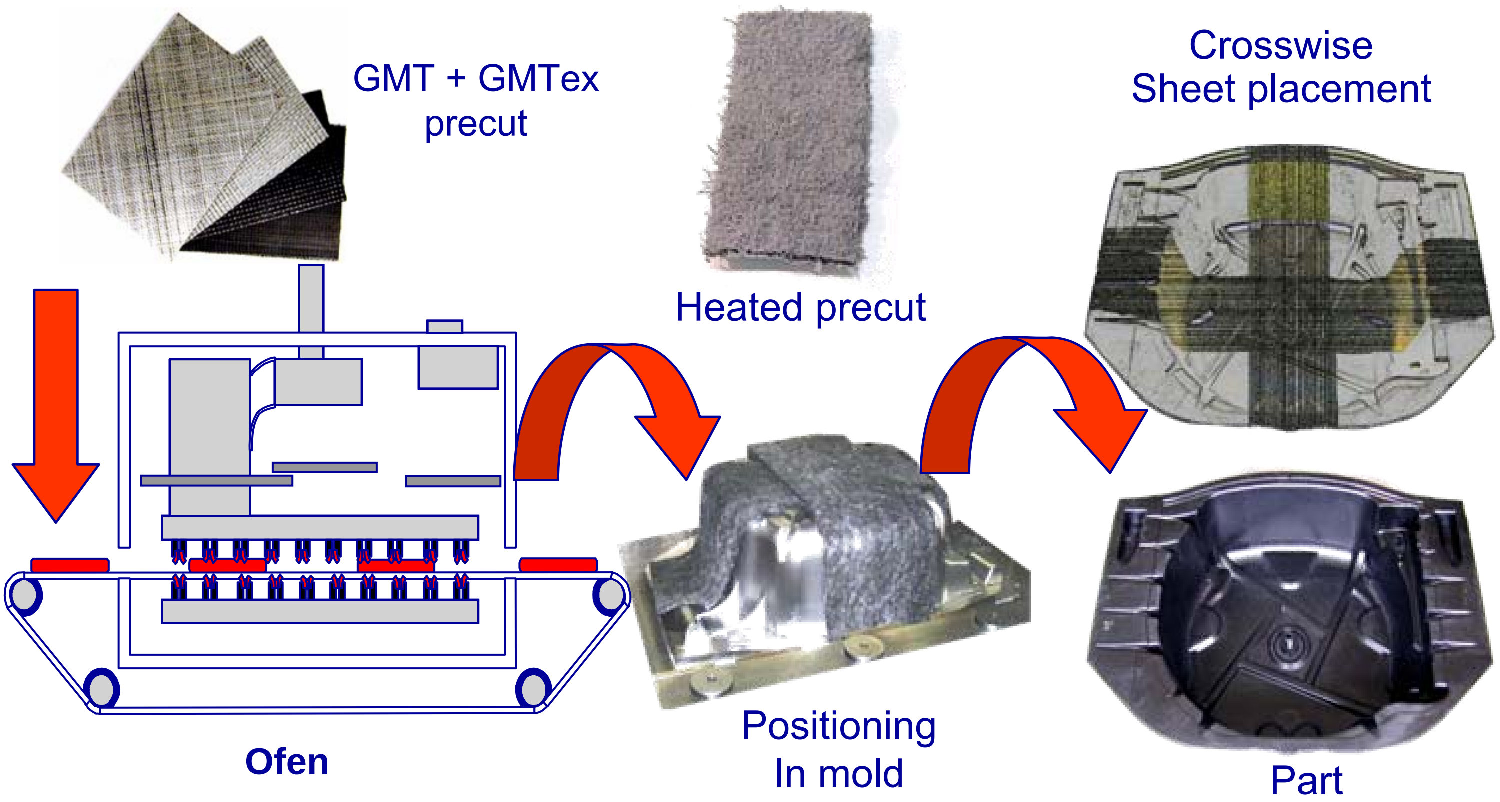


- **Tailored LFT** (LFT-D-ILC with local continuous fiber placement – rovings, profiles, textiles or combination)



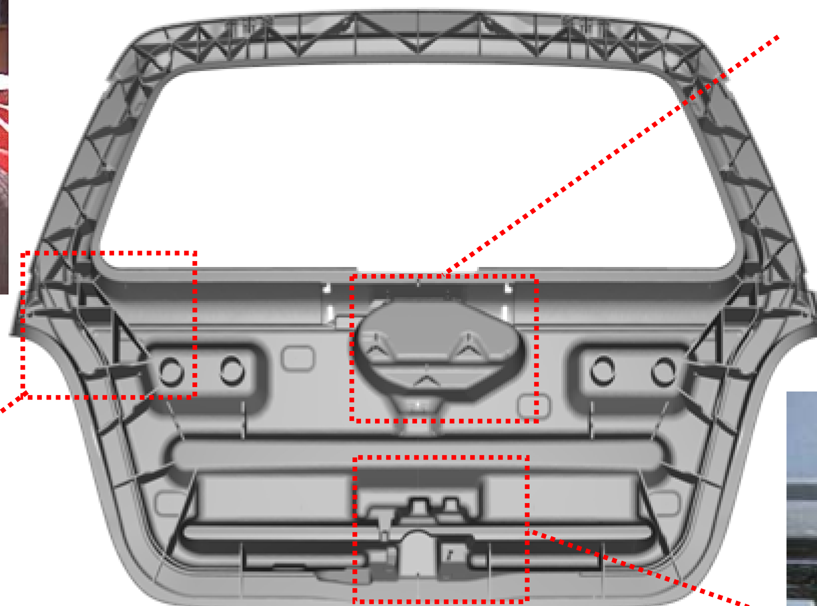
Alternative to metal or metal hybrids

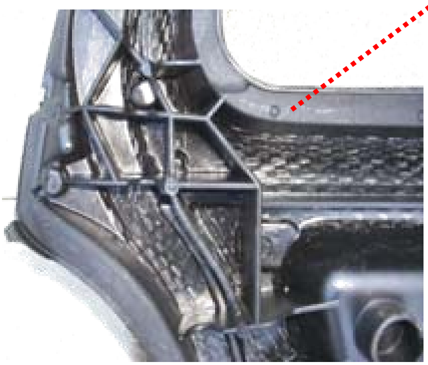
Applications – Spare Wheel Tub



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

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Production Technologies – Compression Molding of GMTex

GMTex

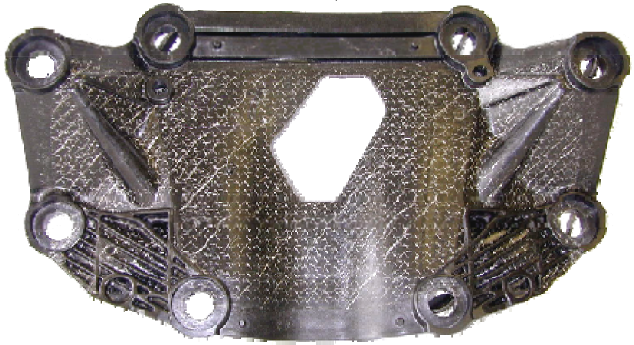
Advantage

- 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

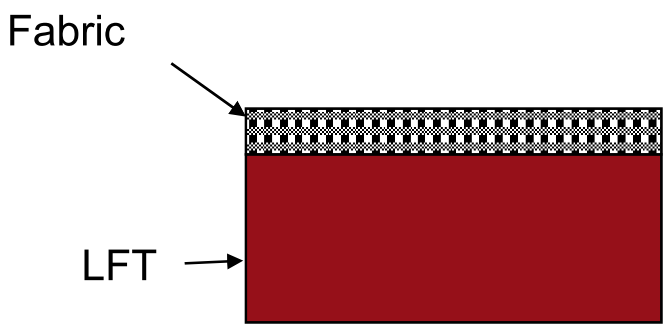
Disadvantage

- 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



simplified approximation:

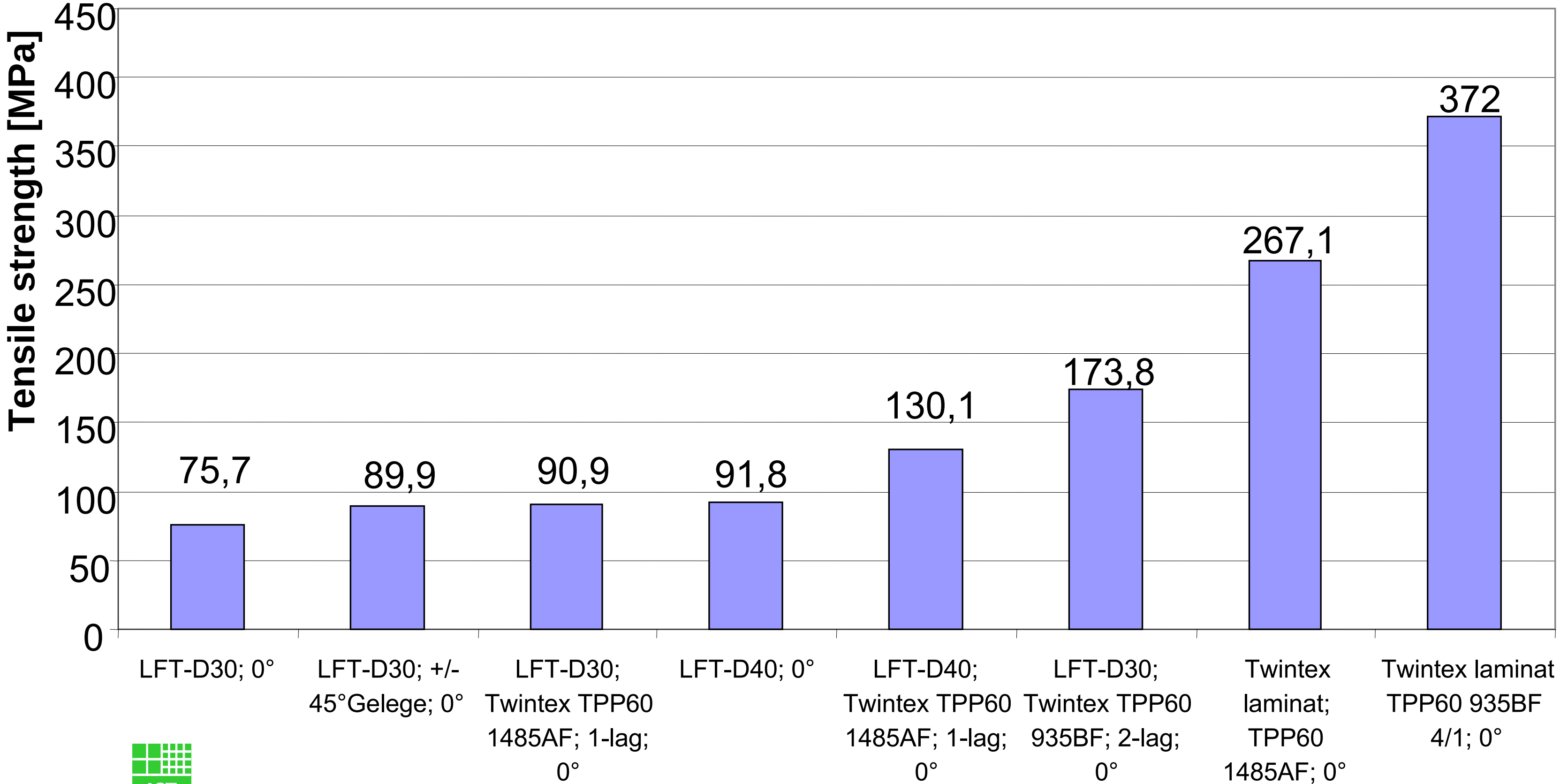
Calculation of Modulus utilizing the rule of mixture:

$$E_C = E_G * v_G + E_{LFT} * v_{LFT}$$

- **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)

Fabric Reinforced LFT – Adjustment of Mechanical Properties

- The variation of fabrics and LFT materials offers a material tailored for each application

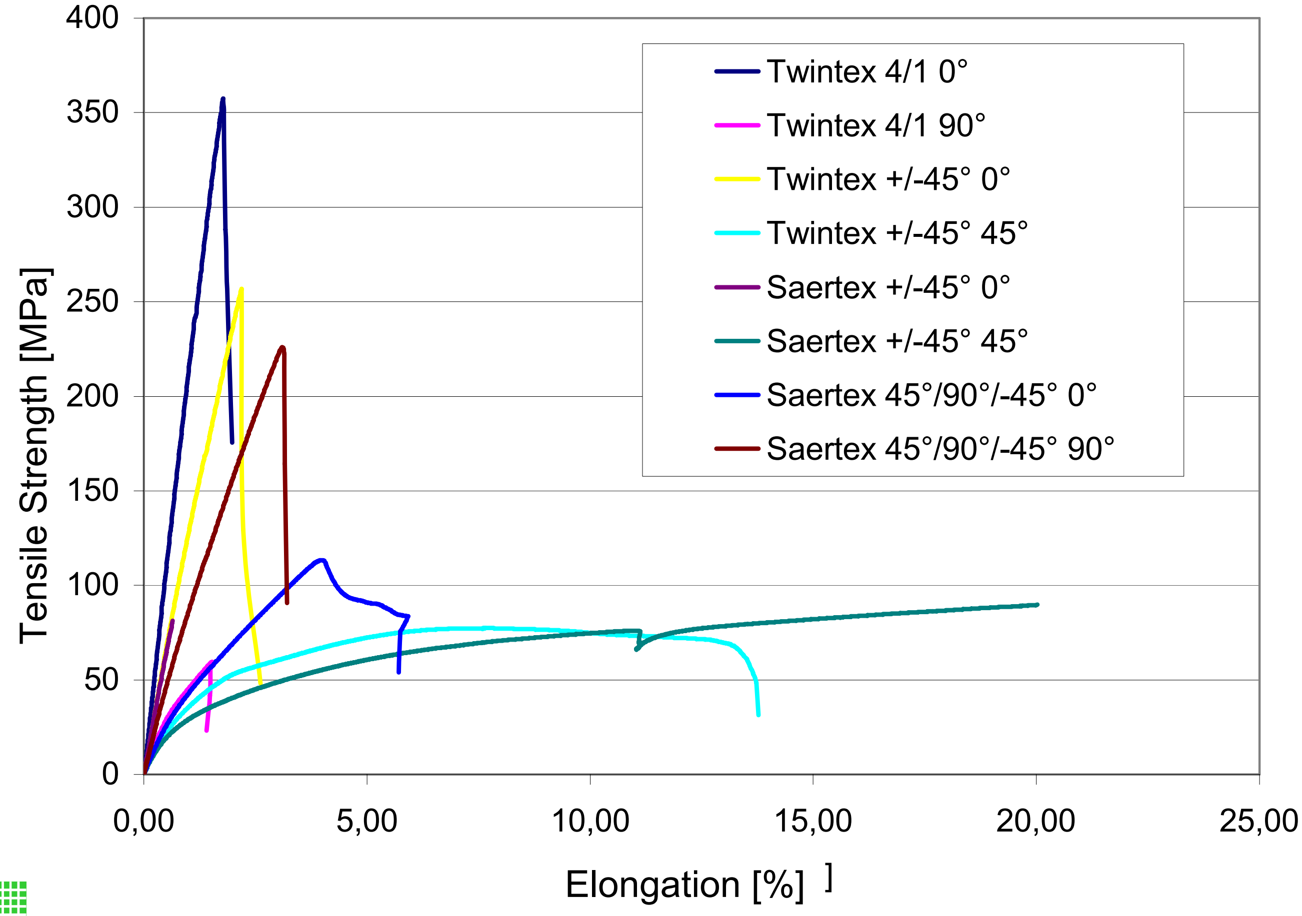


Local Reinforcement Using TWINTEX Fabrics

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 ≠ properties of the component

Warpage…+

…Penetration of the fabric by LFT…+

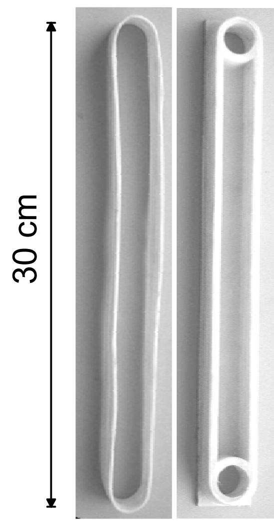
…Influence of geometry =

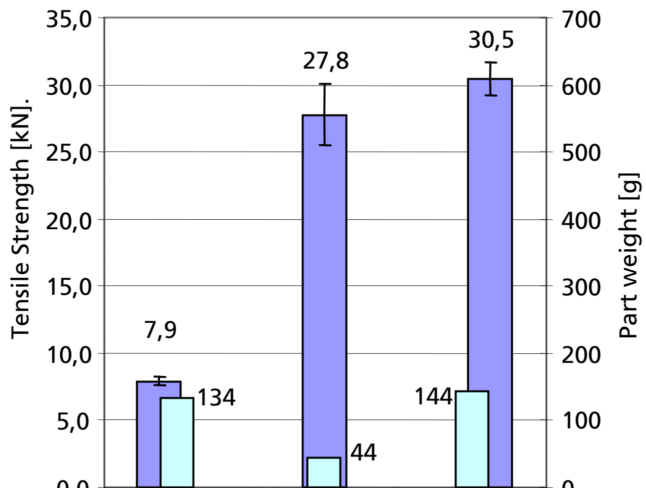
= have to be considered in the design phase!

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

ICT-Demonstrator Continuous fiber structure co-molded LFT-PP/GF





Demonstrator: LFT-PP/GF combined with continuous fiber structure

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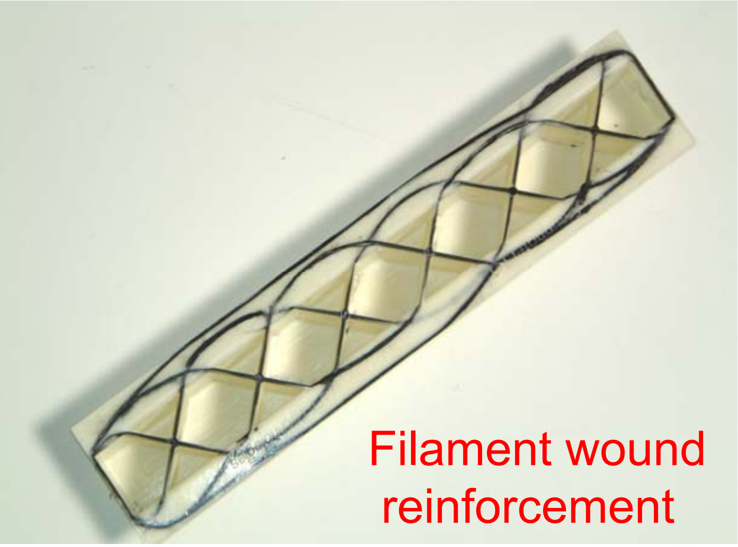
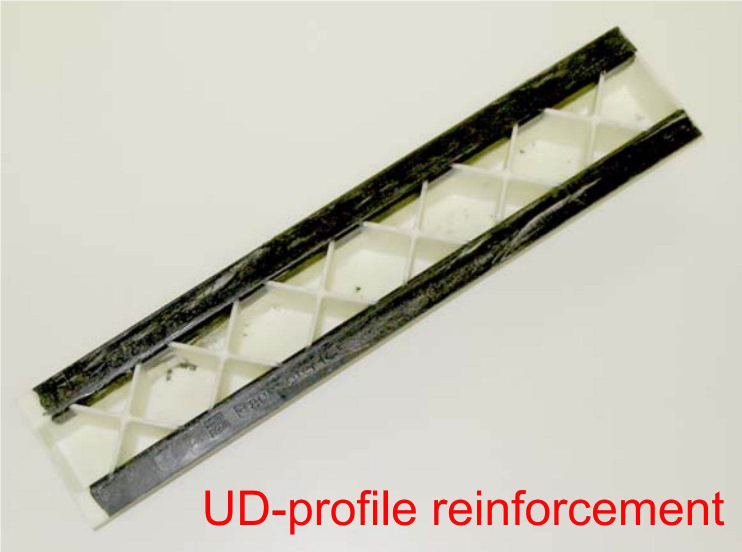
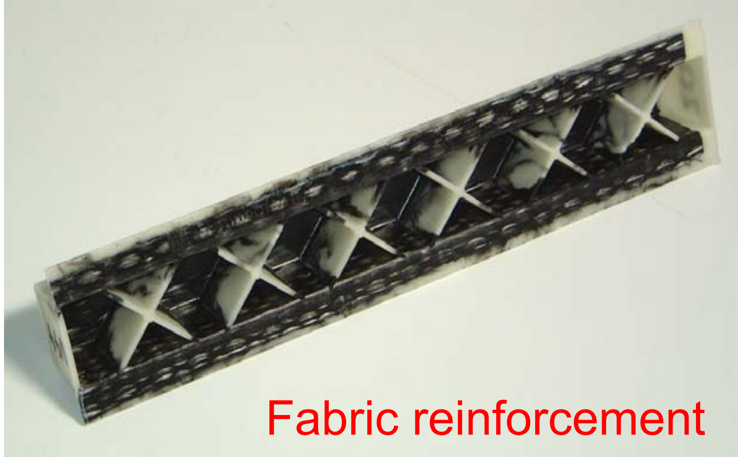
Integration of Different Types of Local Reinforcements







Fusion Bonding of LFT and Continuous Fiber Reinforcements

Cohesion and Adhesion

Fusion Bonding
between
LFT and films

Cohesion force
(equal join partners)

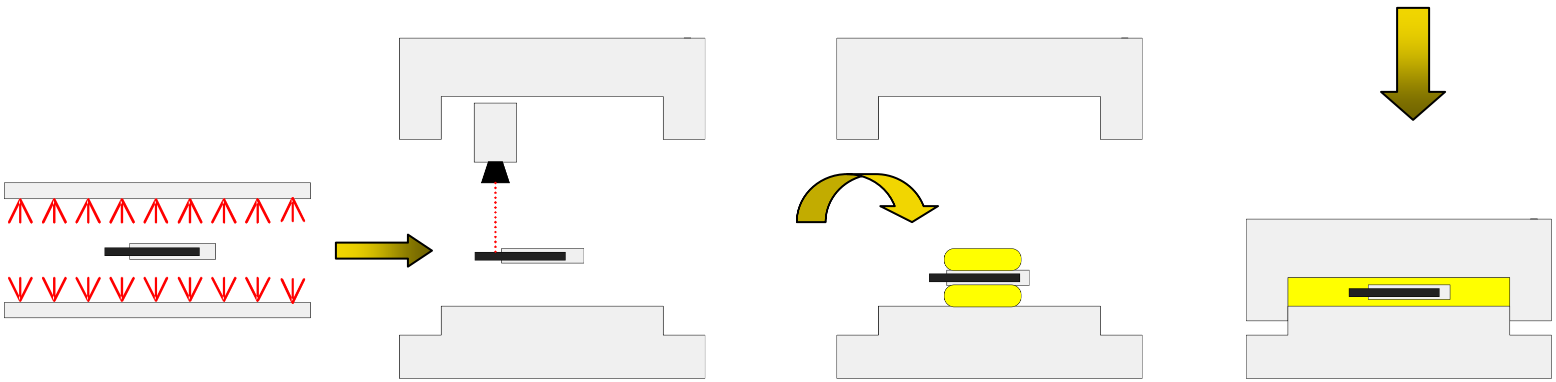
Adhesion force
(different join partners)

Interdiffusion at
polymer-polymer-interface
(LFT / Reinforcement)

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



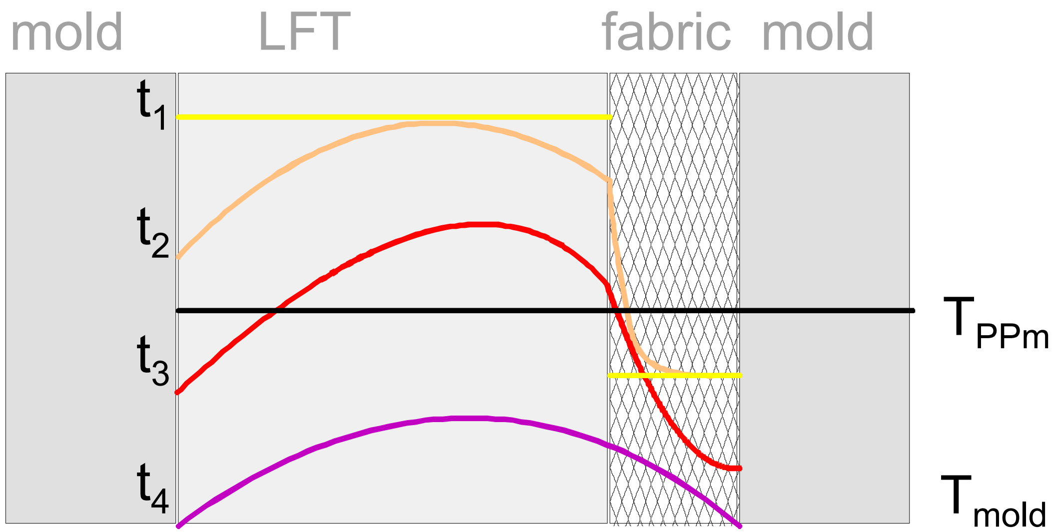
Temperature Curve at Non-Isothermal Bonding

Preheat temperature of reinforcement (important for handling)

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

Example:

T_{LFT} = 230°C
$T_{Interface}$ ≈ 185°C
T_{Fabric} = 140°C
T_{Mold} = 60°C

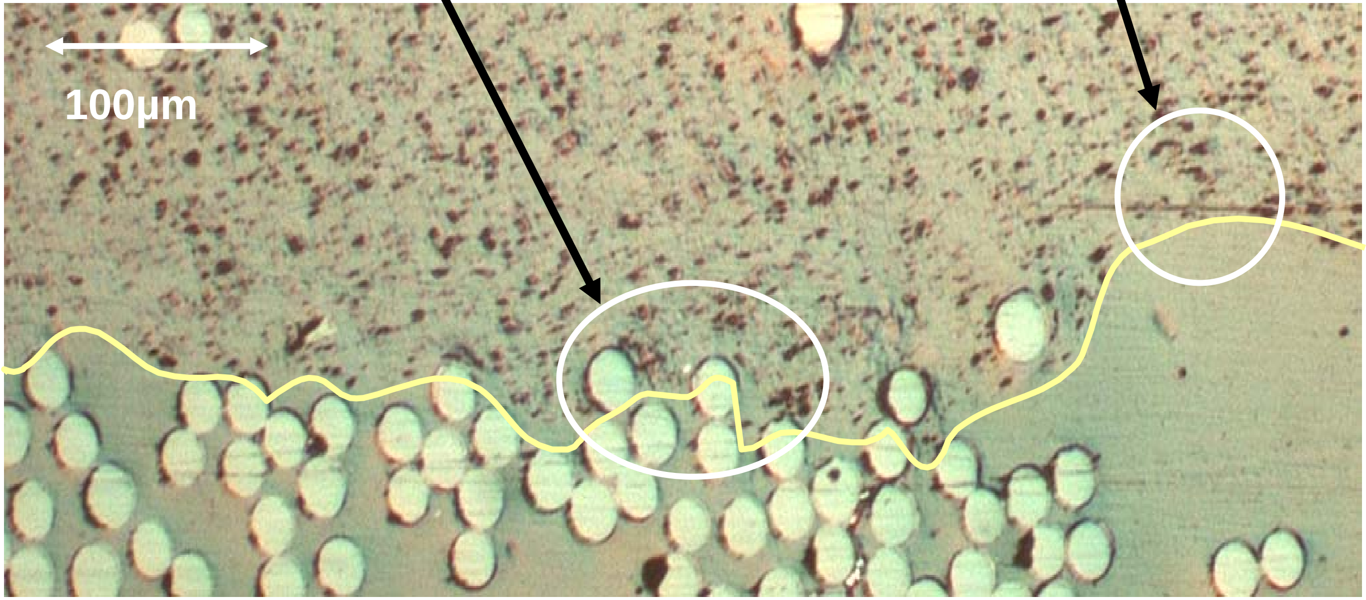


→ Interface temperature exceeds the melt temperature for a short time (Process window)

Micrograph of the Interface LFT/ Reinforcement

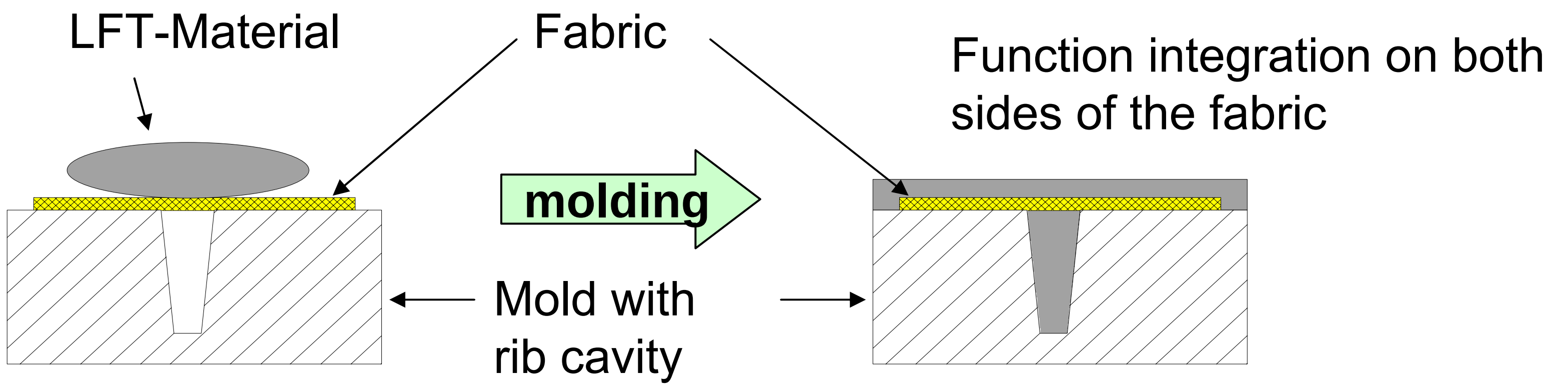
Filaments crossing the polymer-polymer interface

Uneven polymer-polymer interface

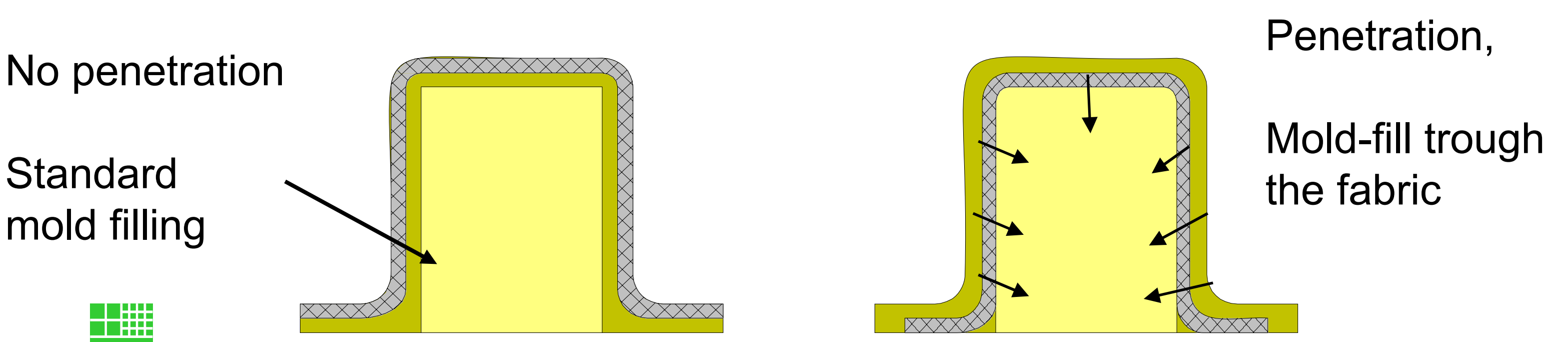


→ Bond strength is based on **interdiffusion**, **fiber bridging**, and **mechanical adhesion** due to an uneven surface in the interface

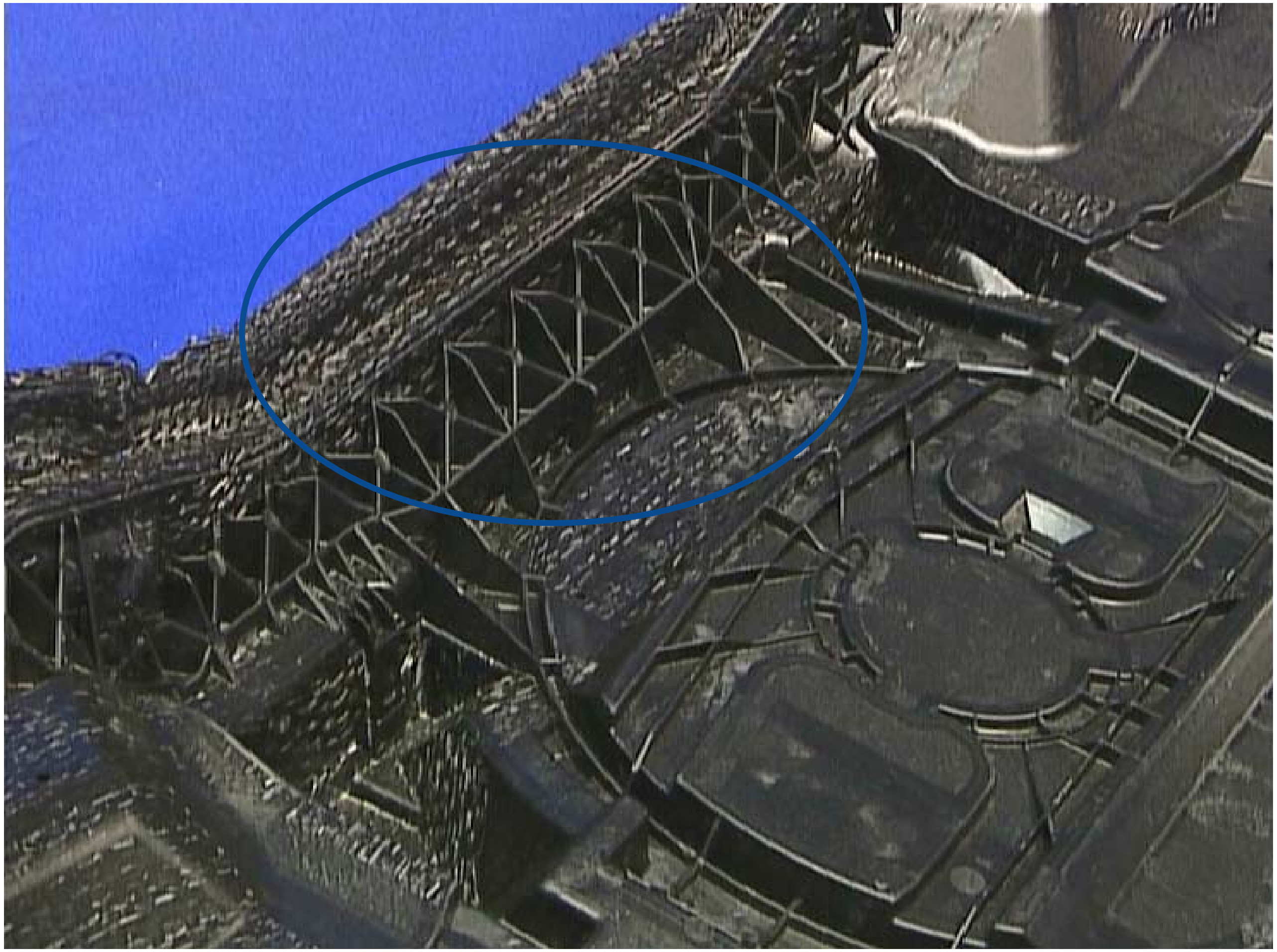
Penetration of Fabrics with LFT-Material



Penetration in the demonstrator part (beam structure)



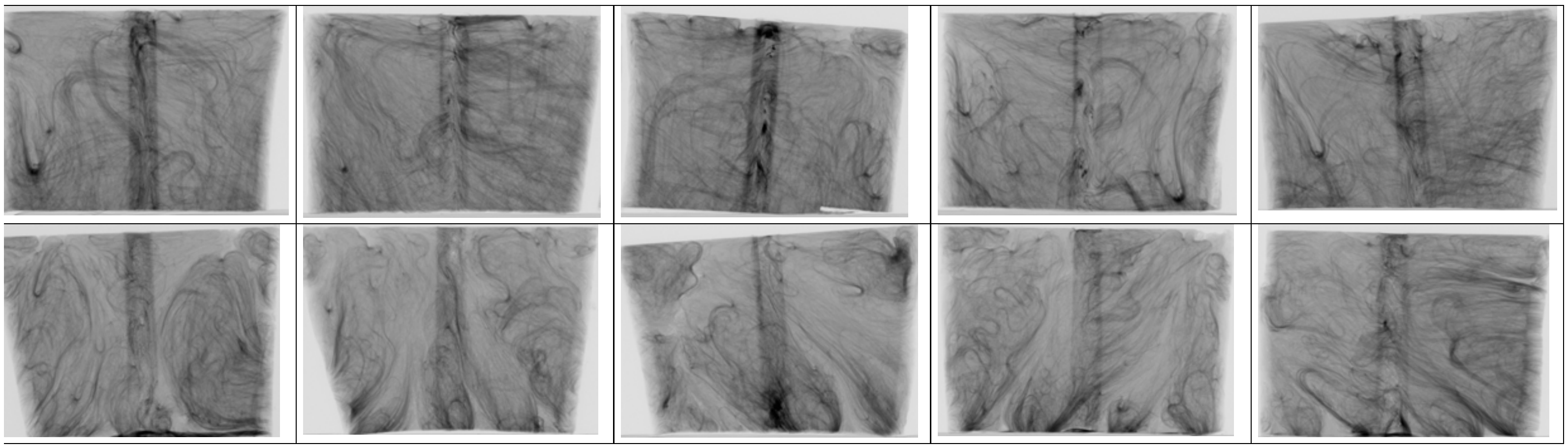
Functional Integration in a Front-End Carrier (by Penetration)



X-ray Images of Penetrated Areas

Rib structure of demonstrator part (LFT PP/GF30)

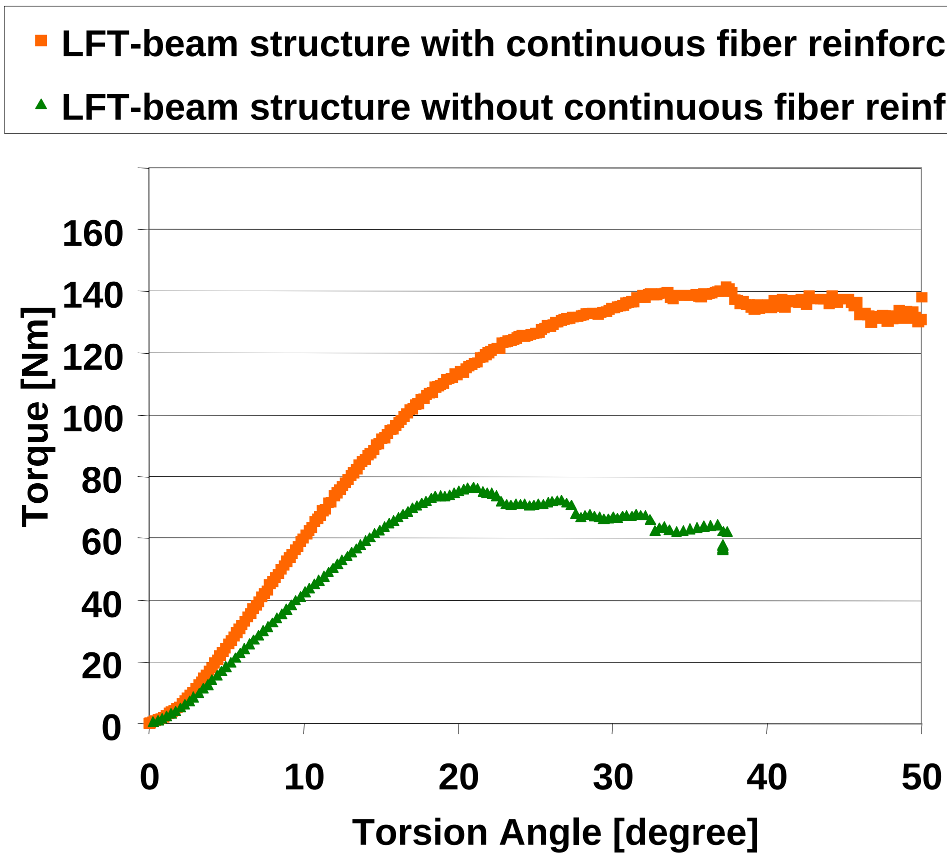
1. Row no Penetration
2. Row penetrated areas

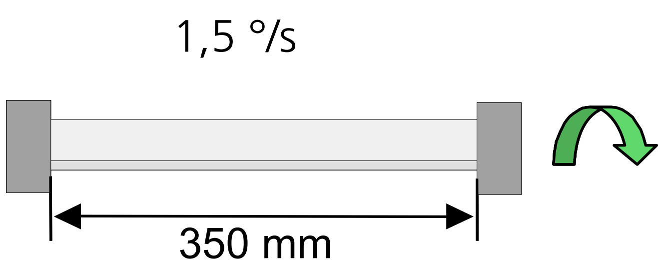


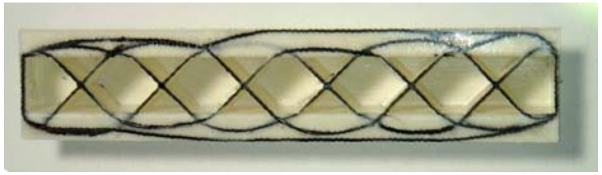
- highly oriented fibers
- Reduction of glass content from 29,9 wt.-% to 26,9 wt.-%

  (Fabric: Twintex P PP60 935 BF 4/1)

Improvement of Torsional Strength by Local Reinforcement







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

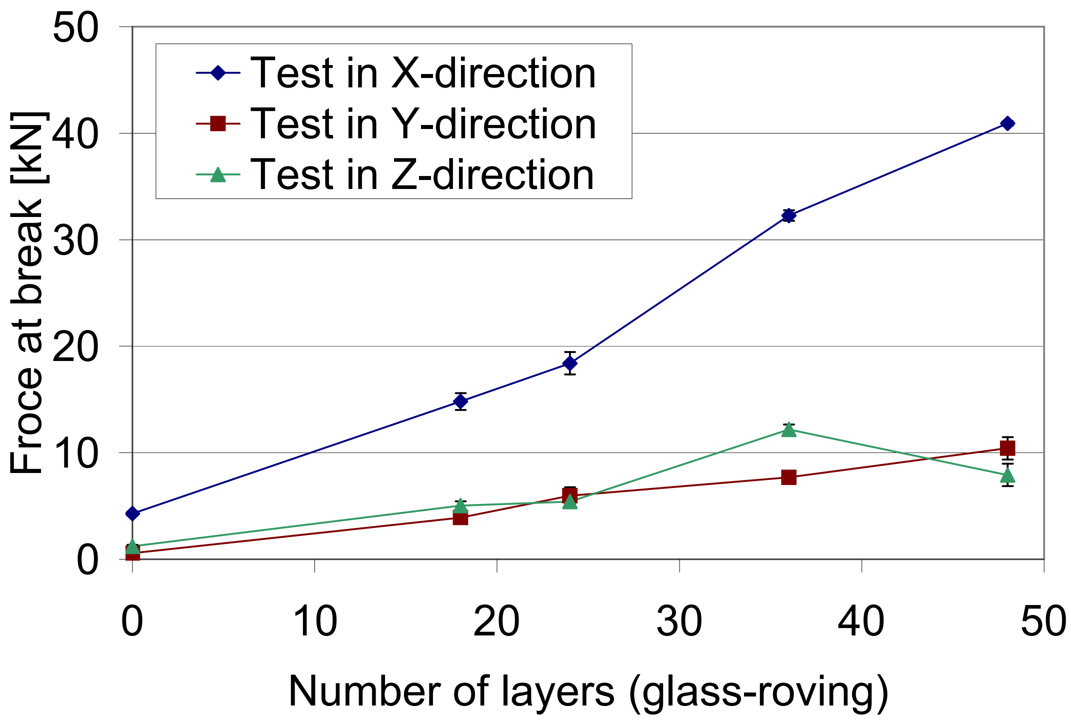
LFT-part with co-molded reinforcement

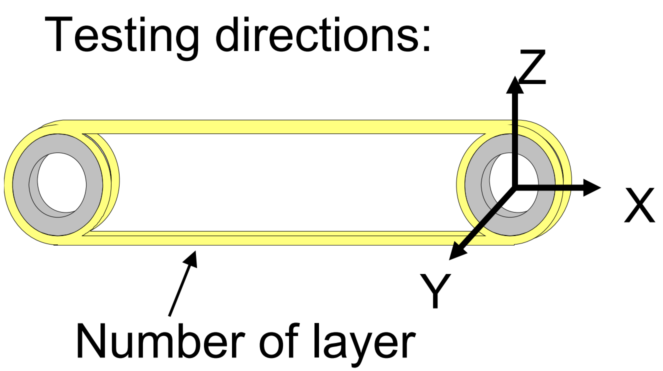
(with and without metal inserts)

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

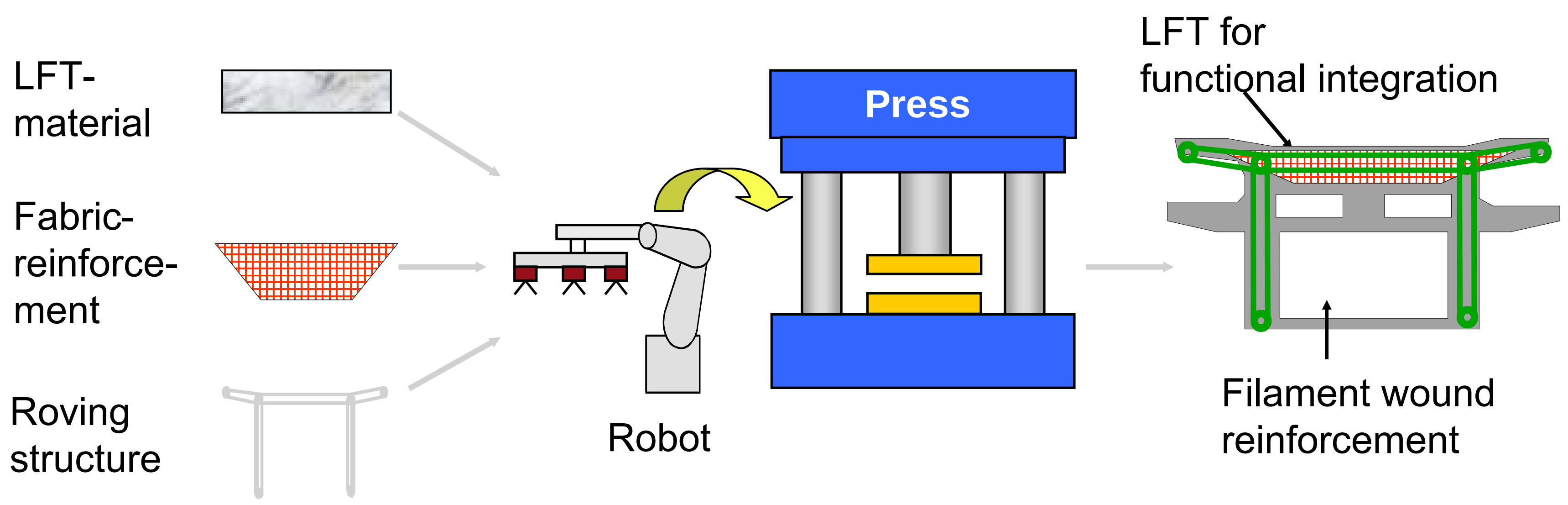




Production Concept for a Tailored LFT Composite Frontend Carrier

UD-reinforcement is preheated as a tailored Preform

LFT-material and UD-reinforcement are assembled in-line to the compression molding step



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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

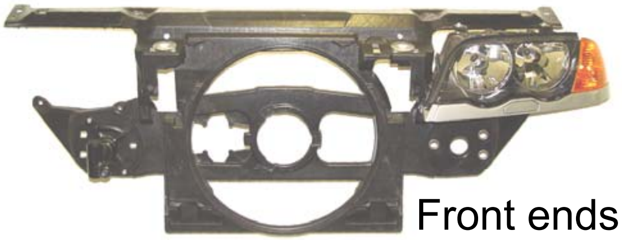
Advantages of automised local fiber placement:

- 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



Front ends

Spare wheel pan: Fabric reinforcement (GMTex)

Door modules

Source :Quadrant

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)

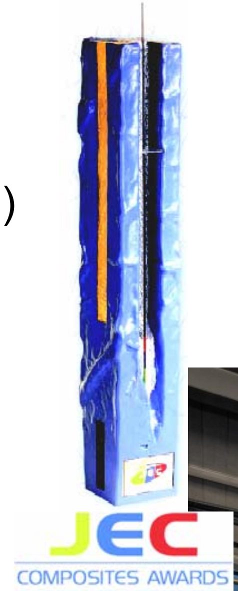
Dieffenbacher „Engineering Area“

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



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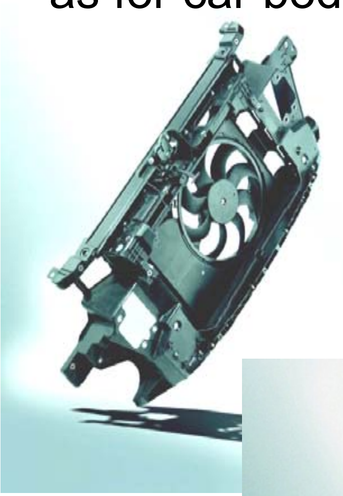
Closing Words

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.



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