MULTI-MATERIAL DESIGN – LIGHTWEIGHT DESIGN FOR ELECTRIC VEHICLES

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Outline

- Basic overview
- Introduktion: Fraunhofer System Research for Electromobility and Lightweight Design
- Demonstrator vehicle “FrECC0“
  - Part concept
  - Simulation (main system, basic materials, joints)
  - Experimental results
  - Concept for high volume production of light structural and impact-resistant applications such as battery trays
- Summary
- Outlook
Basics - History of increased weight – passenger cars

Source: EU „Super Light Car“
Concept BlueZERO – modular concept for electromobility

Source: Daimler AG
Basics - Light weight for electromobility

Multi Material Design

- Advanced LM-Spaceframe
- Hybrid Structures
- Al-Spaceframe
- Hybrid Spaceframe Constructions
- Density reduced Steels
- High Strength Steels
- Shell Constructions Utilizing New Steel Grades
- New Exterior Components
- Advanced Composites
- Composites
- Steel Unibody
- Hybrid Spaceframe Constructions
- Utilizing New Steel Grades
- Advanced Compounds
- High Strength Steels
- Density reduced Steels
- Hybrid Structures
- Steel Unibody

Source: EU „Super Light Car“
Extended networking + projects with industry

- Automotive industry
- Suppliers
- Energy industry
- Chemical industry
- Inf. / comm. industry
- Operators

Energy generation, distribution and conversion
Energy storage
Vehicle concepts
Technical system integration and socio-economic aspects
Vehicle concepts

- Conception in terms of light weight and crash resistance
- Material development
  - Composite-metal hybrid
  - High volume produce ability
- Adaptation and development of production technologies
- Manufacture of demonstrators
Technical System Integration
Fraunhofer e-Concept Car Type 0 „FrECC0“

Fraunhofer components (extract)

Energy generation, distribution and conversion
- Charging device

Energy storage:
- Battery system

Vehicle concepts:
- Safe battery integration
- Wheel hub motor with integrated power electronics
Sub-project „Safe and Reliable Battery Integration“

Content / specification

- Mass of the battery pack approx. 320 kg
- Lightweight supporting structure
- Easy-to-install battery pack
- Analysis of battery positioning with respect to vehicle dynamics
- Protection against intrusion
- Simulated load case (ECE 34): Rear collision, rigid wall 1100 kg, 10 m/s
- Realization of an undeformed space for battery safety
Basics - Principle of high-volume manufacturing process for electromobility

Manufacturing of lightweight carrying structures and impact resistant housing for high-volume production

- “One shot” manufacturing of hybrid components made from thermoplastics and tailored local reinforcements such as fabrics, tailored blanks and metals
- Thermoplastics tailor functions, design and joining
- Technology development
- Material selection and modification
- Interface optimization

Example:
Audi A6, metal hybrid roof cross member

Source: Lanxess
Basics - Principle of high volume manufacturing process for electromobility

- Pretreatment of metal inserts
- Heating of local continuous fiber structures
- Positioning of the insert structures and LFT material in the mold
- Locally-reinforced part in a molding cycle for load-bearing applications
Basics – Possibilities for local reinforcements

- Fabric reinforcements
- Unidirectional tapes
- Wound structures

Metallic inserts
Continuous fibers
Fabric reinforcement
Metallic mounting parts
Metallic inserts

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Modelling of the vehicle concept

- Analysis of battery positioning with respect to vehicle dynamics
- Carrier concept of the battery system
- Crash performance
Integration of stable and impact resistant energy storage

(1) Function integration and geometry:
- LFT PP/GF30 (molding compound)

(2) Attachments for the cross beam structure:
- Metallic inlays (IMA* and PMA***)

(3) Massive reinforcement for floor structure and wall (impact resistance):
- Organic sheet (PP/GF70***/IMA)

(4) 2-shell structure of the carrier made from thermoset CFK/GFK sandwich (RTM/PMA)

(5) EMS (electronic battery module controller)

* In-mold assembly
** Post-mold assembly
*** 47 vol% fiber content
FE shell model of the battery tray

- FE shell model (quad. elements S8R)
- Cross-beams are represented by connectors
- Floor insert is modeled as Coupling-Constraint Typ distributing
- Step 1: the weight of the battery modules (175kg) is applied by pressure loading
- Step 2: the crash load (27 kN for each half of the tray) is applied
- The crash load is applied as a point load onto one of the reference points controlling the coupling of the base insert
- Material behavior is linear-elastic
Stress distribution on loading (weight and crash load)

Maximum stress of 15.5 MPa does not lead to failure.
Maximum stress on base (around the cross ribs).

When the woven inlay is taken into account, the max. stress decreases to 14.3 MPa.
Investigations on

- Quasi static tensile behavior with regard to the interface between the LFT and the reinforcements

- **5-material combination**
  - LFT-PP/GF30 (base material)
  - LFT-PP/GF30 + wire mesh 5/1 stainless steel
  - LFT-PP/GF30 + wire mesh 2/1 stainless steel
  - LFT-PP/GF30 + wire mesh 0.5/0.2 stainless steel
  - LFT-PP/GF30 + organic sheet (OG)

- **Sample geometry:**
  - prismatic, 250 x 25 x 5 mm³
Sample production – part 1

Gravimetric dosing of raw materials

In-line compounding

Feeding of glass fibers

Mixing extruder

Pre-treatment of metal inlays

Transfer of reinforcements and LFT strands into the mold

Co-molding process in a hydraulic press

Press
Experimental results – reinforcements

Tensile test (quasi static)

![Tensile Test - Force / Displacement](image.png)

- LFT-PP/GF30
- PP/GF30 + 5/1 s.steel
- PP/GF30 + 1/0,5 s.steel
- PP/GF30 + 0,5/0,2 s.steel
- PP/GF30 + OG

Displacement s in mm vs. Force F in kN
Experimental results – reinforcements

Tensile test (quasi static)
Experimental results – reinforcements

Tensile test (quasi static)
Experimental results – reinforcements

Tensile test – quasi static

- Decreased elongation at the LFT side in region of yield point
  ➔ Delamination

- Behavior of PPGF40 + OG
  ➔ Assumption: too less matrix material in the region of the interface between LFT and organic sheet reinforcement
Experimental investigation – overview part 2

Investigations on

- the strength of the interface between the LFT and the steel (without mechanical interlocking)
  - influence of the surface pretreatment
- the strength of the joint with mechanical interlocking
  - influence of the geometry of the interlocking

pull-out specimen

long-fiber reinforced thermoplastic (PA6.6 GF40)

with and without mechanical interlocking

steel (HC420 LA)
Sample production – part 2

- Gravimetric dosing of raw materials
- Feeding of glass fibers
- Mixing extruder
- portioning of LFT strands
- Transfer of metal inlay and LFT strands into the mold
- Pre-treatment of metal inlays
- Final test plate

Co-molding process in a hydraulic press
Results of the investigation on adhesion

Influence of pre-treatments on the metal inlay and press parameters to increase the adhesion effects between LFT (PA6.6 GF40) and metal:

- Pressure by co-molding LFT and metal inlay was varied from 180 to 250 bars.
- Preliminary degreasing using isopropanol (wet chemical method) of the metal inlays in an ultrasonic bath for 10 minutes.
- Investigation of different surface treatment methods to increase the roughness of the metal inlay.

**Etching**
- Nitric acid or sulfuric acid
- Etch time was varied between 5 and 120 sec
- Acid concentration was varied between 5 and 30%

**Abrasive blasting**
- Corundum F80 (fine, 185 μm) or Corundum F24 (coarse, 710 μm)
Results of the investigation on adhesion

Influence of co-molding pressure (sulfuric acid)

Influence of pre-treatment methods
Results of the investigation on surface roughness of metallic inlay

Examples for interferometry analysis of the surface topography:

**Etching**
*(sulfuric / nitric acid)*

- 10 sec
- Ra = 1.02 μm
- 10 sec
- Ra = 1.75 μm
- F80 (fine)
- Ra = 1.75 μm
- F24 (coarse)
- Ra = 2.59 μm

**Abrasives blasting**
*(corundum)*

- 10 sec
- Ra = 1.75 μm
Results of the investigation on mechanical interlocking

- Increasing the number and the size increases pull-out force.
- The variation of shape does not have a significant influence on the strength.
- The reduction of the inlay thickness from 2mm to 1mm reduces the strength.
Simulation of the tensile test across the rolling direction

Improvement study of intrinsic metal inlay
Simulation of the tensile test across the rolling direction

Assembly scenario of the battery tray

Intrinsic metallic inlay
Exterior joiner
Simulation of the tensile test across the rolling direction

Experimental set-up

- Test sample
- Clamping frame
- Desk
- Applied load in both directions
- Connector plate
- Base
Simulation of the tensile test across the rolling direction

FE model

Fixation of knots

Top layer - LFT (PPGF30)

Intrinsic and outer metal sheets for load distribution

„Organic sheet“ – 1 mm Glass fiber fabric with PP matrix
Simulation of the tensile test across the rolling direction

Simulation result

- First failure at changeover between base material and metal inlay
- Second failure occurs close to the fixation

Graph showing:
- Reaction force vs. displacement
- LFT-PP/GF30 (Base material)
- LFT-PP/GF30 + Organic sheet (base material)
Verification of tensile test across the rolling direction

Tensile testing result

First failure will occur at the LFT material

Final failure of the organic sheet

Slide 34
Simulation of tensile test across the rolling direction

Results

- **Failure was mainly influenced by the base material**
  - Co-molded organic sheet with PP/GF30 increased E-Modulus by a factor of 10 and failure load by a factor of 2 due to supporting effect
  - Organic sheet withstand higher stress loads
  - Changes of the design of the metallic inlays (inlay smaller than exterior metal sheet) will lower stress peaks

- **Simulation provide qualitative answers**
  - Characterizations of the materials such as LFT and fabric reinforcements are currently not complete
  - Calculated values and simplified models are used for the first draft

- **Outlook and experiments**
  - Static and fatigue tests are ongoing, taking into account the influence of temperature
Summary

- The combination of local reinforcements and metallic components in one part has a high potential.
- The chosen materials and process technologies can be used for high volume production.
- The chosen materials achieve the targets for quasi-static loads and impact.
- The simulation models for materials and material joints agree the experiments. More complex question will require additional material characterisations and adjustments of the material models.
- Simulations show potential design improvements such as cross beam structures and load distribution into the wall.
Outlook

- Final creep and fatigue results have to be determined
- Improvements of simulation models such as image of the anisotropy of LFT materials and interface behavior between LFT and reinforcements
- Improvements to the joining technology
- Use of unidirectional reinforcements such as tailored blanks
Outlook – tailored blank

Unidirectional Tape

Tailored Blank made by RELAY Station

Thermoform 3D Part

Consolidate Tailored Blank into Solid Laminate

Source: Fiberforge
Outlook – tailored blank

- Development of a fully automated manufacturing cell for thermoplastic structural applications
- Cycle times for high volume production is given
Members and partners

Members:

- BASF Future Business GmbH
- BMW
- Bosch Rexroth AG
- Daimler AG
- Deutsche Accumotive GmbH & Co KG
- Evonik Degussa GmbH
- Fräger GmbH
- GAIA Akkumulatorenwerke GmbH
- Göppel Bus GmbH
- HOPPECKE Batterien GmbH & Co. KG
- H.C. Starck GmbH
- Johnson Controls SAFT
- Leclanche Lithium GmbH
- Li-Tec Battery GmbH
- Merck KGaA
- SB LiMotive GmbH
- Süd Chemie AG
- ...
Further information

Information web page:
www.electromobility.fraunhofer.de

Information web page:

Forum Elektromobilität / Verein Forum Elektromobilität e.V.:
www.forum-elektromobilitaet.de
Thanks for your attention!