Co-compression molding of tailored continuous-fiber-inserts and inline-compounded long-fiber-thermoplastics

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The holistic consideration of materials, production processes and methods in design, simulation and characterization requires new interdisciplinary approaches to realize an intelligent Multi-Material-Design.
Contents

- Principles of combining continuous-fiber and discontinuous-fiber materials
- Case-study – Underbody shielding
  - Introduction of the study
  - Basic flow-study for improved understanding of mold filling
  - Manufacturing and analysis of a tailored underbody shield demonstrator
- Conclusion
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Principles of combining continuous-fiber and discontinuous-fiber materials

Challenges in applying continuous-fiber semi-finished products

- Technical challenges
  - Continuous-fiber-reinforced semi-finished products such as wovens or laminates are formed into shell-like structures
  - Limited drapeability and flowability of this material class 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
Principles of combining continuous-fiber and discontinuous-fiber materials

Benefits of continuous-fiber-reinforcements

- Semi-finished products contain fiber volumes of up to 60-70 %
  - High mass-specific part properties achievable
- Part designs can be 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
Principles of combining continuous-fiber and discontinuous-fiber materials

Requirements for realizing function-integrated, technical applications

- Consideration of hybrid structures incorporating continuous- and discontinuous-fiber materials to overcome the technical and economical challenges introduced priorly.
Principles of combining continuous-fiber and discontinuous-fiber materials

Design space and technical requirements
→ Specified installation space and preliminary design based on structural requirements and boundary conditions

Structural analysis
→ Determination of main load paths
→ Definition of load bearing and non bearing sections

Part optimization
→ Structural and topological optimization algorithms to implement local continuous-fiber-reinforcements

Optimized part design
→ Final design including local reinforcements in main load paths
Principles of combining continuous-fiber and discontinuous-fiber materials

Approach for realizing function-integrated parts

- Combination of local continuous-fiber-reinforcements and established high-volume process technologies
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Case study – Underbody shielding

Introduction of the study

- Requirements for underbody shielding:
  - Protect inner car components against stone impact
  - Reduce air-drag and hence fuel consumption
  - Reduce noise

- Case study objectives:
  - Achieve an significant increase in impact performance
    - Not within the scope of this presentation
  - Show the feasibility of co-compression-molding UD-tapes and D-LFT to create complex structures
  - Demonstrate high potential of function-integrated components made from discontinuous- and continuous-fiber materials
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Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

Materials:

- **D-LFT**
  → PP/GF30: Polypropylene reinforced by 30 mass-% discontinuous glass-fibers

- **UD-Tapes**
  → PP/GF70: Polypropylene reinforced by 70 mass-% continuous glass-fibers

Semi-finished products made from UD-Tape:

- Tape fabrics
- Tape laminates

Source: Fiberforge
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Equipment and process parameters:
  - Plaque tool
    - 400 mm x 400 mm, shear edge, no insert fixation, 3 mm plaque thickness
  - Tool temperature: 75 °C
  - Hydraulic press
    - Press force and dwell time: 3.200 kN, 45 s
  - IR oven for heating of continuous-fiber inserts
    - Ceramic IR heaters @ 350 °C
    - Heating time dependent on insert wall thickness
      - 0.5 mm (un-/consolidated) → 30 s / 30 s
      - 1.5 mm (un-/consolidated) → 140 s / 60 s
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

Terminology:

The following slides do only show a representative excerpt of the performed investigation.

Dimensions:

- Major flow direction of LFT
- Secondary flow direction of LFT
- D-LFT
- Tape material (tape fabric and tape laminate)
- Tape material (tape fabric and tape laminate)

Dimensions:

- 200 mm
- 100 mm
- 380 mm
- 50 mm
- 380 mm
- 130 mm
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Test configurations:
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Summarized results for inserts of 0.5 mm thickness:
  1. Tool temperature of 75 °C (initial insert temperature: 200 °C) causes rapid insert cooling and sticking-effect in the insert/tool interface
  - Even challenging test configurations can be achieved without fixation
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Summarized results for inserts of 0.5 mm thickness:
  2. However, if D-LFT causes insert movement, severe insert damage occurs
     - A strong correlation of insert orientation relative to D-LFT flow direction is apparent
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Summarized results for inserts of 0.5 mm thickness:
  3. An initial overlap of the D-LFT strand and tape insert significantly reduces the risk of localized insert damage due to penetration effects. Thin tape fabrics and thin UD laminates are most prone to penetration effects.
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Summarized results for inserts of 0.5 mm thickness:
  - Qualitative evaluation of co-molding tape inserts with D-LFT (w/o insert fixation)
Summarized results for inserts of 1.5 mm thickness:

1. Thicker inserts show increased risk of insert movement and damage, once D-LFT hits the insert during mold filling
   - Main reasons are insert height (obstacle) and increased amount of inner heat in the insert (slowing down insert cooling)
Case study – Underbody shielding
Basic flow-study for improved understanding of mold filling

- Summarized results for inserts of 1.5 mm thickness:
  2. More pronounced difference between consolidated and unconsolidated material becomes visible
  - Increased risk of D-LFT being pressed in-between plies
Case study – Underbody shielding
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- Summarized results for inserts of 1.5 mm thickness:
  - Qualitative evaluation of co-molding tape inserts with D-LFT (w/o insert fixation)
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Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Part specifications:
  - Material: PP/GF30
  - Wall thickness: approx. 2.5 mm
  - Mass: approx. 2.8 kg
  - Dimensions: 775 x 1,114 mm²

The mold used is a standard D-LFT production tool and hence not optimized for the specific requirements of co-compression molding with continuous-fiber inserts.
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Material components of the demonstrator
  - Areal impact protection made from tape fabric (0.5 mm)
  - Local tailored tape laminates (0.75 mm)
  - Remaining structure as well as complex geometries (e.g. ribs) are made from D-LFT (PP/GF20)
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Manufacturing and analysis of a tailored underbody shield demonstrator

D-LFT

Tailored tape laminate

Press cycle of 30 sec (tool temp. ≈ 45°C)

Modified underbody shield

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Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Analysis of the underbody shield demonstrator to determine challenges in co-compression molding of tape inserts and D-LFT in complex geometries

- Preparation of microsections

- Preparation of SEM pictures

- CT-scanning
  (DATA NOT READY YET, WILL BE IMPLEMENTED PRIOR TO SPE ACCE)

→ Positions of samples in the analysis process
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Degree of deformation of continuous-fiber inserts must be taken into account during part design to avoid imperfectly shaped sections
- For complex geometries improved tool/handling/preforming technologies become key
- The standard D-LFT tool used in this study contained a high number of ribbings next to each other
- This, in combination with the manual handling procedure increased the risk for local imperfections in draping.
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Highly complex rib structures can be filled by the D-LFT even through continuous-fiber inserts of 1.25 mm thickness

- Current investigations focus on the quantitative determination of filter effects caused by the continuous-fiber inserts
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Penetration of thin tape fabrics (here: 0.5 mm) is concentrated in areas of tape strip crossings.
- Fibers in thin tape laminates (not shown here) with pure UD orientation tend to be pushed apart by the D-LFT perpendicular to the 0° direction of fibers.
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

Co-compression molding of D-LFT and continuous-fiber inserts can result in severe local insert damage.

- The presented demonstrator was a feasibility study based on a standard D-LFT mold. No measures could be taken for process optimization.
- Adjustments such as automated handling, insert fixation, tool heating etc. could improve results significantly.
Case study – Underbody shielding
Manufacturing and analysis of a tailored underbody shield demonstrator

- Despite the discussed challenges, the feasibility study did show that in most areas of the demonstrator, severe insert damage was avoided even without complex processing technologies.
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Conclusion

- A basic flow-study was conducted to create an improved understanding of the limits in co-compression molding of D-LFT and continuous-fiber inserts.
- It was shown that even without insert fixation even complex combinations are feasible.
- A complex high-volume (former) serial production part was modified by implementing inserts made from UD-tapes.
- Even with numerous limitations (low tool temp., manual insert and D-LFT handling, no insert fixation etc.) the feasibility of manufacturing highly-complex parts using co-compression molding of D-LFT and continuous-fiber inserts was shown.
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