Opportunities and Challenges of Composites Forming Simulation for Digital Product Development

SPE ACCE 2023

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Outline

1. Company introduction

2. SimuDrape

3. Industrial use cases

4. Summary and conclusion

Outline

1. **Company introduction**
2. SimuDrape
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1. Company introduction

Opportunities through advanced simulation for composites

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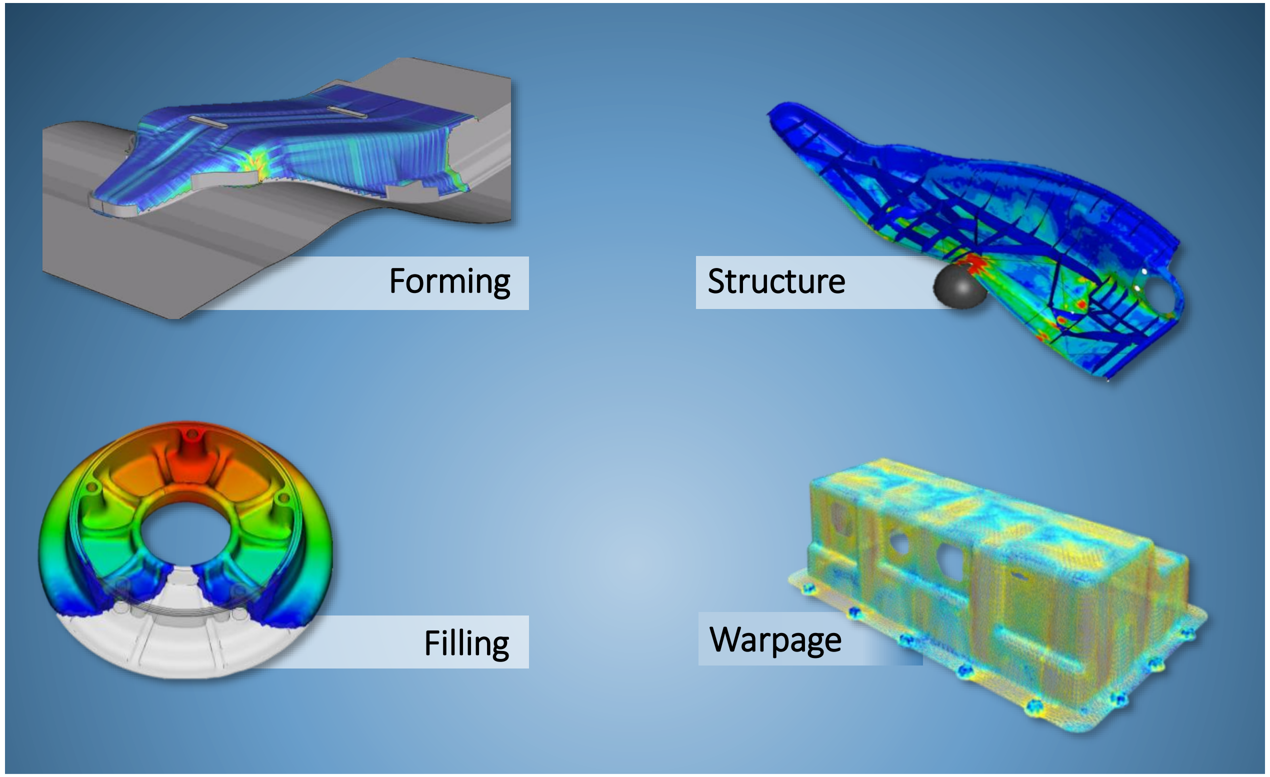
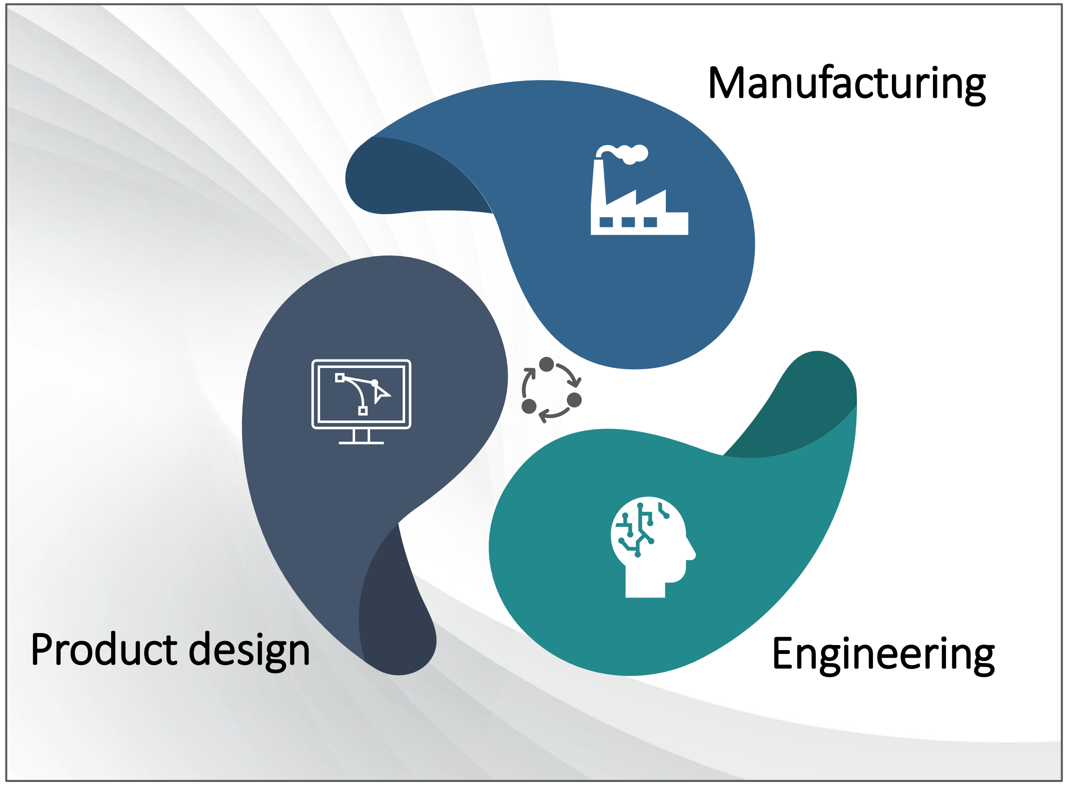


Increased material efficiency + Increased manufacturing efficiency

= Sustainable products and manufacturing processes



Our goal is to enable efficient products as well as efficient manufacturing through advanced simulation.

Integrated process simulation enables cost- & time-efficient product development cycles.

1. Company introduction

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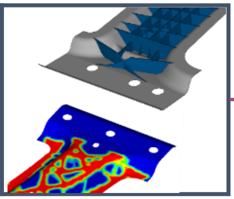
Digital Composites Engineering

Benefits of the SIMUTENCE virtual process chain

Project journey example

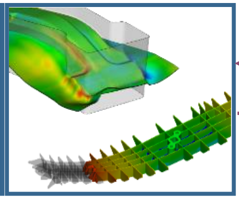
Design and optimization
Material and process specific product design



Conceptual studies ↑↓

Geometry, layup and load cases

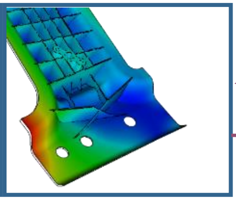
Molding simulation
Prediction of manufacturability and manufacturing effects



Feasibility studies ↑↓

Fibre orientation, FVC, degree of cure

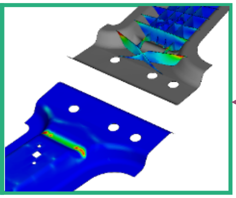
Warpage simulation
Prediction of solidification, warpage and residual stresses

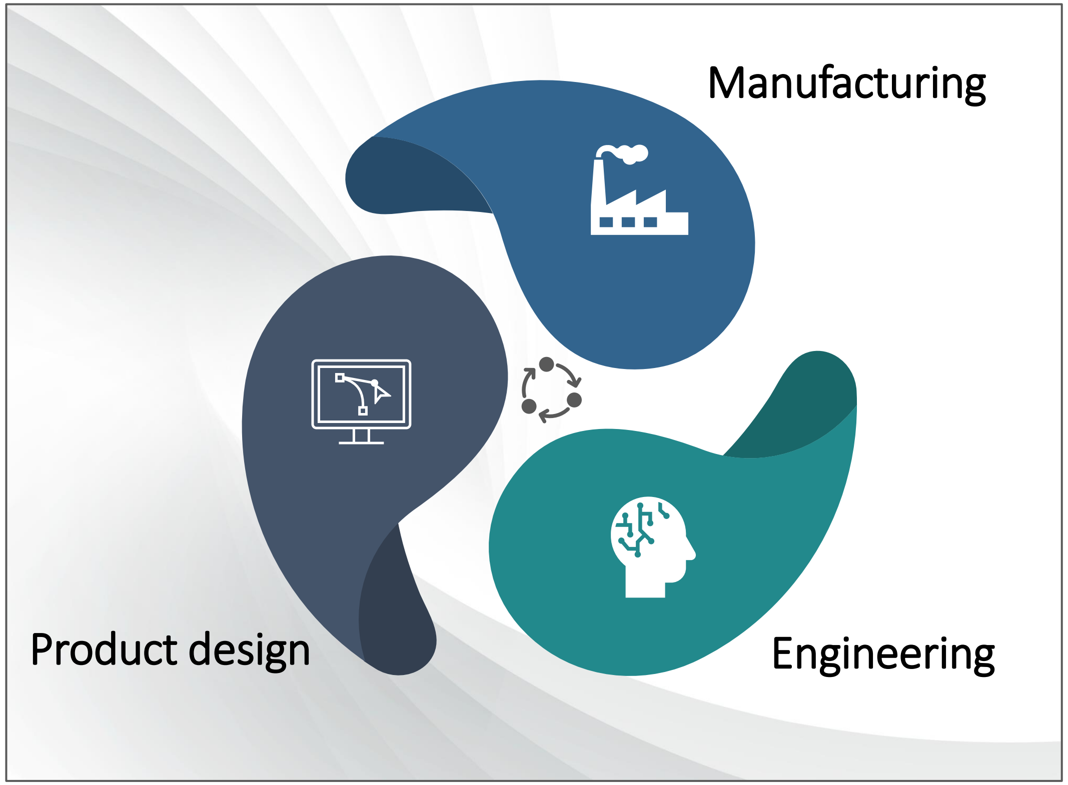


Performance validation ↑↓

Stresses, strains, weak spots?!

Structural simulation
Analysis of structural part performance





Our goal is to enable efficient products as well as efficient manufacturing through advanced simulation.

Integrated process simulation enables cost- & time-efficient product development cycles.

1. Company introduction

Manufacturing process technologies

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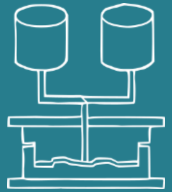
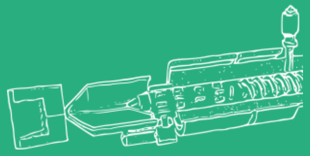
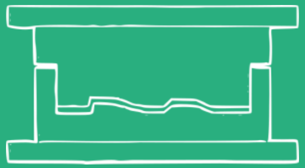
Resin transfer molding



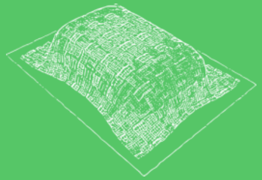
Thermoset injection molding



LFT compression molding



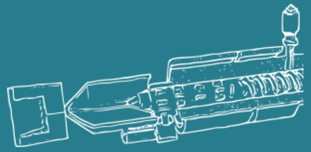
Textile draping (preforming)



SMC & GMT compression molding

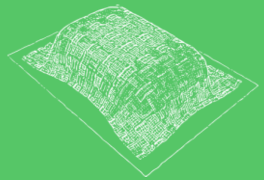
State of the art → **In-house SIMUTENCE solutions**

Thermoplastic injection molding

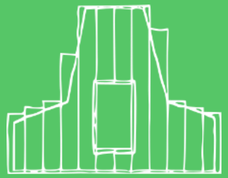


3D skeleton winding

Membrane forming



Press forming
UD-tape, organosheet & prepreg



Hybrids
LFT & UD-tape

We support you with product and process design for process technologies relevant for large and medium scale production

Opportunities for collaboration

Training & consulting

- Identification of suitable engineering and simulation **strategies**
- **Consulting and support** on strategies for materials characterization, product development, and part manufacturing

Engineering services

- **Product development** as a service
- **Virtual design** and **optimization** of manufacturing processes and parts
- Prediction of **manufacturing effects**
- Materials **characterization** and **modeling**

Software add-ons

- Tailored **software add-ons** for enhancing established simulation software
- Self-developed **simulation approaches** that go beyond the state of the art
- **Customized solutions** for your challenge

We tailor our collaboration to your specific challenge

1. Company introduction

International R&D network

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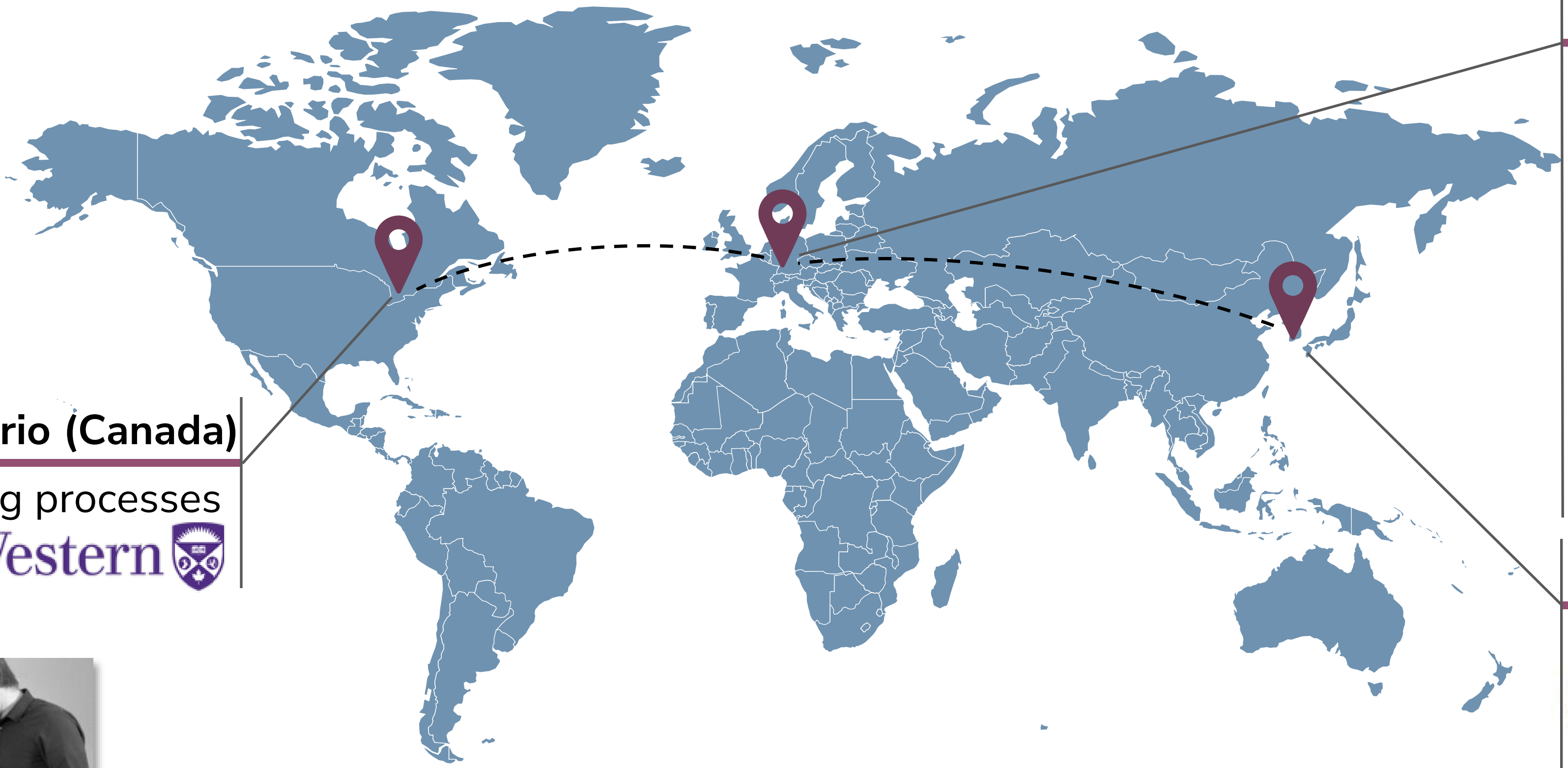
Digital Composites Engineering

Founded in **2019** → **Spin-off** from the Karlsruhe Institute of Technology (KIT) → Located in **Karlsruhe (Germany)**



Karlsruhe (Germany)
Method development
Material characterization
Manufacturing processes
KIT – Karlsruher Institut für Technologie
FAST – Institute of Vehicle System Technology
IAM – Institut für Angewandte Materialien
Fraunhofer ICT

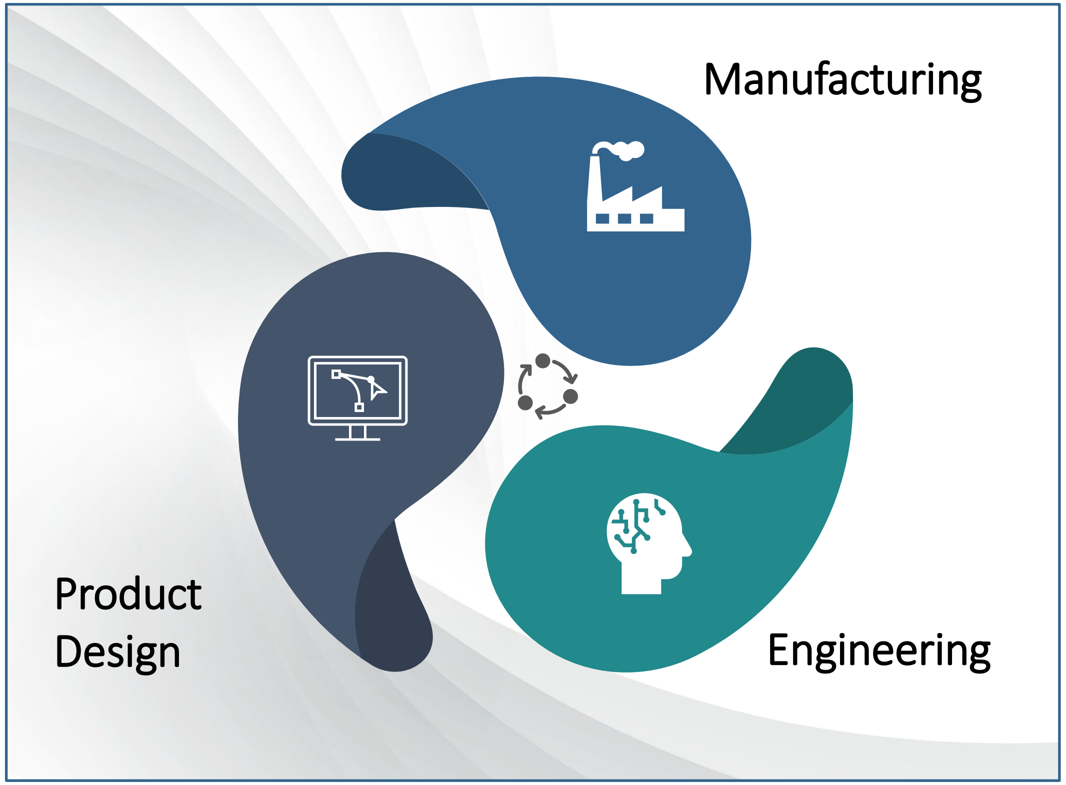
London, Ontario (Canada)
Manufacturing processes
Western

Ulsan (Republic of Korea)
Manufacturing
UNIST – Ulsan National Institute of Science and Technology

Our agile team and excellent global research network can provide you with the latest available solutions!

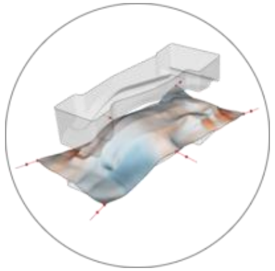
2. SimuDrape

Key features in a nutshell

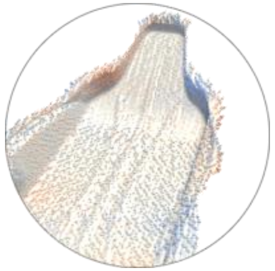


Composites forming simulation enables the virtual design and optimization of manufacturing processes and the prediction of manufacturing effects.

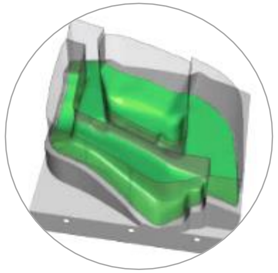
Key features



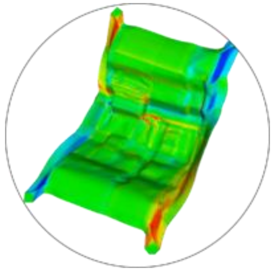
Gripper modeling
Model and optimize local gripping including gripper kinematics.



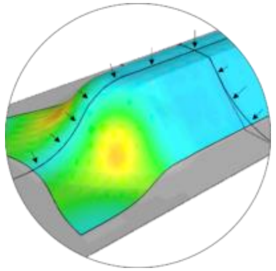
Fiber orientation prediction
Predict the local fiber orientation to establish a virtual process chain.



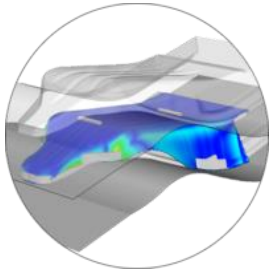
Tailoring determination
Determine a blank for near-net shaped forming to reduce material waste.



Defect prediction
Predict local defects such as wrinkling behavior to validate manufacturability.



Membrane forming
Model membrane forming processes using hyperelastic material modeling.



Sequential forming
Model sequential forming processes with an arbitrary number of stamps.

Integrated process simulation enables cost- & time-efficient product development cycles.

2. SimuDrape

Working principle

SimuDrape

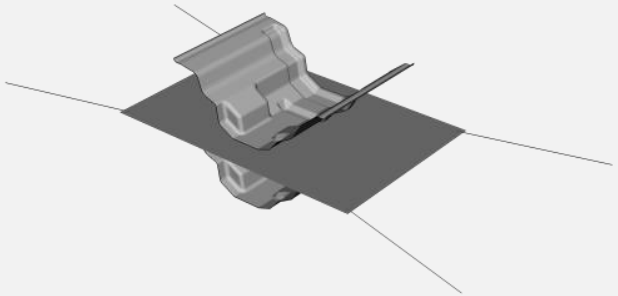
SimuChain

Transfer of manufacturing effects to downstream FEA

Pre-Processing
(ABAQUS/CAE + SimuDrape)

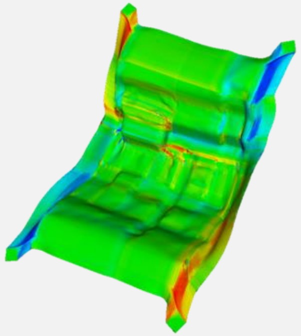
ImportTools
Automatic assembly of the die and stamps or membranes and assignment of boundary conditions.

CreateModel
Automatic stacking of the laminate and assignment of material(s).



Analysis
(ABAQUS/Explicit+ SimuDrape)

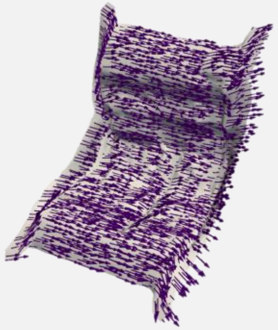
ABAQUS solver API
VUMAT, VUGENS, VUINTERACTION
The ABAQUS API is adopted to model the specificities for composites in forming processes.



Post-Processing
(ABAQUS/CAE + SimuDrape)

ExportOri
Export of fiber orientation, fiber volume content and further state variables to a neutral exchange format (VTK).

TailorBlank
Determine the tailoring of a blank for near-net shaped forming.



SimuDrape covers all steps required for modeling and analysis of composites forming.

Outline

1. Company introduction
2. SimuDrape
3. **Industrial use cases**
4. Summary and conclusion

3. Industrial use cases

Virtual design of thermoforming processes

Project goals

- Creation of a standardized process for the virtual design of thermoforming processes with tape laminates
- Application to an undercover protection (skid plate) for a battery electric vehicle (BEV)

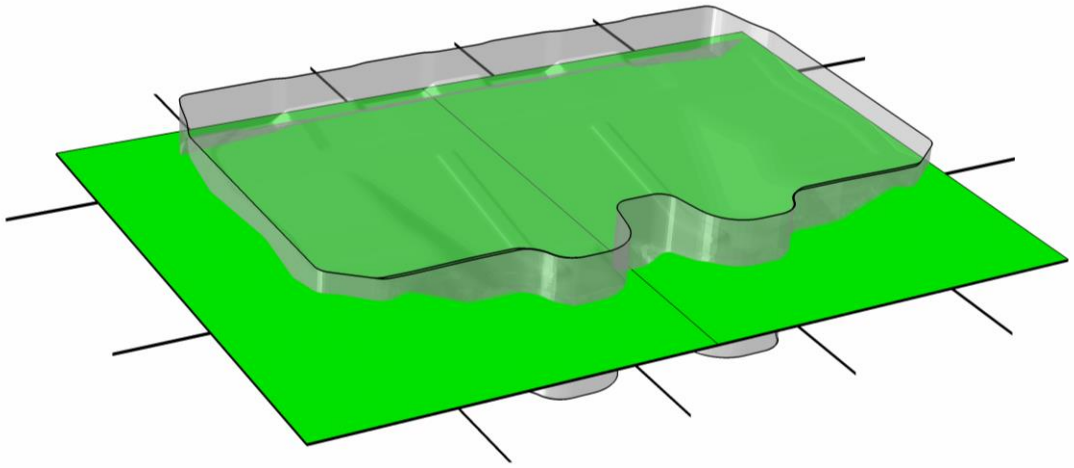
Project partners

TOYOTA

AERLYTE

Western UNIVERSITY · CANADA

in cooperation with Fraunhofer



Thermoforming simulation of an undercover protection (skid plate) for a battery electric vehicle (BEV)

3. Industrial use cases

Virtual design of thermoforming processes

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1 Materials characterization and analysis
- Shearing, bending, slipping
- Thermal and kinetical behavior

Preparation

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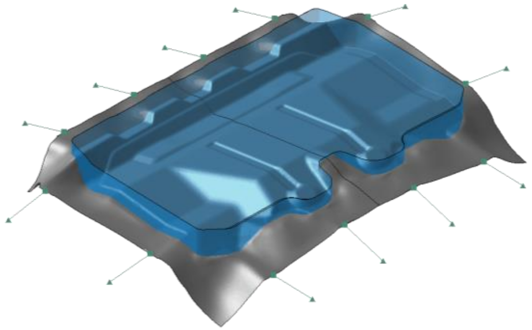
2 Part analysis & tool definition
- CAD | Part-as-molded
- Analysis | Tip angle & center of gravity
- CAD | Tool concept and surfaces for forming simulation
- Analysis | Laminate loading plane

3 Forming simulation & optimization
- FEM | Model setup, test, and optimization
- FEM | Analysis of manufacturability and optimization of processing parameters
- Analysis | Tailored blank size & maximum mold block size

Iterative execution



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4 Reporting & closing
- Standardized reporting
- Transfer of CAD (part as-molded & gripper setup)

Finalization

3. Industrial use cases

Virtual design of thermoforming processes

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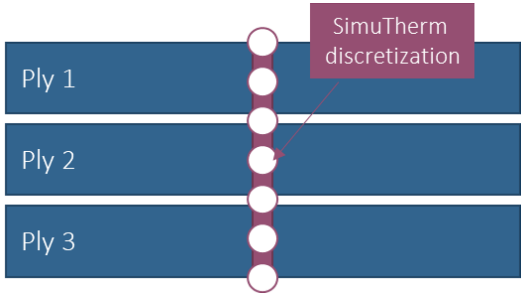
1 Materials analysis

Step 1.1: SimuTherm model setup

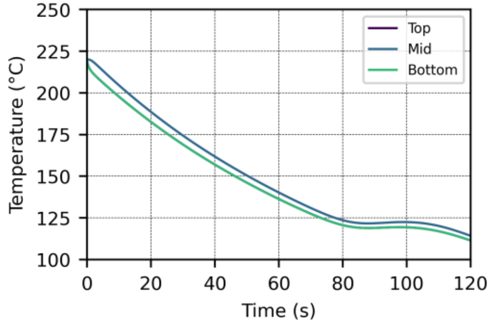
- 1D thermal analysis through the Simutence tool SimuTherm
- Predictions almost in real-time
- Determination of the processing window using through-thickness prediction of temperature and crystallization



Schematic of the SimuTherm discretization

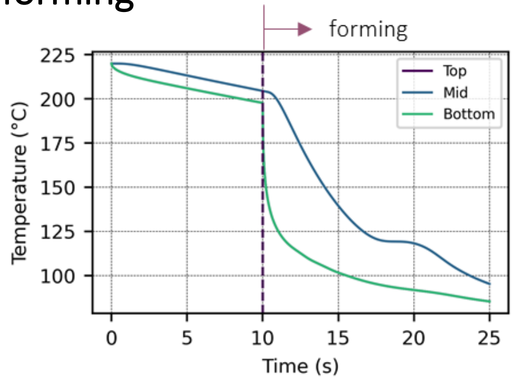
Step 1.2: Analysis of cooling without/prior to forming

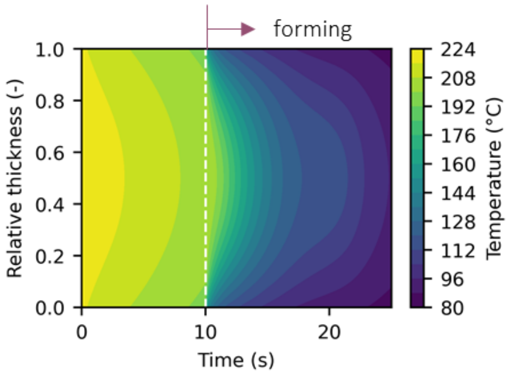
- Modeling of cooling of the laminate after release from the oven:
  - Quiescent environment (free convection)
  - Transfer (Forced convection)
- Determination of the initial forming temperature as a function of transfer time

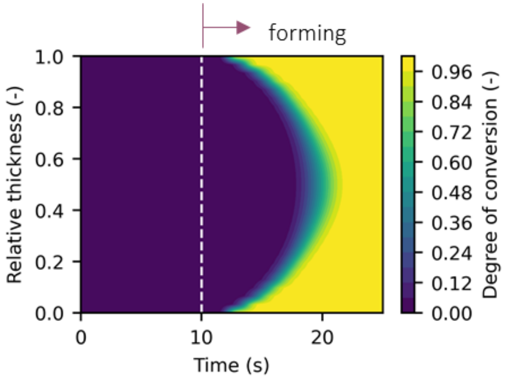


Step 1.3 Analysis of cooling including forming

- Modeling of transfer from the oven to the mold and forming
- Both-sided pressurized mold contact is modeled during forming
- Processing window and required dwell time determined through crystallization







Virtual design of thermoforming processes

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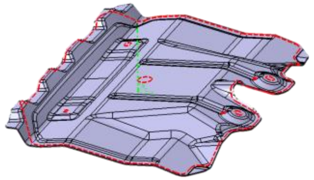
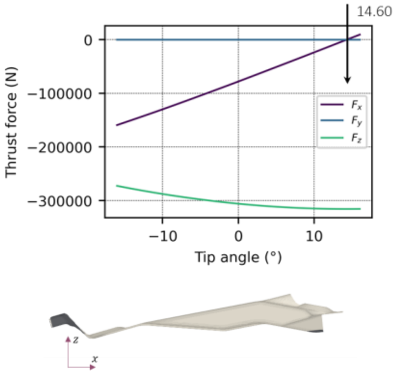
2 Part analysis & tool definition

Step 2.1: Tip angle determination

- Part rotation by the tip angle enables the reduction of thrust forces during forming



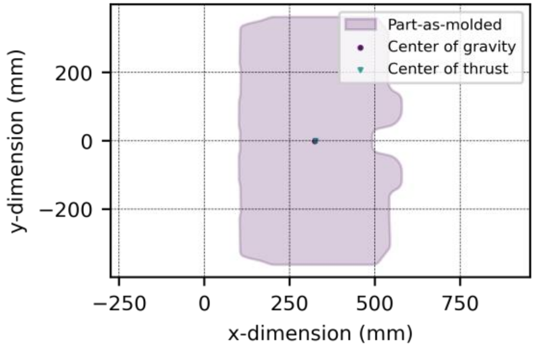
CAD data of the part as-molded



Part rotation to mitigate thrust forces

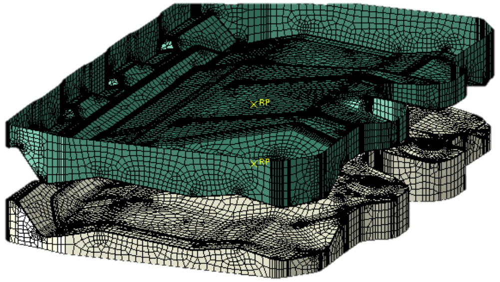
Step 2.2: Determination of the center of gravity

- The mounting position of the mold in the press is an essential information for the shop floor
- The center of gravity as well as the center of thrust moments is evaluated



Step 2.3: Derivation of the tool surfaces

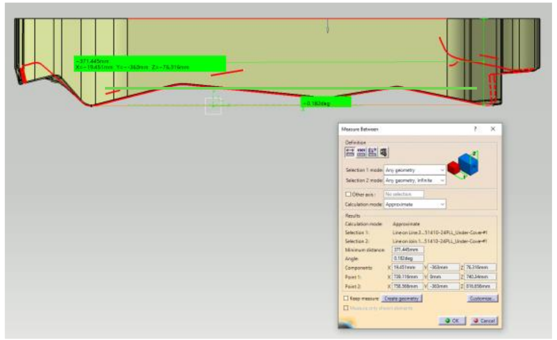
- Forming simulation models the tools as rigid surfaces
- CAD for the part as-molded is created to derive the surfaces of the tools



Discretized tool data derived upon the part as-molded

Step 2.4: Definition of the laminate loading plane

- The laminate loading plane is optimized to reduce the required deep drawing length



Virtual design of thermoforming processes

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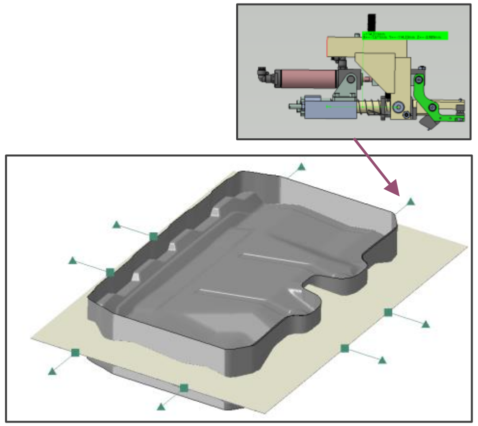
3 Forming simulation & optimization

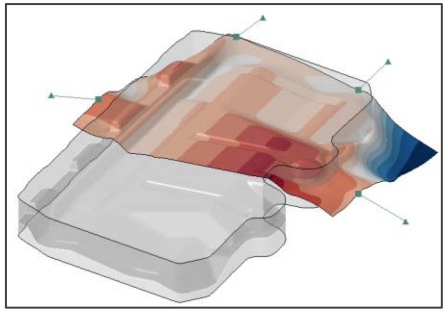
Step 3.1: Model setup with SimuDrape

- SimuDrape is used for fully automatized model setup
- Emphasis on accurate gripper modeling including its kinematics through so-called translator elements



Step 3.2: Model tests with reduced complexity

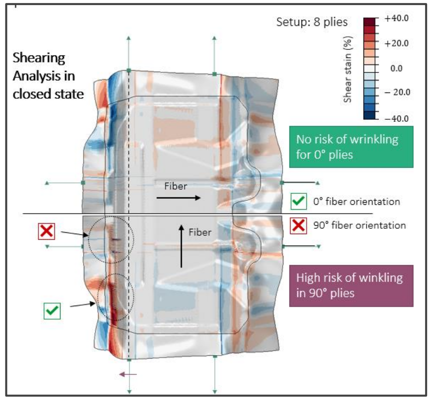
- Model tests with a reduced number of plies and coarse discretization
- Validation of the model setup
- Short lead time for first analysis of manufacturability



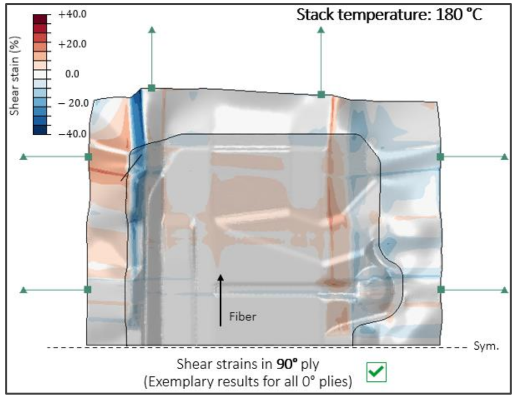
Step 3.3: Optimization of manufacturability

- Manufacturing without defects requires that no wrinkles and localized shearing occurs
- The results of forming simulation are analyzed layer-by-layer to investigate the manufacturing quality

- Forming simulation enables to vary and optimize virtually:
  - Geometry of the part and the part as-molded
  - Gripping (location, force, kinematics)
  - Forming temperature



Evaluation of manufacturability.



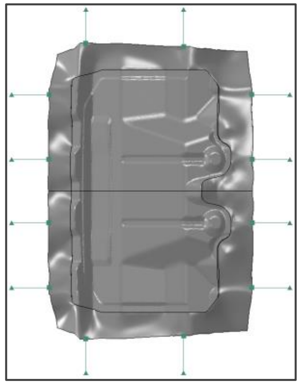
Optimized manufacturable setup.

3. Industrial use cases

Virtual design of thermoforming processes

3 Forming simulation & optimization

Step 3.4: Tailored blank for near-net shaped forming



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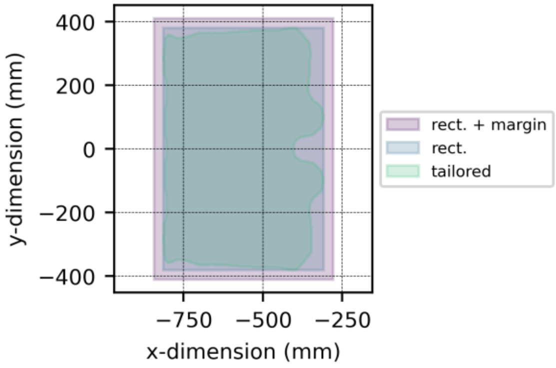
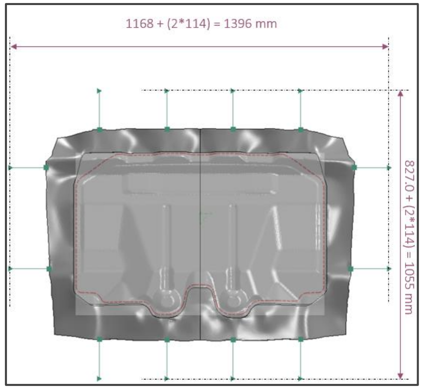


Step 3.5: Determination of the maximum mold block size

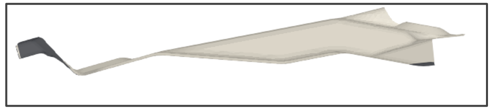
- The gripper design and the elongation of grippers influences the maximum block size of the mold
- The maximum block size is an essential information for the mold make to ensure manufacturing as designed

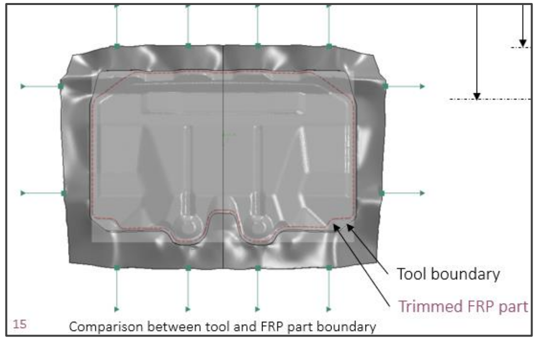


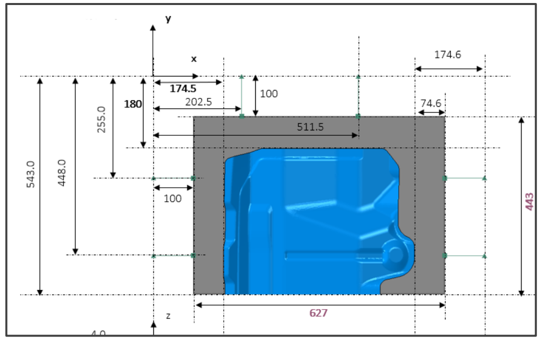
4 Reporting & closing

Combined results and information for mold manufacturing

- The gained information on part as-molded, gripper positions, and maximum block size is condensed and transferred to the mold maker







3. Industrial use cases

Virtual process chain for impact simulation

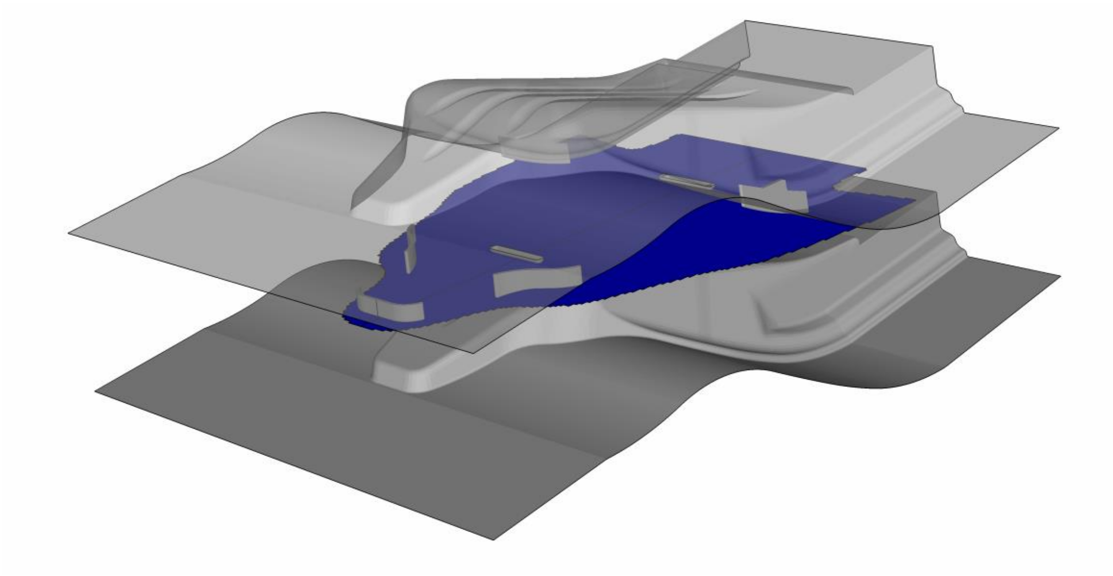
Project goals

- Benchmark of existing materials characterization and modeling approaches for a PLA basalt tape
- Creation of a virtual process chain for impact simulation
- Benchmark of a virtual process chain to consider the local fiber orientation in impact simulation

Project partners

Fraunhofer ICT

Fraunhofer IWM



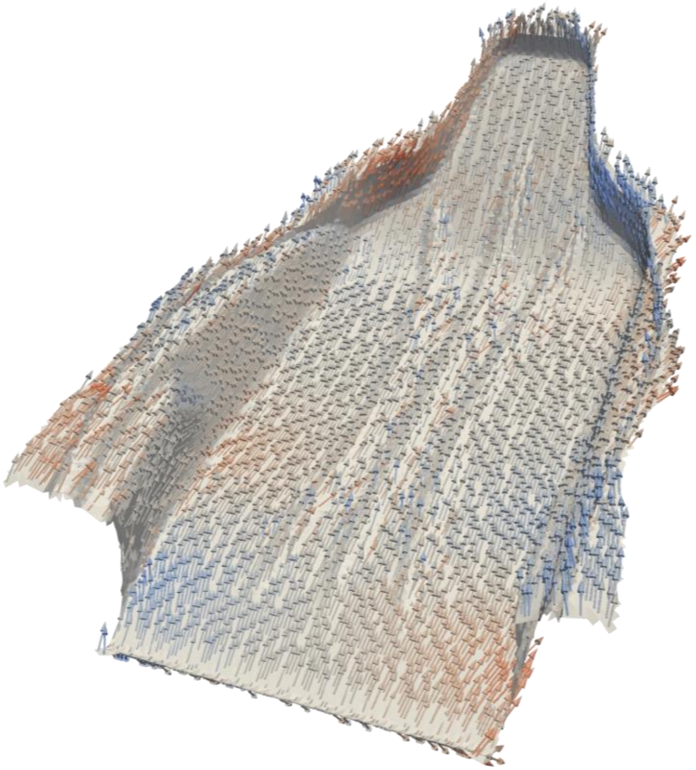
Thermoforming simulation of a seatback structure including a local predraping

3. Industrial use cases

Virtual process chain for impact simulation

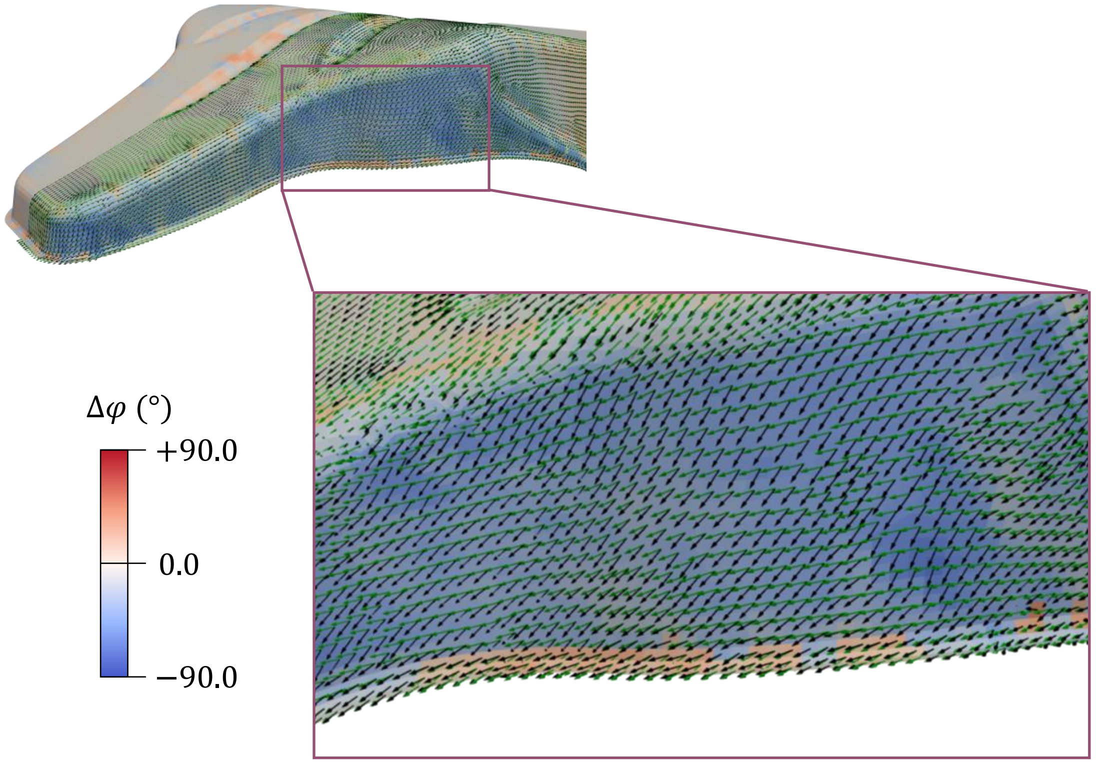
Fiber orientation prediction

Thermoforming simulation predicts the local fiber orientation layer by layer.



Comparison of predicted and ideal fiber orientation

Significant deviation between the predicted (black) and the ideal (green) fiber orientation in double-curved areas.

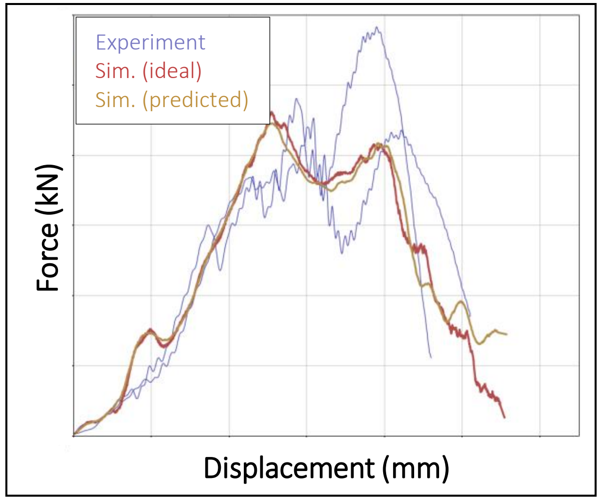


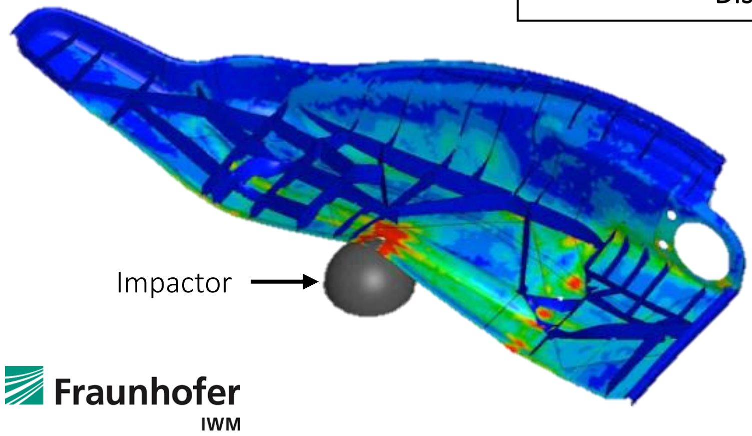
The local fiber orientation changes in double-curved areas due to shear-induced fiber rotation.

3. Industrial use cases

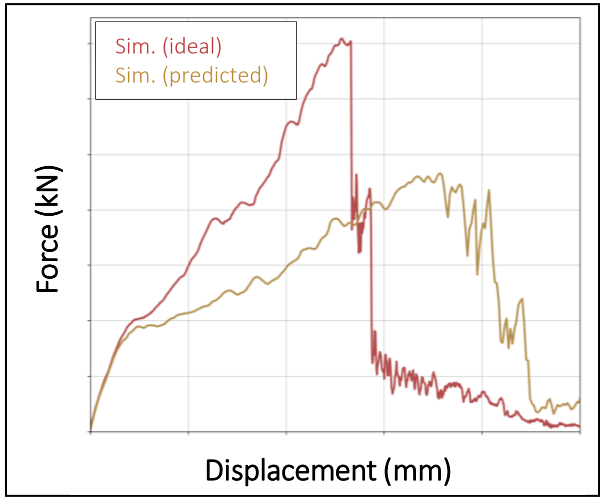
Virtual process chain for impact simulation

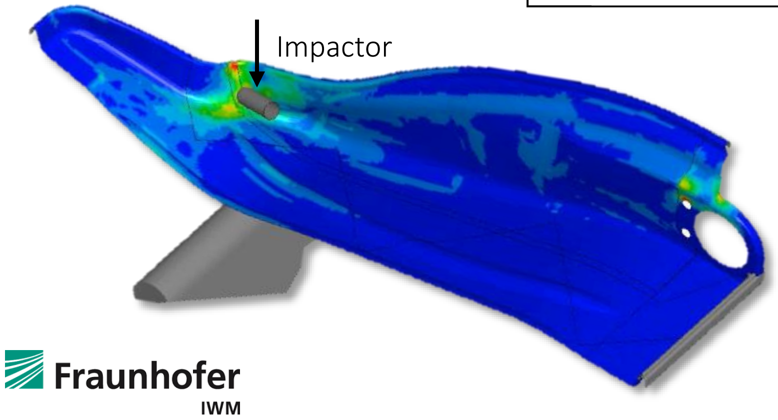
Validation of impact simulation





Virtual study impact in double-curved area





The forming-induced local fiber orientation can significantly influence component failure.

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Product design using a virtual process chain

Project goals

- Design of a service hole cover of a lift gate for a pick-up truck in sandwich construction
- Virtual design of the thermoforming process
- Virtual validation of load requirements including the consideration of manufacturing effects

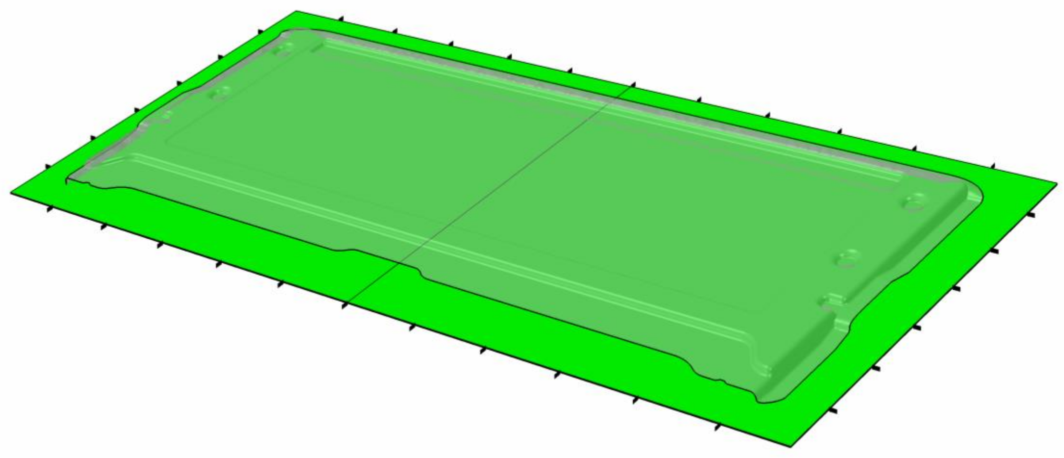
Project partners

TOYOTA

AERLYTE

Western University · Canada

in cooperation with Fraunhofer



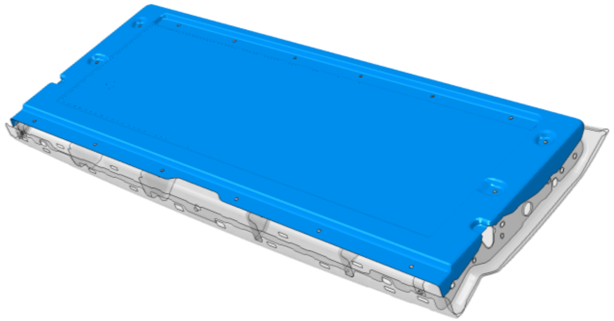
Thermoforming simulation for service hole cover of a lift gate for a pick-up truck

3. Industrial use cases

Product design using a virtual process chain

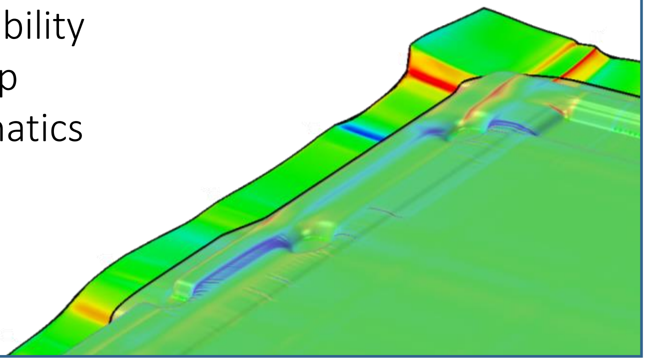
Part design

- Design of a sandwich part
  - Tape laminate skins
  - Foam core
- Fitting of the designed part into the existing assembly



Forming simulation

- Validation of manufacturability
- Optimization gripper setup considering gripper kinematics
- Prediction of local fiber orientation

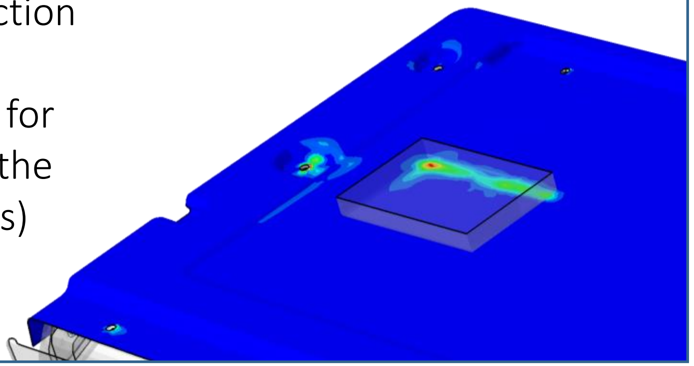


Conceptual phase

Finalization phase

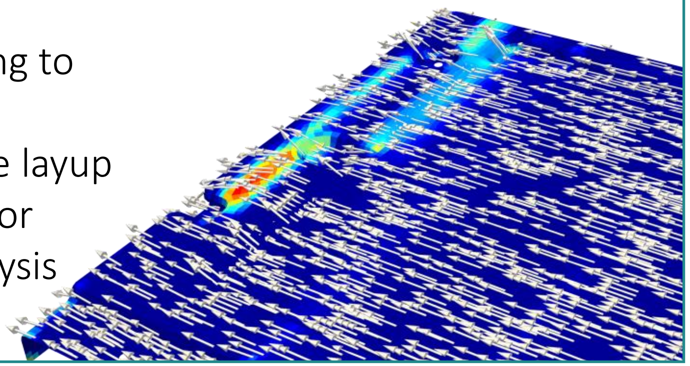
Structural analysis (FEA)

- Prediction of the deflection for several load cases
- Analysis of local failure for the skins (Hashin) and the core (compaction stress)



Transfer of fiber orientation

- Mapping of local fiber orientation from forming to structural simulation
- Creation of a composite layup using laminate theory for efficient structural analysis



Focusing on design and structural analyses in conceptual phases for simple parts can be time-efficient.

4. Summary and conclusion

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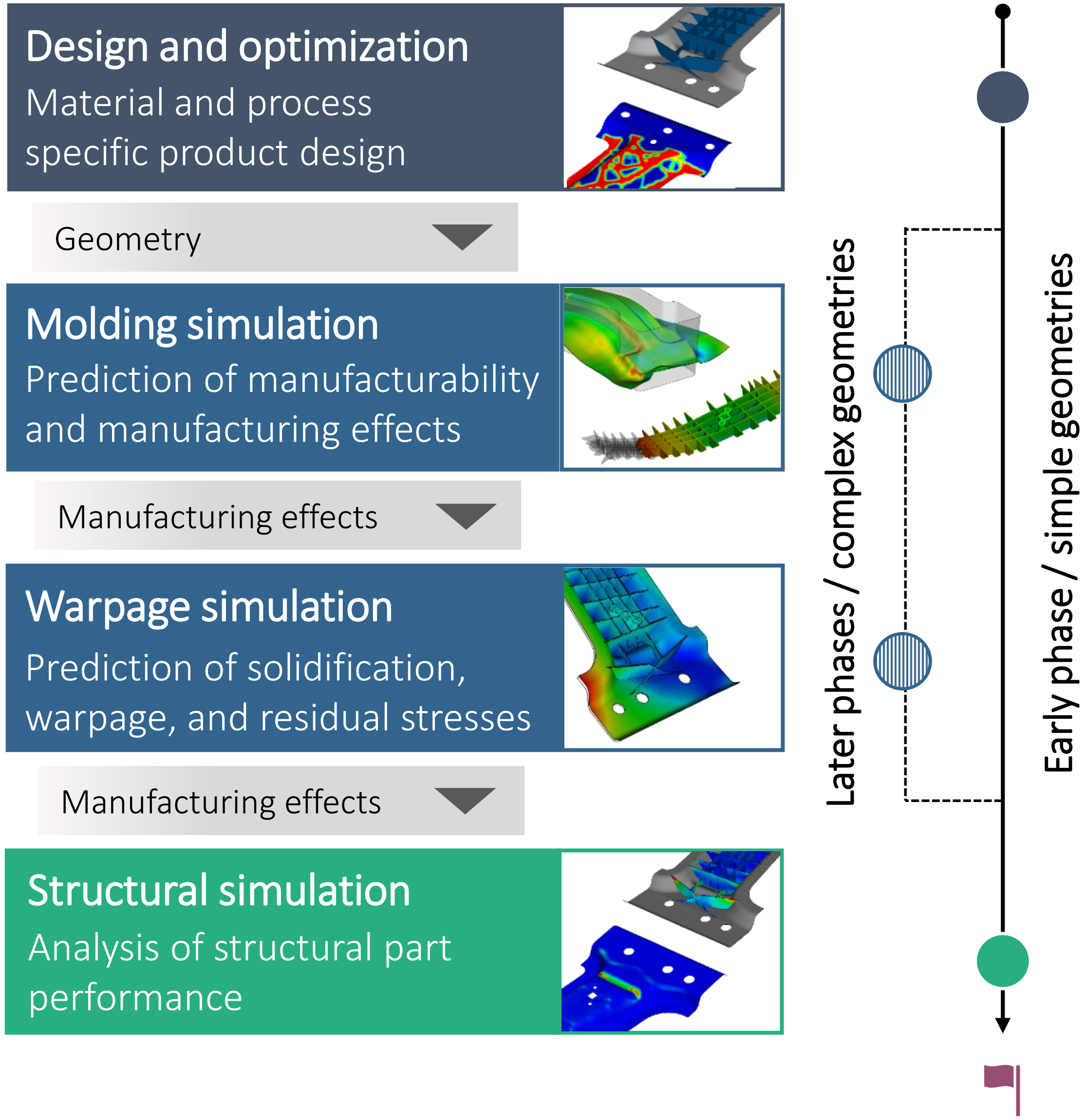
Opportunities:

- Composites forming simulation enables the virtual validation and optimization of manufacturing already in early product development phases
- A virtual process chain is capable to predict, retain, and consider manufacturing effects in downstream FEA

Challenges:

- A trade-off between educated decisions and high-fidelity simulation is crucial for efficiency
- Standardized interfaces, simulation setups, and reporting are essential to achieve short lead times
- Efficient simulation and materials characterization approaches are required in the industrial context
- Consideration of materials characterization in time and budget planning is essential for the successfully establishing digital product development



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Opportunities and Challenges of Composites Forming Simulation for Digital Product Development

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