SIMUTENCE
virtual composite solutions

Advanced Macroscopic Modelling Approaches for FE Composite Forming Simulation Using Abaqus

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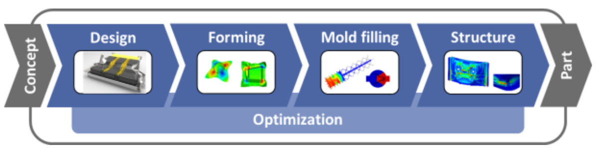
Hanau, 06.12.18

Institute of Vehicle System Technology - Lightweight Technology

R&D Network

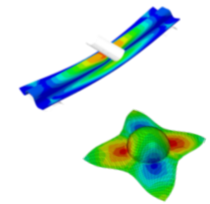
Industrial Method Development

SIMUTENCE
virtual composite solutions



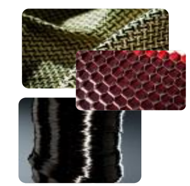
Academic Method Development

KIT Karlsruher Institut für Technologie
FAST Institut für Fahrzeugsystemtechnik



Material Characterization

KIT Karlsruher Institut für Technologie
IAM Institut für Angewandte Materialien



Manufacturing Process Development

Germany
Fraunhofer ICT

North America
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Agenda

- Introduction & Motivation
- Framework for Composite Forming Simulation
- Application Examples
  - UD-NCF
  - Thermoforming
  - Wet Compression Molding (WCM)
  - Formability Optimization
- Summary & Conclusion

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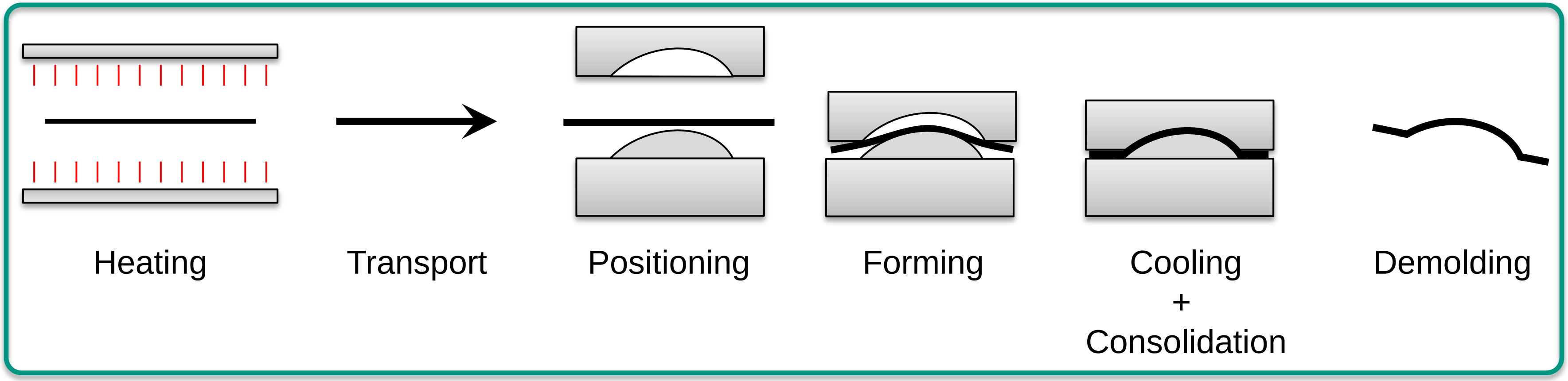
Introduction & Motivation

- Manufacturing of continuously fiber-reinforced composite requires forming of two-dimensional pre-products into final part's geometry
  - Draping of engineering textiles (preforming)
  - Thermoforming of thermoplastic tapes

- The forming step hast a significant impact on structural performance
  - Fiber reorientation
  - Fiber volume content
  - Fiber waviness



Schematic illustration of a thermoforming process route

Introduction & Motivation

- Forming of continuously fiber-reinforced composites might be accompanied with forming defects depending on:
  - Layup sequence
  - Material behavior
  - Process conditions

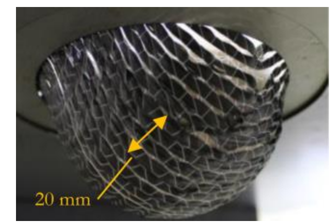
Thermoplastic UD-Tapes

Wrinkling

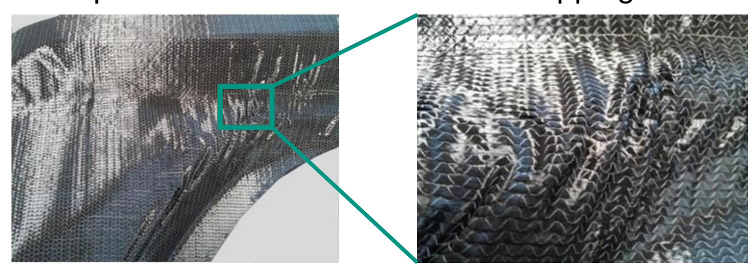
In-plane undulation and gapping

Engineering Textiles

In-plane undulation



Gapping

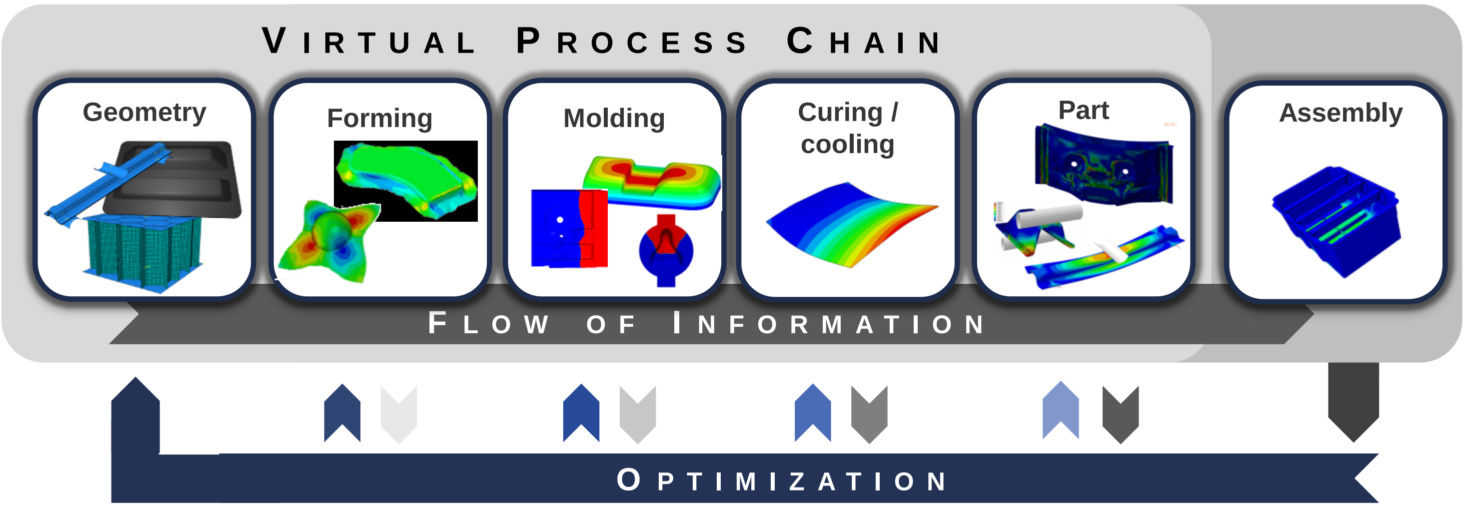


Wrinkling

Introduction & Motivation

R&D focus of KIT-FAST and SIMUTENCE:

- Virtual representation of continuous process chains



- Finite Element forming simulation is highly suitable for process design
  - Prediction of forming defects and fiber orientation
  - Determination of tailored blanks
  - Optimization of process parameters

Kärger et al.: *Development and validation of a CAE chain for unidirectional fibre reinforced composite components*. Composite Structures 132: 350–358, 2015.

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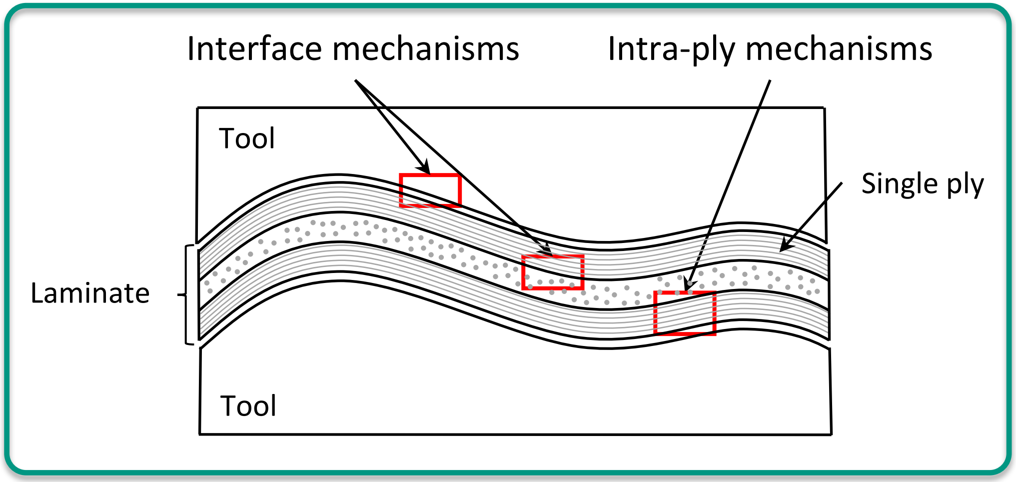
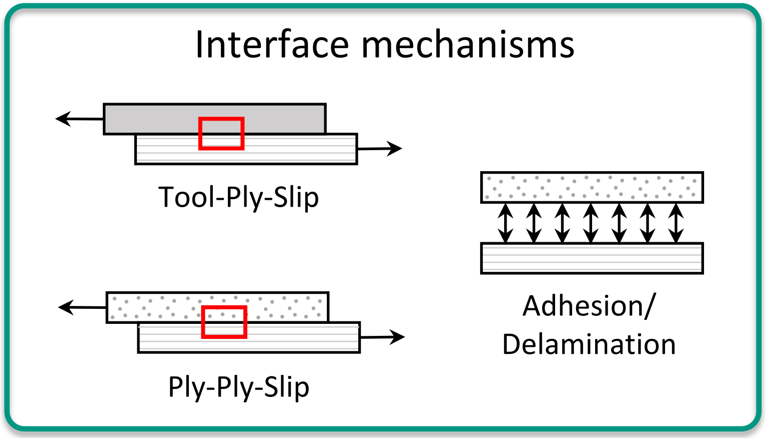
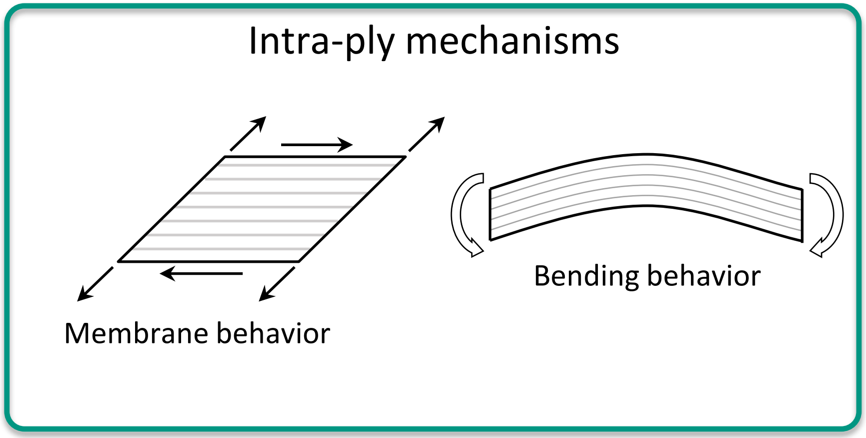
Framework for Composite Forming Simulation
Deformation mechanisms

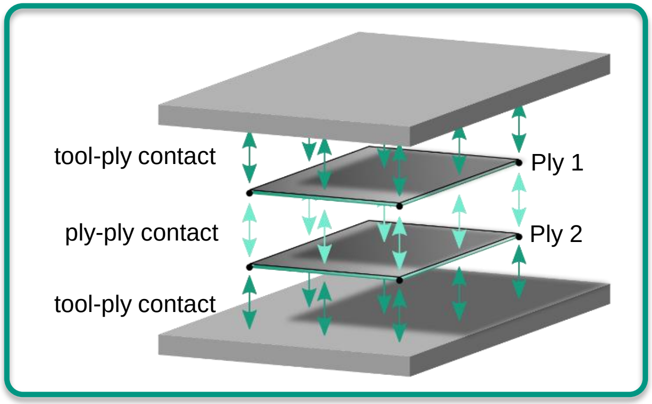




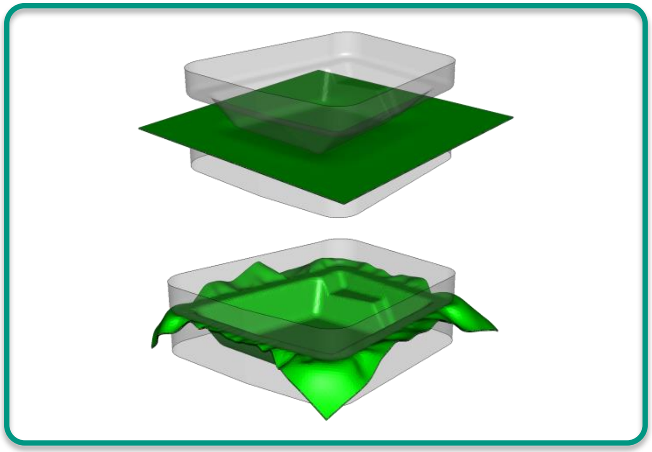


Framework for Composite Forming Simulation
Macroscopic forming simulation

- Requirements for process design:
  - Consideration of process conditions
  - Prediction of manufacturing effects
- Application of macroscopic Finite Element forming simulation
  - Layer-by-layer modeling of the laminate
  - Constitutive modeling of the relevant deformation mechanisms
- Development of composite forming add-ons for Abaqus by SIMUTENCE and KIT-FAST
  - Advanced finite elements, contact and material modeling
  - Automatized pre- and postprocessing



Macroscopic forming simulation approach for a flat blank

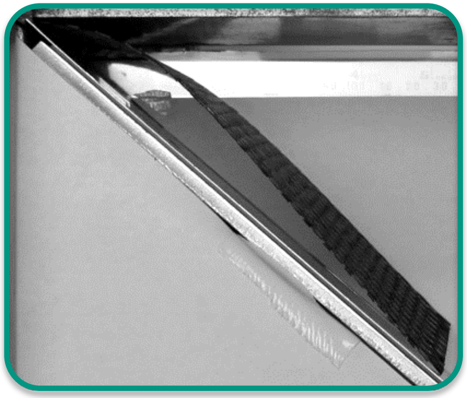


Finite Element forming simulation applied to a generic geometry

Dörr et al.: *A Benchmark Study of Finite Element Codes for Forming Simulation of Thermoplastic UD-Tapes*. CIRP CCMPM 2017, 2017; 66:101–6.

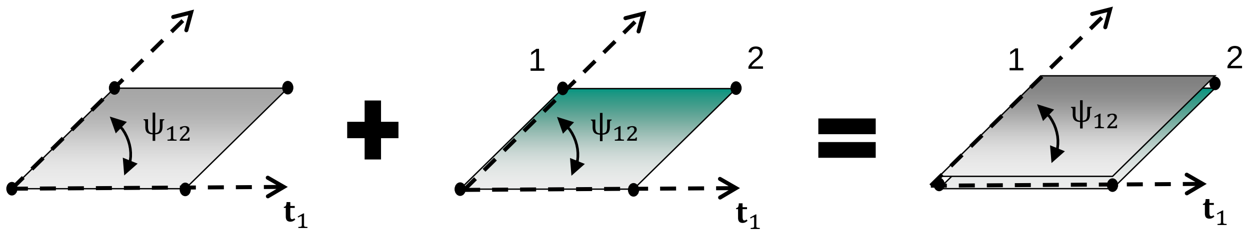
Framework for Composite Forming Simulation
Intra-ply modeling

- Modeling of intra-ply mechanisms
  - Relative motion between fibers at process conditions leads to very low bending stiffness
  - Conventional plate theories non-applicable
  - Decoupling based on Abaqus built-in methods is not sufficiently possible



Fabric within a Cantilever test

- Decoupling of membrane and bending behavior based on subroutine modeling:



Membrane behavior
Membrane element
Subroutine:
(V)UMAT

Bending behavior
(Shell element)
Subroutine:
(V)UGENS/ (V)UEL

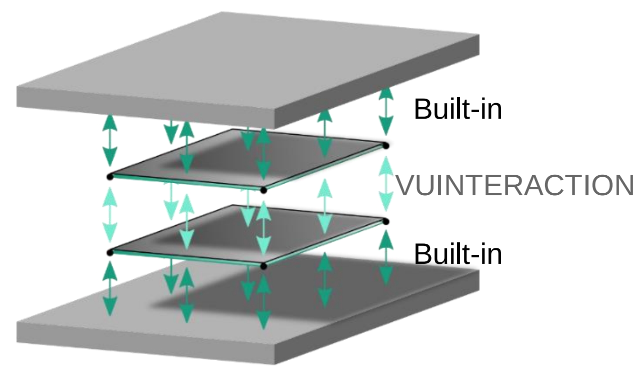
Decoupled membrane and bending behavior

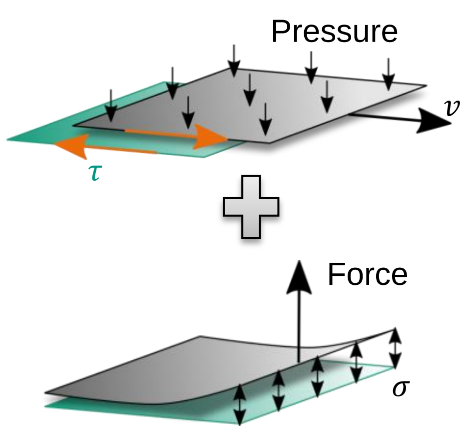
Dörr et al: *A viscoelastic approach for modeling bending behavior in Finite Element forming simulation of continuously fiber reinforced composites*, Composites: Part A, 2016.

Framework for Composite Forming Simulation
Interface modeling

- Restrictions of Abaqus for interface modelling:
  - Tacking: Cohesive zones
  - Slipping: Frictional behavior
  - No simultaneous tacking and friction can be modelled
- Interface mechanisms based on subroutine modeling (VUINTERACTION):
  - Decoupling of normal and tangential behavior
  - Separation in normal direction
  - Pressure- and rate-dependent friction modelling:

$$\tau = \mu p + \eta v + \tau_0$$





Dörr et al: *Modelling approach for anisotropic inter-ply slippage in finite element forming simulation of thermoplastic UD-tapes*, AIP Conf. Proc. 1960, 020005 (2018).

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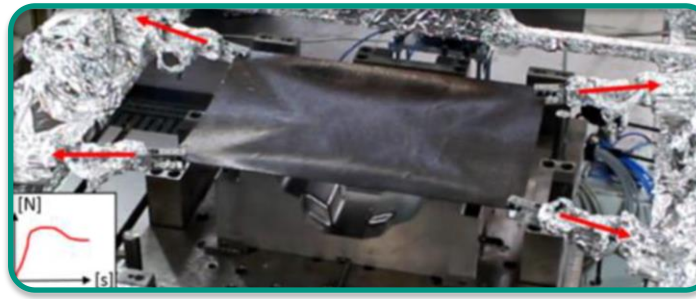
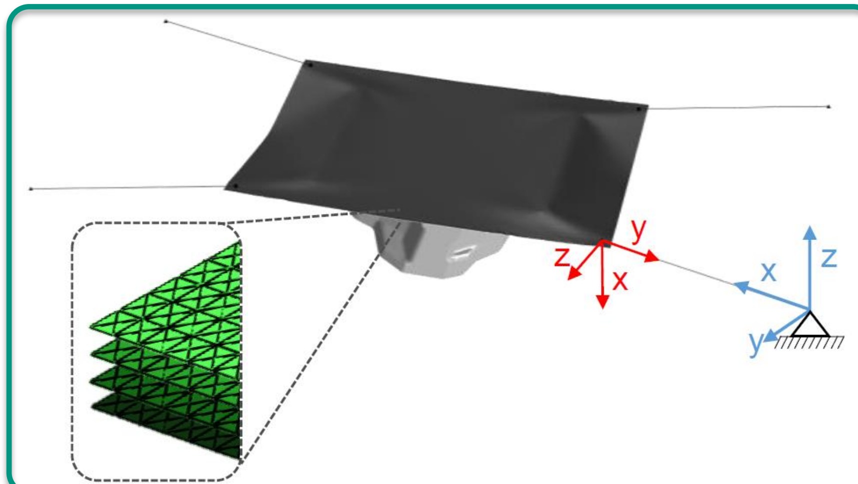
Application examples
Thermoforming

- Available approaches for:
  - UD-tapes (unidirectional)
  - Organosheets (woven)
- Modelling capabilities:
  - Finite strain viscoelasticity
  - Coupled thermomechanics
  - Recrystallization
- Transfer and gripping
  - Gripper-kinematics is modeled by translator elements
- Validation based on experimental tests and online measurements



Gripper assisted thermoforming of multilayered, thermoplastic tape-laminates

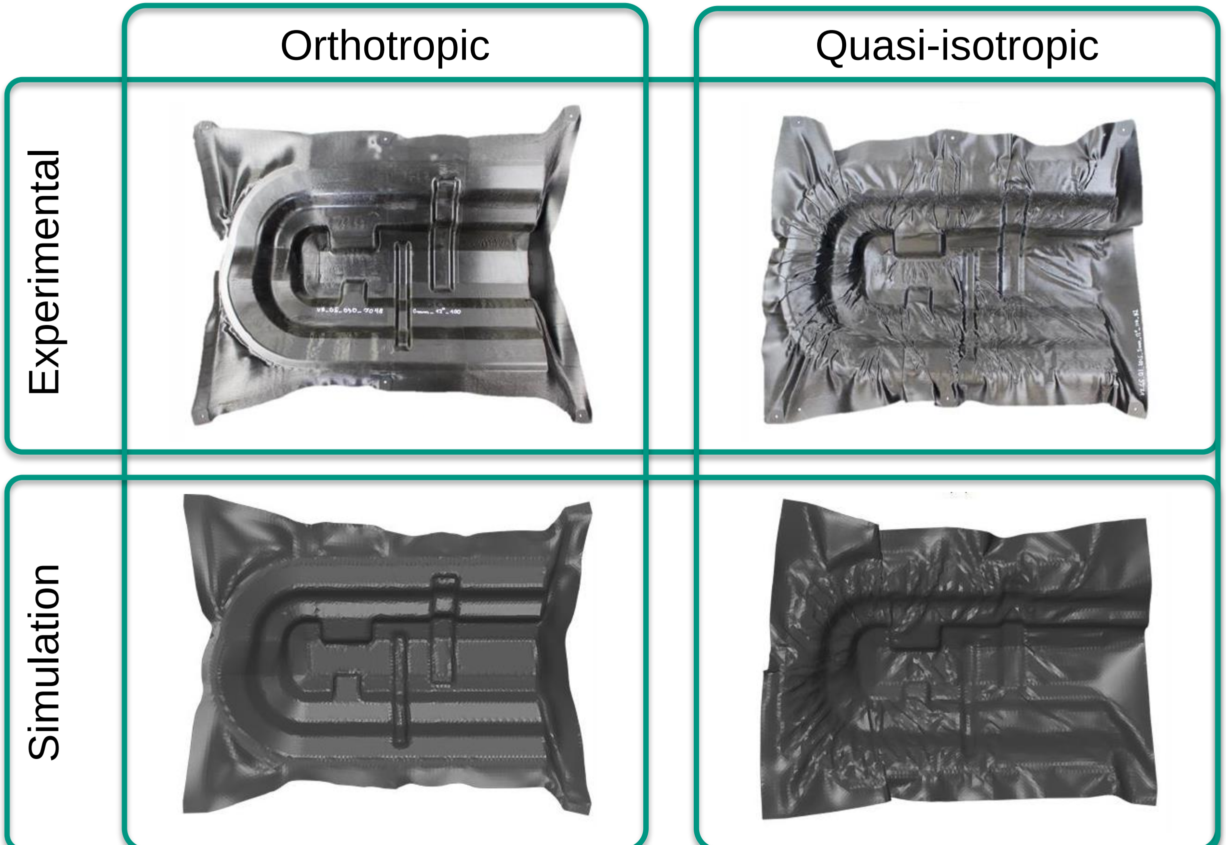


Simulation setup for gripper-assisted forming simulation taking into account gripper kinematics

Poppe et al*: Modeling and Validation of Gripper Induced Membrane Forces in Finite Element Forming Simulation of Continuously Reinforced Composites*. AIP Conference Proceedings 1896, 030003 (2017).

Application examples
Thermoforming

- Validation of thermoforming simulation for a generic geometry

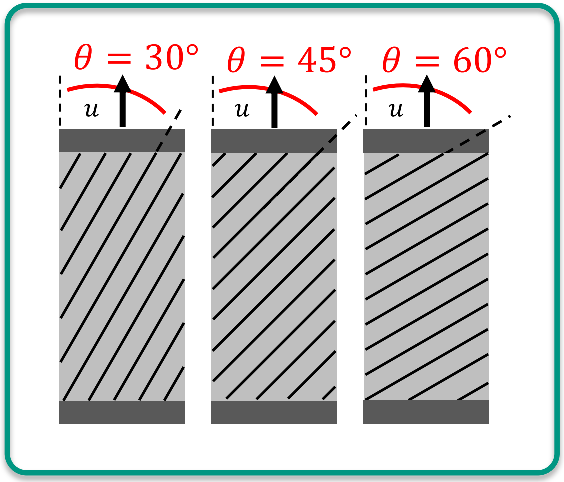


Poppe et al*: Modeling and Validation of Gripper Induced Membrane Forces in Finite Element Forming Simulation of Continuously Reinforced Composites*. AIP Conference Proceedings 1896, 030003 (2017).

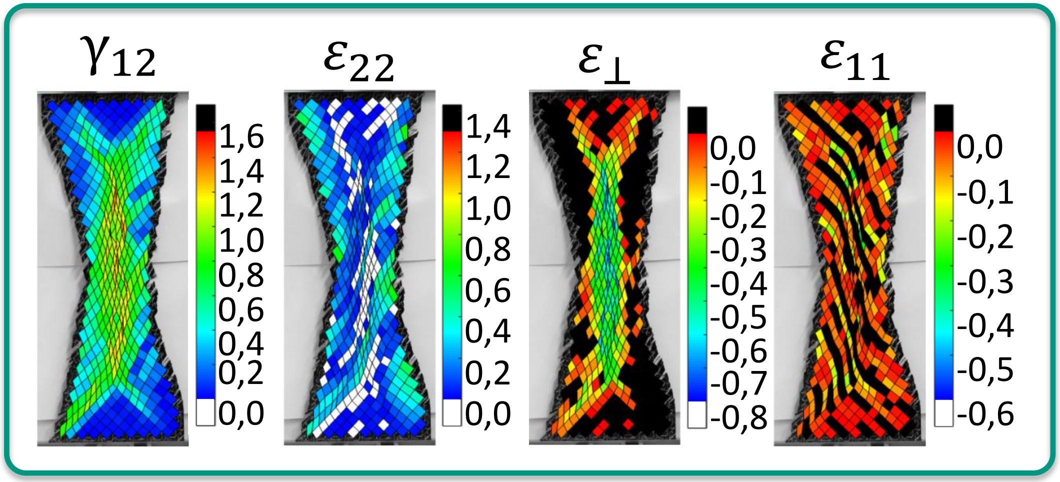
Application examples

Unidirectional non-crimp fabrics (UD-NCF)

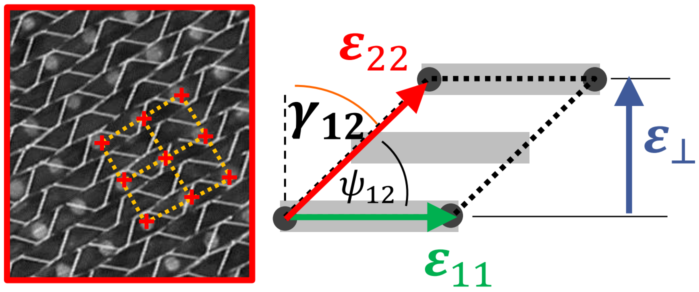
- Off-axis tension tests



- Results 45°-tension test (bias extension)



- Optical strain measurement

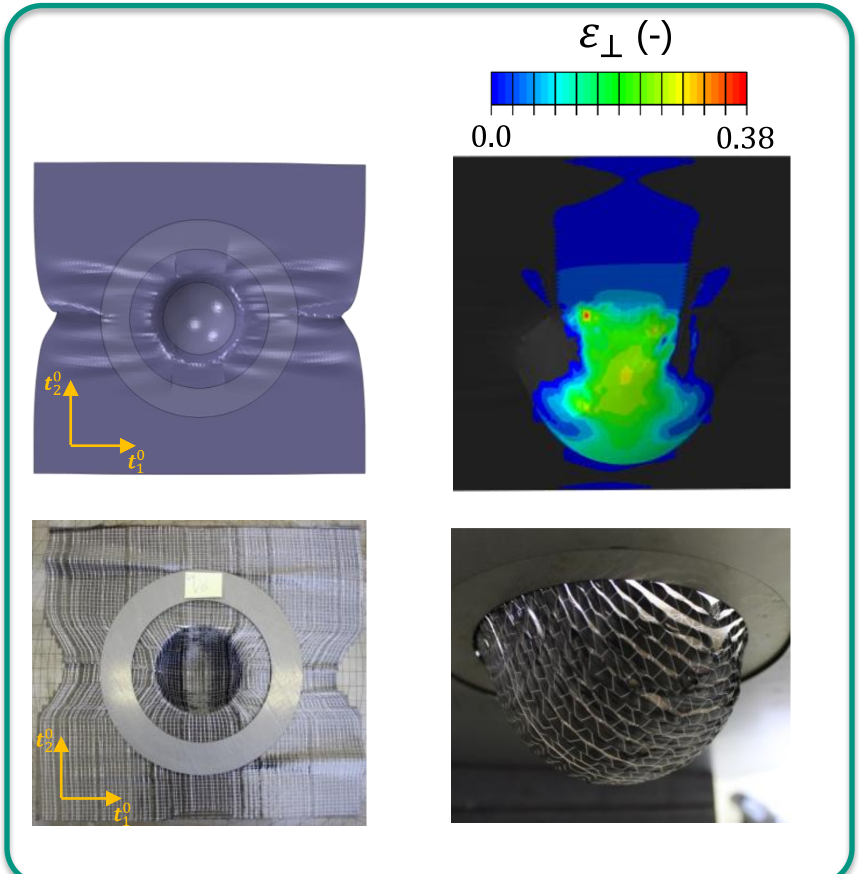


- Pure shear is no intrinsic deformation mode of UD-NCF
  - Superimposed ε_{22} and γ_{12} strains
- $\varepsilon_{11} < 0$: local buckling of tows
- Positive ε_{22}- and negative $\varepsilon_{\perp}$-strains occur simultaneously

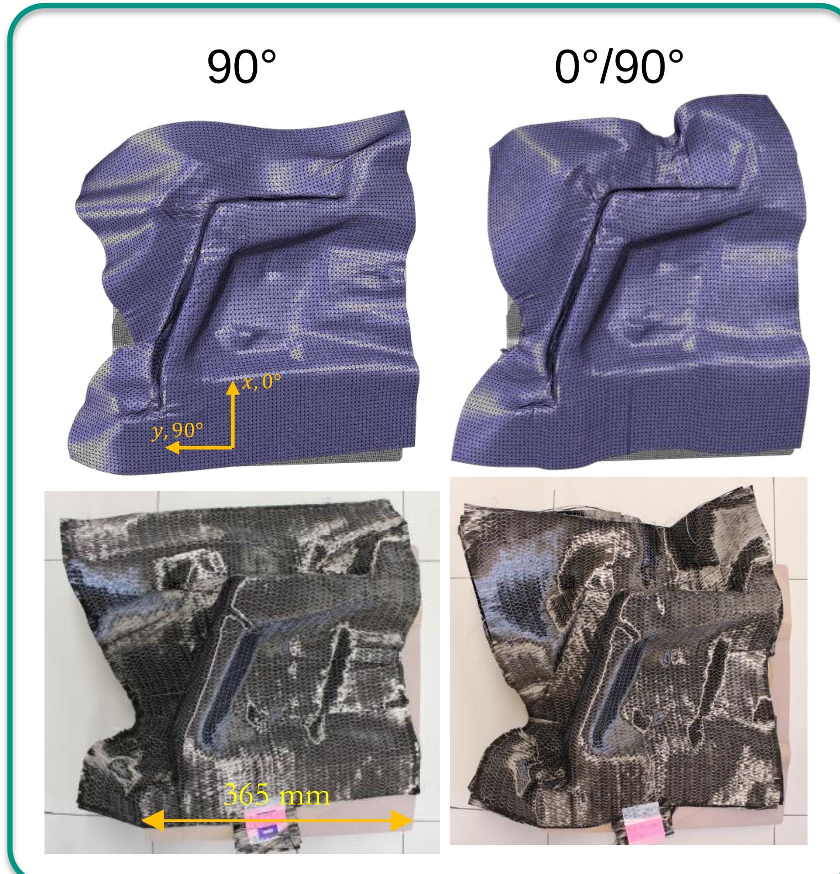
F.J. Schirmaier et al: *Characterisation of the draping behaviour of unidirectional non-crimp fabrics (UD-NCF)*, Composites: Part A, 2016.

Application examples
Unidirectional non-crimp fabrics (UD-NCF)

- Hemisphere test



- Light-pod preforming



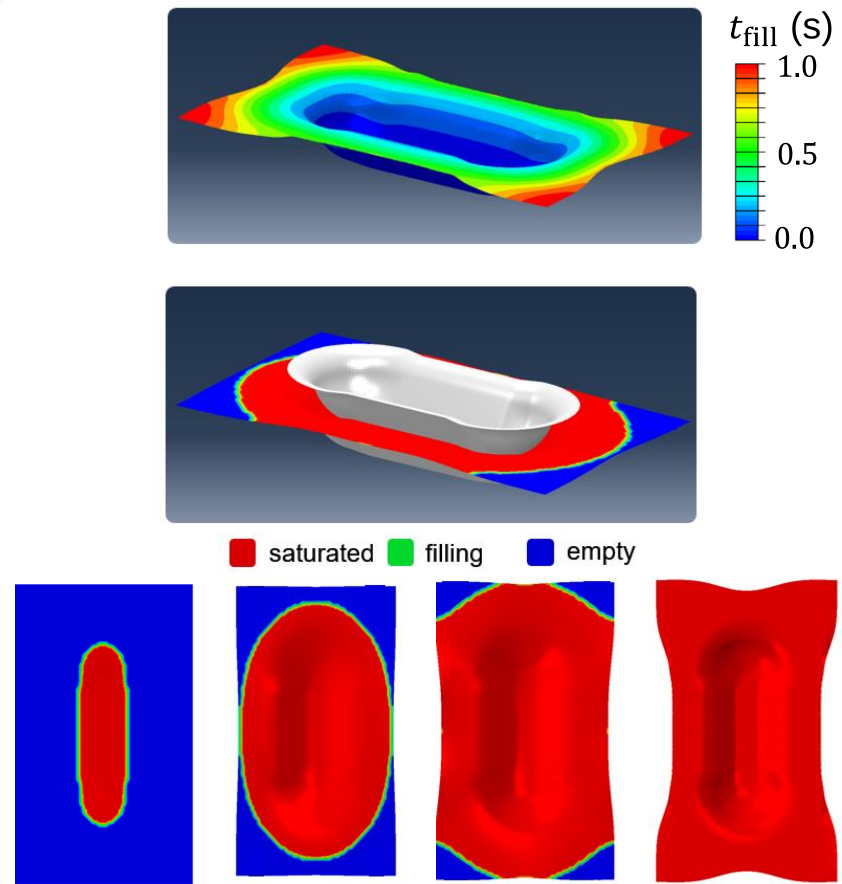
F.J. Schirmaier et al: *A macroscopic approach to simulate the forming behaviour of stitched unidirectional non-crimp fabrics (UD-NCF)*, Composites: Part A, 2017.

Application examples
Wet Compression Molding (WCM)

- WCM simulation approach includes:
  - Viscous draping stage
  - Fluid propagation during viscous draping
- Modelling approach
  - Fluid progression modeled by Darcy's law:

$$\boldsymbol{v} = -\frac{\boldsymbol{K}}{\eta\phi}\nabla p$$

  - Superimposed Darcy-Propagation-Element (VUEL)
  - Coupling between fluid progression and infiltration-dependent material models
  - ➢ **Simultaneous fluid progression and forming modeling**



Fluid progression during double-dome forming

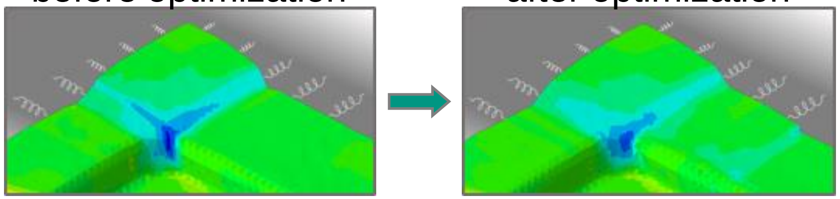
Poppe et al.: *A 2D modeling approach for fluid propagation during FE-forming simulation of continuously reinforced composites in wet compression molding*. AIP Conf. Proc. 1960, 020005 (2018).

Application examples

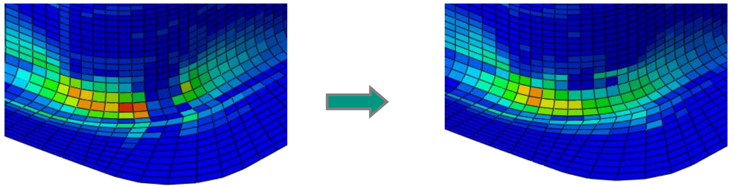
Formability Optimization

- Integrated process optimization along the CAE-chain
  - Virtual optimization of manufacturing processes
  - Improved mechanical performance and product quality
  - Consideration of manufacturing effects in structural analyses

before optimization after optimization

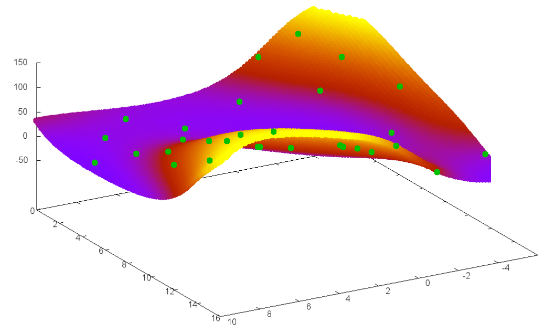


Optimization of grippers: Shear angle reduced by ≈ 9 %



Improved performance: Material effort reduced by ≈ 10 %

- Machine learning algorithms
  - Reduced numerical effort and computation time
  - Rapid and reliable determination of global optima
  - Deduction of 'easy-to-interpret' process-windows for end users



Exemplary meta-model from sampled test data

Kärger et al.: *Forming optimisation embedded in a CAE chain to assess and enhance the structural performance of composite components*. Composite Structures 2018;192:143–52.

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Summary & Conclusion

- Virtual design of composites requires consideration of manufacturing effects
  - A virtual process chain enables accurate and efficient product design
- Advanced process simulation is highly promising
  - Virtual process design and validation of manufacturability
  - Prediction of manufacturing effects (e.g. fiber reorientation)
- The applicability of Abaqus to composite forming simulation based on built-in modeling approaches is very limited
- User-interfaces make Abaqus highly promising for the application to composite forming
- SIMUTENCE offers services, and supplies and develops a virtual process chain in collaboration with KIT-FAST

Thank you for your attention.

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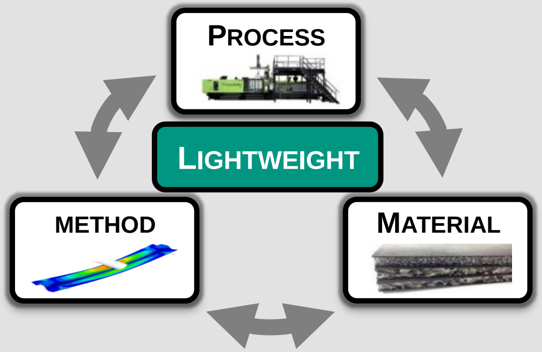
Lightweight Design Network



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