

Drapiersimulation von trockenen und duro- oder thermoplastisch imprägnierten Textilien

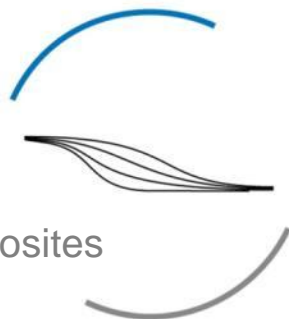
Dipl.-Ing. Dr. techn. Roland M. Hinterhölzl, MSc. Alexane Margossian

4. Fachkongress Composite Simulation

Fellbach, 26.02.2015



Institute for Carbon Composites



donated by



Agenda

- 1 Introduction**
- 2 Kinematic and Finite Element draping methods**
- 3 Macroscopic Finite Element simulations**
- 4 Conclusion**

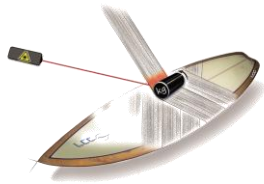
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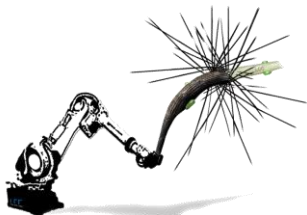
The Institute for Carbon Composites

Research Groups

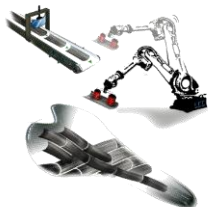
Process Technology for Fibers + Textiles



Automated Fiber Placement

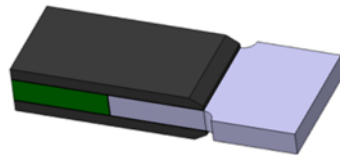


Braiding

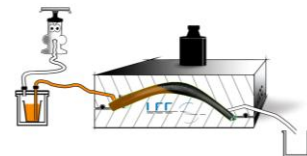


Tailored Textiles

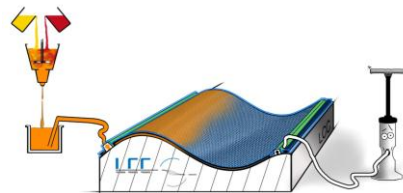
Process Technology for Matrix Materials



Hybrid Materials + Structures

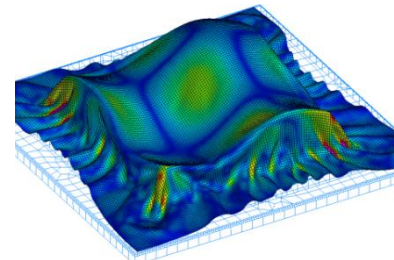


Tooling Systems

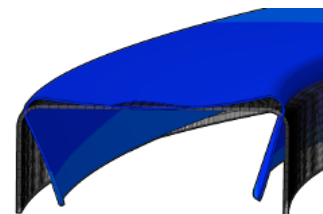


Production Systems

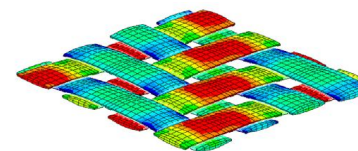
Simulation



Forming and Flow Process Simulation



Compaction, Curing and Consolidation Simulation



Material Modeling and Structural Analysis

Material Behavior and Testing



Composite Testing Lab



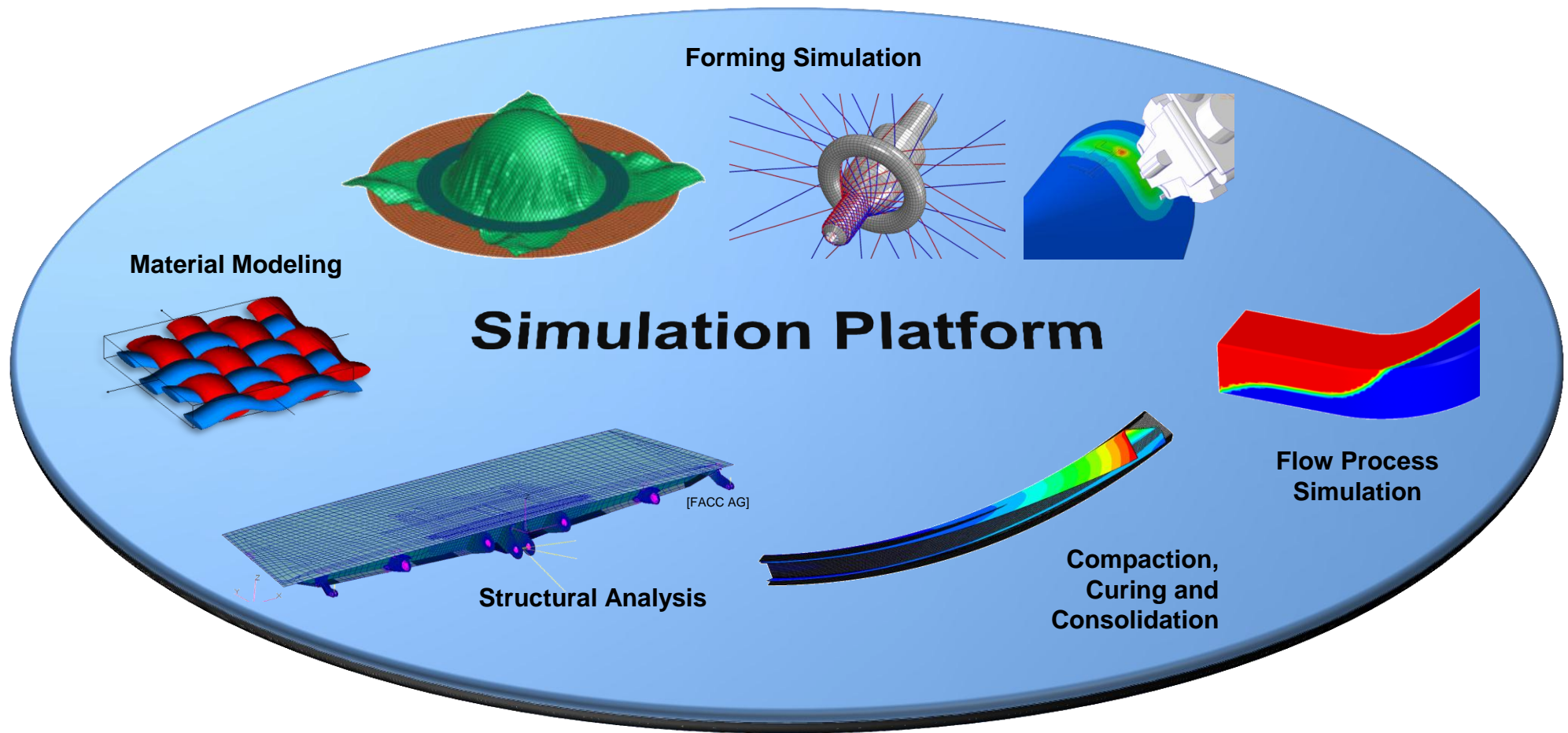
Test Method Development



High Strain Rate Behavior

The Institute for Carbon Composites

Simulation Platform

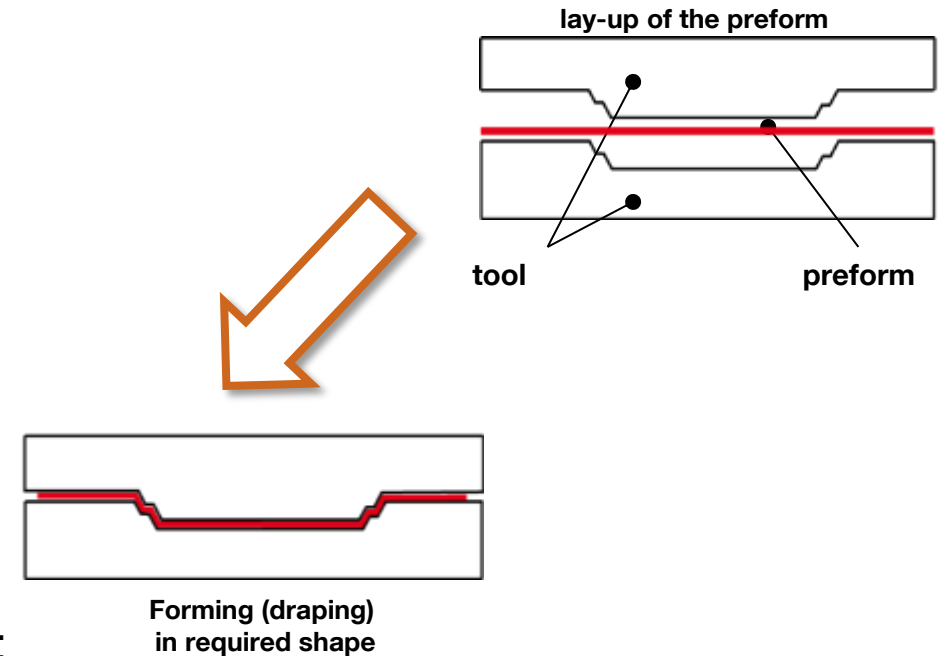


Forming Simulation - Motivation

- Process development / optimization
 - Geometry and alignment of the flat preform
 - Drapeability inspection (feasibility study)
 - Prediction of draping defects
 - ...

- Embedding in process simulation platform – Basis for:
 - LCM simulation
 - Curing and PID simulation
 - Structural simulation

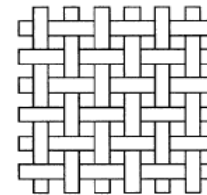
- Part design (design to process)
 - Prediction of fiber alignment
 - Prediction of fiber volume fraction
 - ...



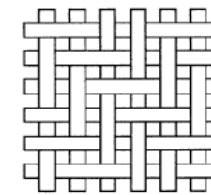
Airbus A380 – Pressure Bulkhead

Forming Simulation - Motivation

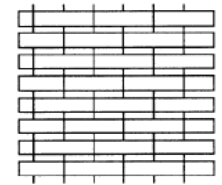
- Textiles
 - woven, Non-Crimp Fabrics (NCF), UD, etc.
 - dry or pre-impregnated



plain weave

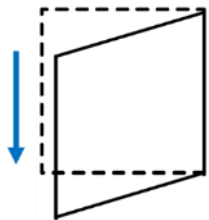


twill weave

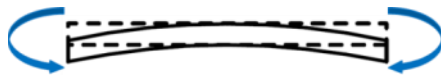


NCF

- Deformation modes



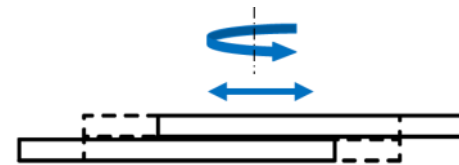
Shear



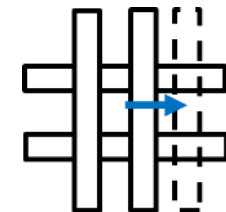
Bending



Elongation

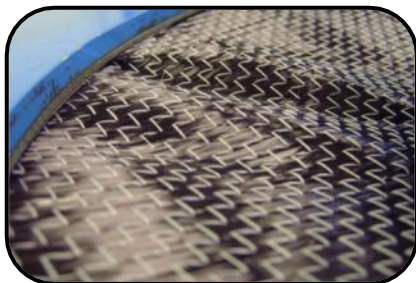


Inter-ply Motion

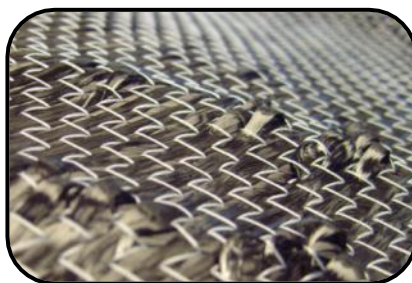


Intra-ply Motion

- Defects



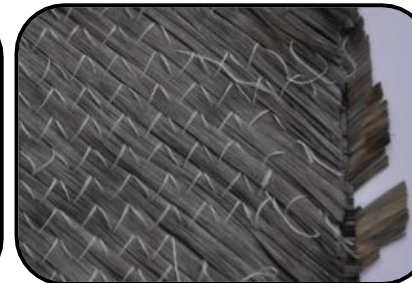
Wrinkling / Folds



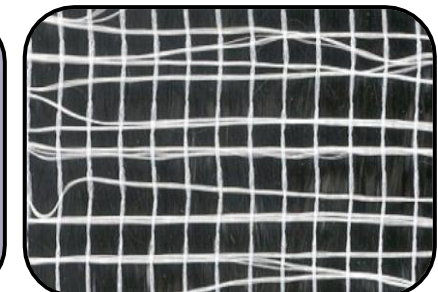
Loops



Gaps / Voids



Fiber Pull-Out



Damage of Stitching

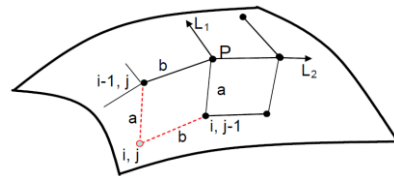
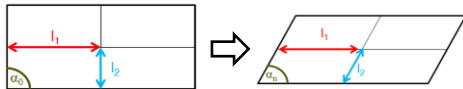
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Numerical Approaches for Draping Simulation

Kinematic Approach

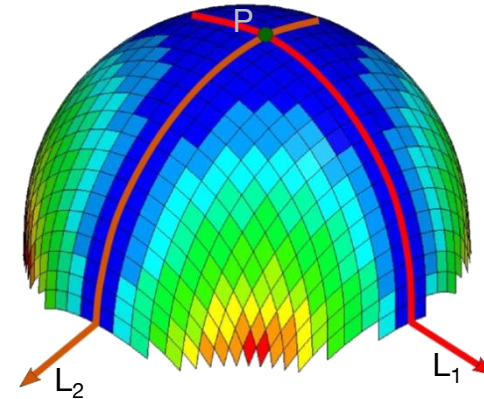
- pin-joint method [Mack 1950]
- purely geometrical approach
- computation of the fiber direction
- direct cut geometry generation



$$(x_{ij} - x_{i-1,j})^2 + (y_{ij} - y_{i-1,j})^2 + (z_{ij} - z_{i-1,j})^2 = a^2$$

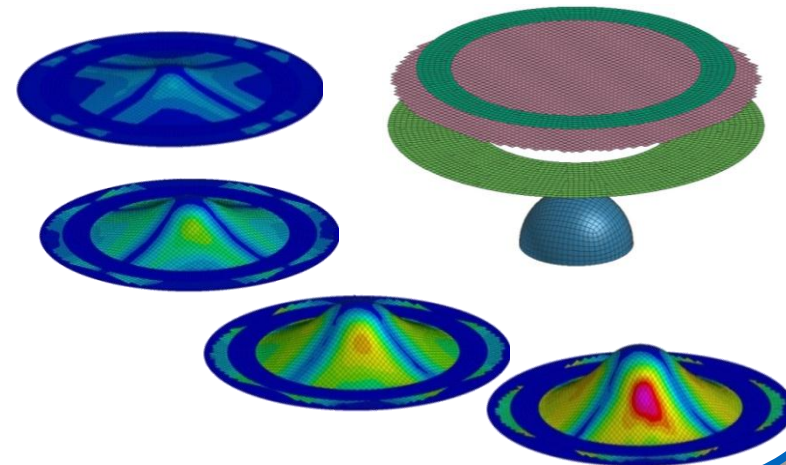
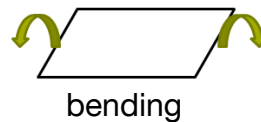
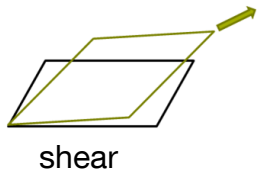
$$(x_{ij} - x_{i,j-1})^2 + (y_{ij} - y_{i,j-1})^2 + (z_{ij} - z_{i,j-1})^2 = b^2$$

$$F(x_{ij}, y_{ij}, z_{ij}) = 0$$



Finite Element Approach

- modeling of the preform with the finite element method
- simulation of the draping process and the tools
- consideration of forces, friction, velocities, etc.
- prediction of deformation modes and defects in the preforms

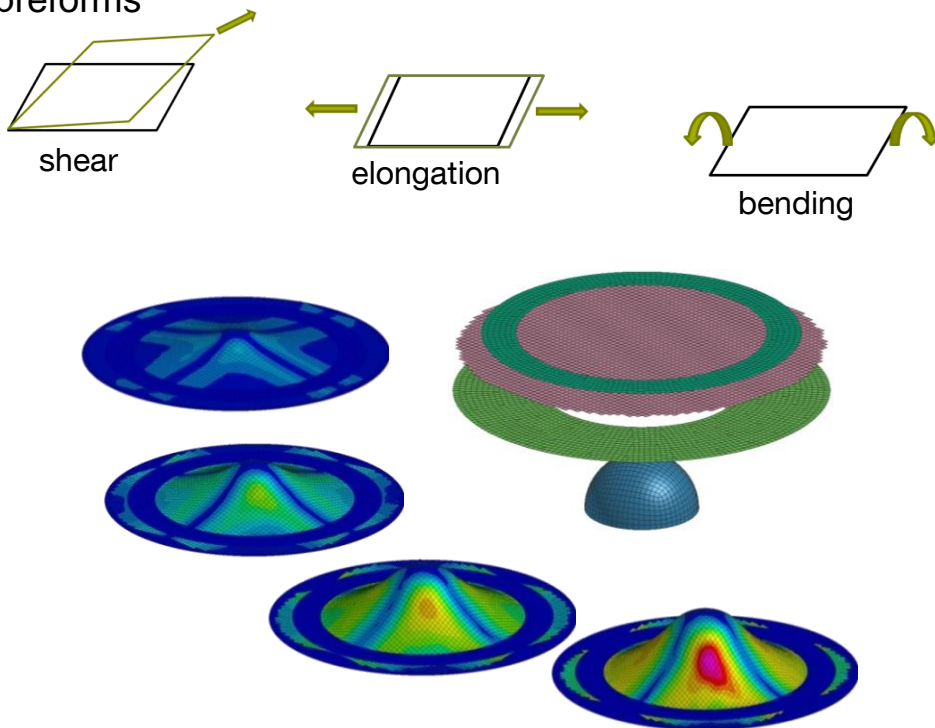


level of detail

Finite Element Approaches for Draping Simulation

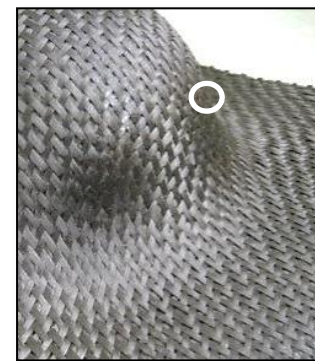
Macro-FE Approach

- modeling of the preform on ply-level with shell elements
- simulation of the draping process and the tools
- consideration of forces, friction, velocities, etc.
- prediction of deformation modes and defects in the preforms

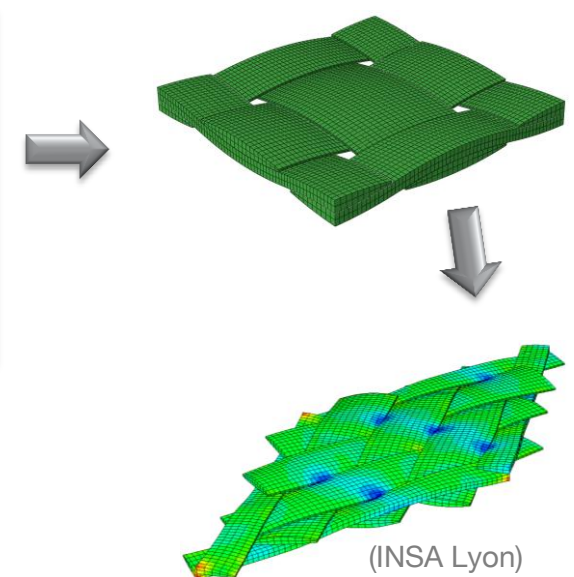


Meso-FE Approach

- modeling of the preform on yarn-level with 2D/3D elements
- consideration of friction between yarns, weaving structure,...
- prediction of deformation modes and behavior of units cells
- Not yet suitable for forming simulation (computational cost) on part scale



(INSA Lyon)



(INSA Lyon)

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 - 3.2** Validation on sub-component level
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Material characterization and material modelling

- Picture Frame Test
- ...

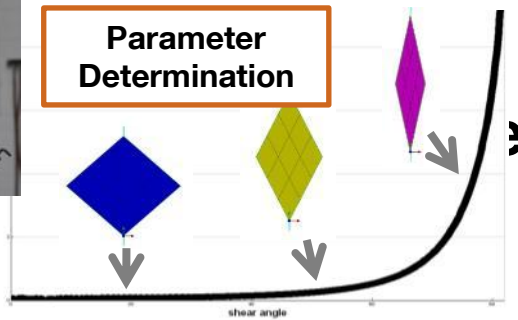
Validation on test geometry

- Hemisphere
- Double Dome
- ...

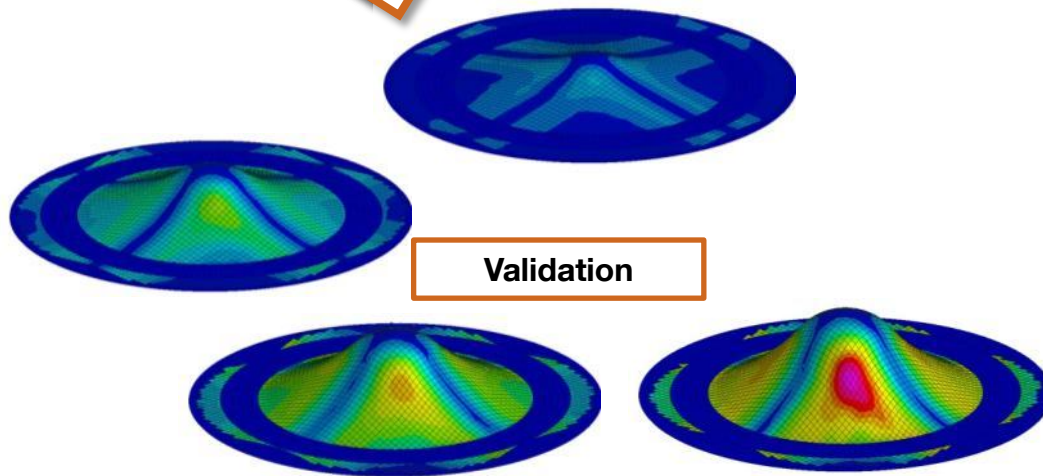
Process simulation (design and optimization)

- Diaphragm draping
- Drape forming
- Hand lay-up
- ...

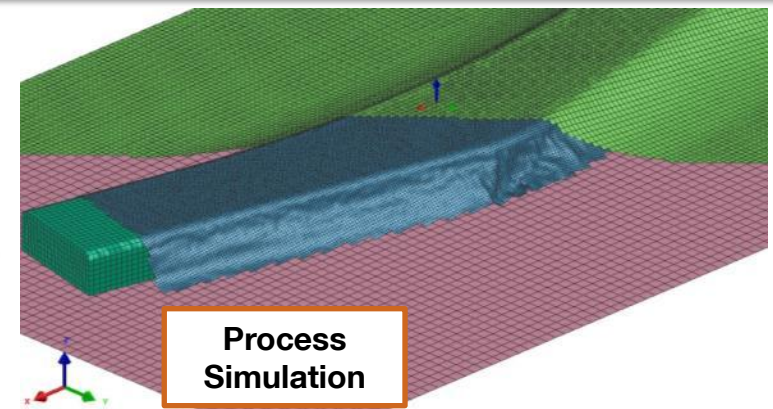
Parameter Determination



Validation



Process Simulation

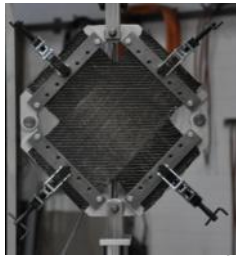


Agenda

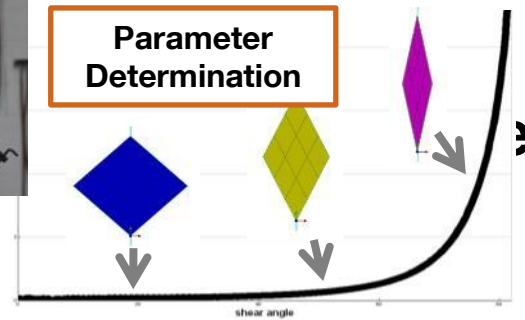
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Parameter Determination



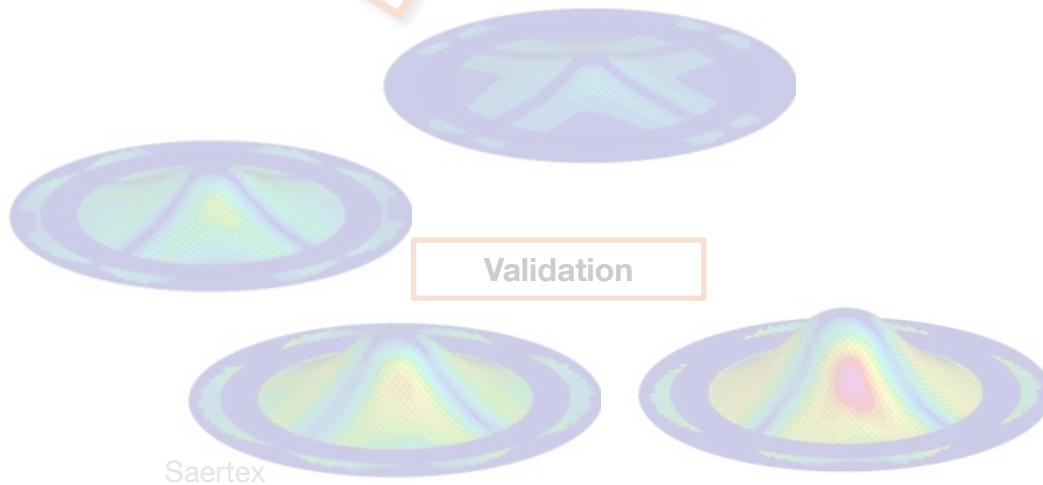
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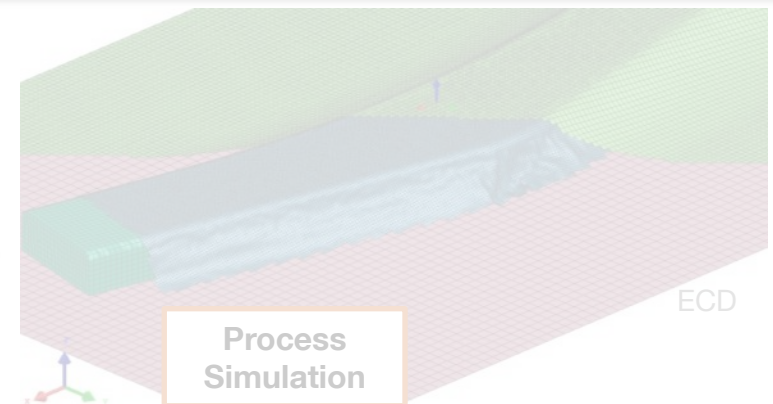
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- ...

Validation



Process Simulation



Material characterisation

Overview

- Test must occur in the same conditions as forming (temperature, speeds)
- No standard

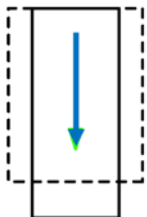
Tensile

Uniaxial Tension Test

Biaxial Tension Test

KES-F

Tensile tests
(DMA-System)



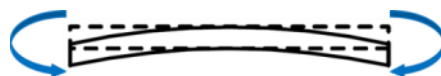
Bending

Cantilever Test

KES-F

Vertical cantilever

Bending tests
(DMA-System)



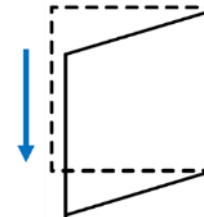
Shear

Picture Frame Test

Bias Extension Test

KES-F

Rheometer



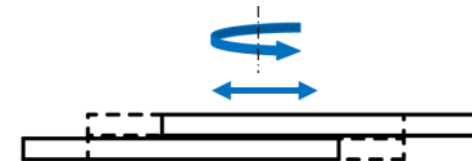
Friction

“Sledge test”

Pull-Out & Pull-Through Processes

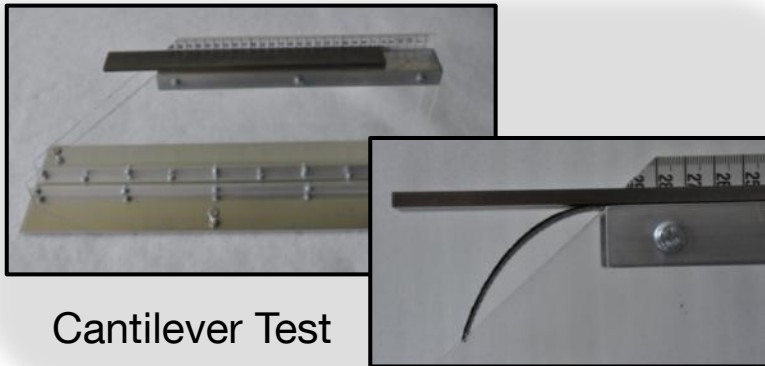
KES-F

Rheometer

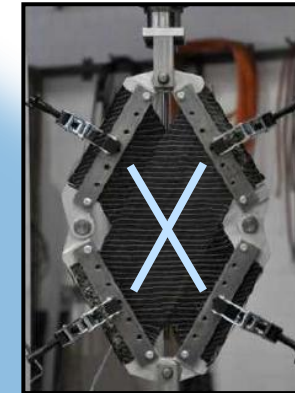
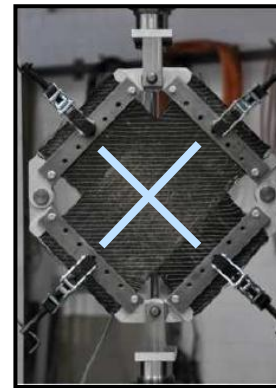


Test Devices at TUM-LCC

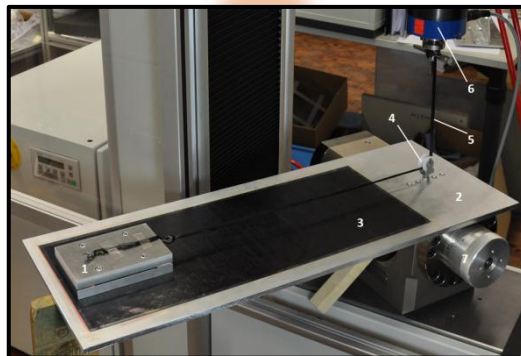
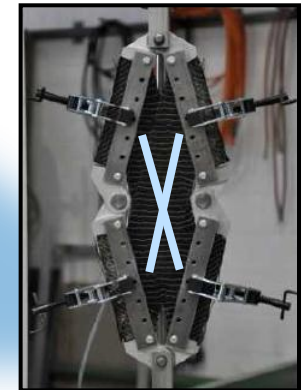
Dry Textiles



Cantilever Test



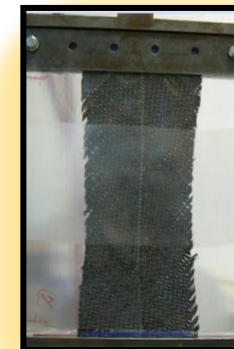
Picture Frame Test



Friction Test



Tensile Test



Bias Extension Test

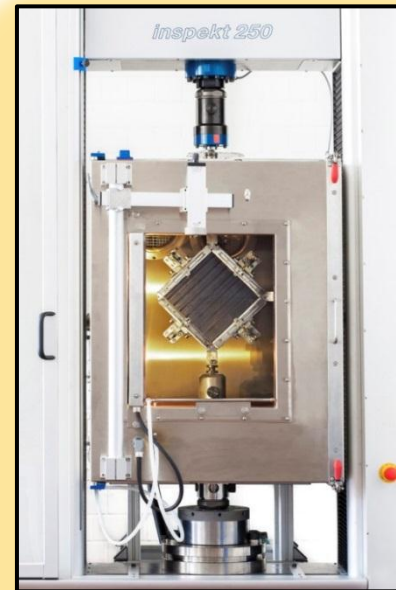
Test Devices at TUM-LCC

Pre-impregnated composites

- Load cells: 10kN, 1kN
- Thermal chamber: -50°C to +350 °C



Hegewald & Peschke 250 kN



Picture frame test



Tensile test
cross fibre direction

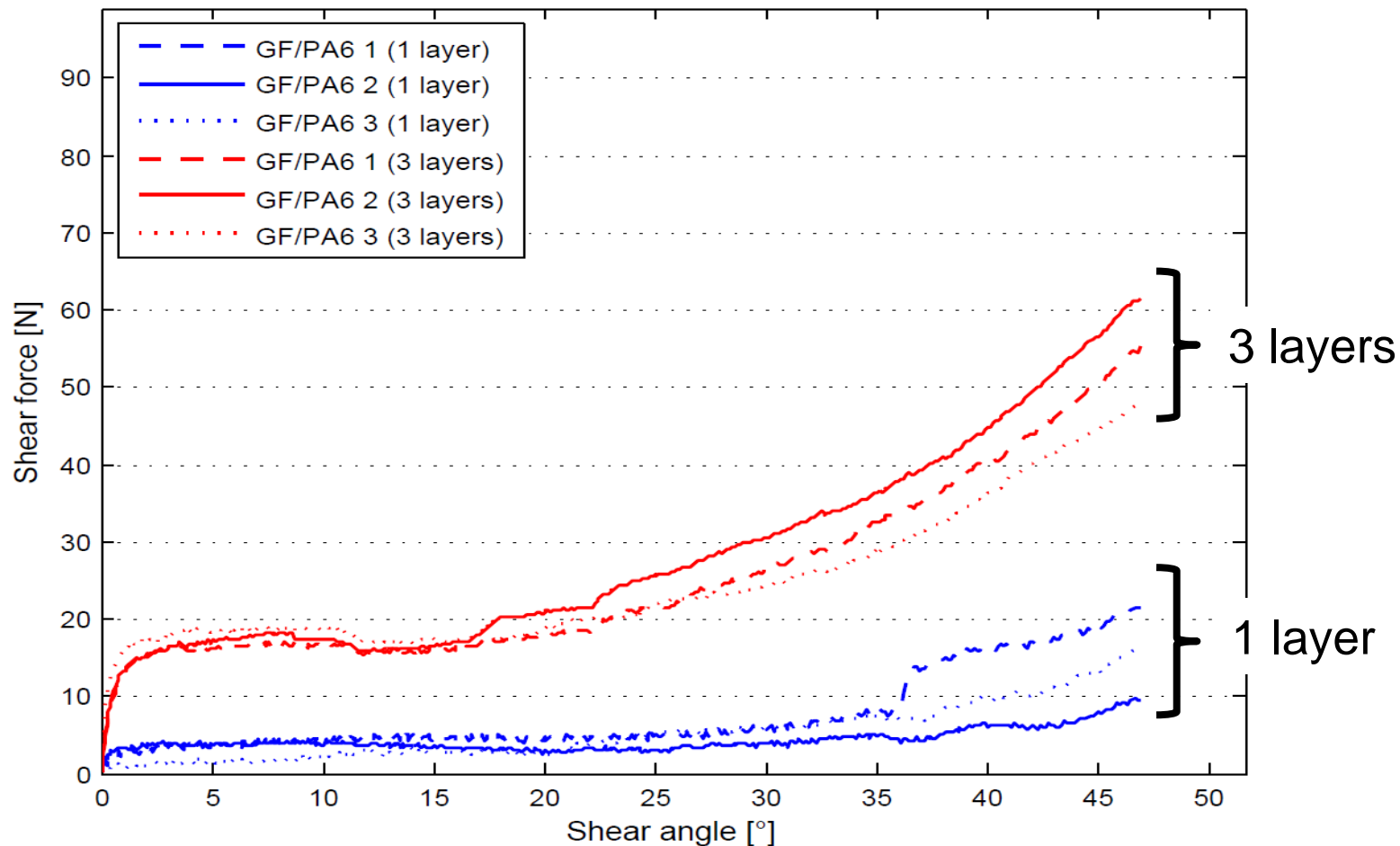


Friction test

Test Devices at TUM-LCC

Picture Frame Results

Woven Glass Fiber PA6 (240°C)



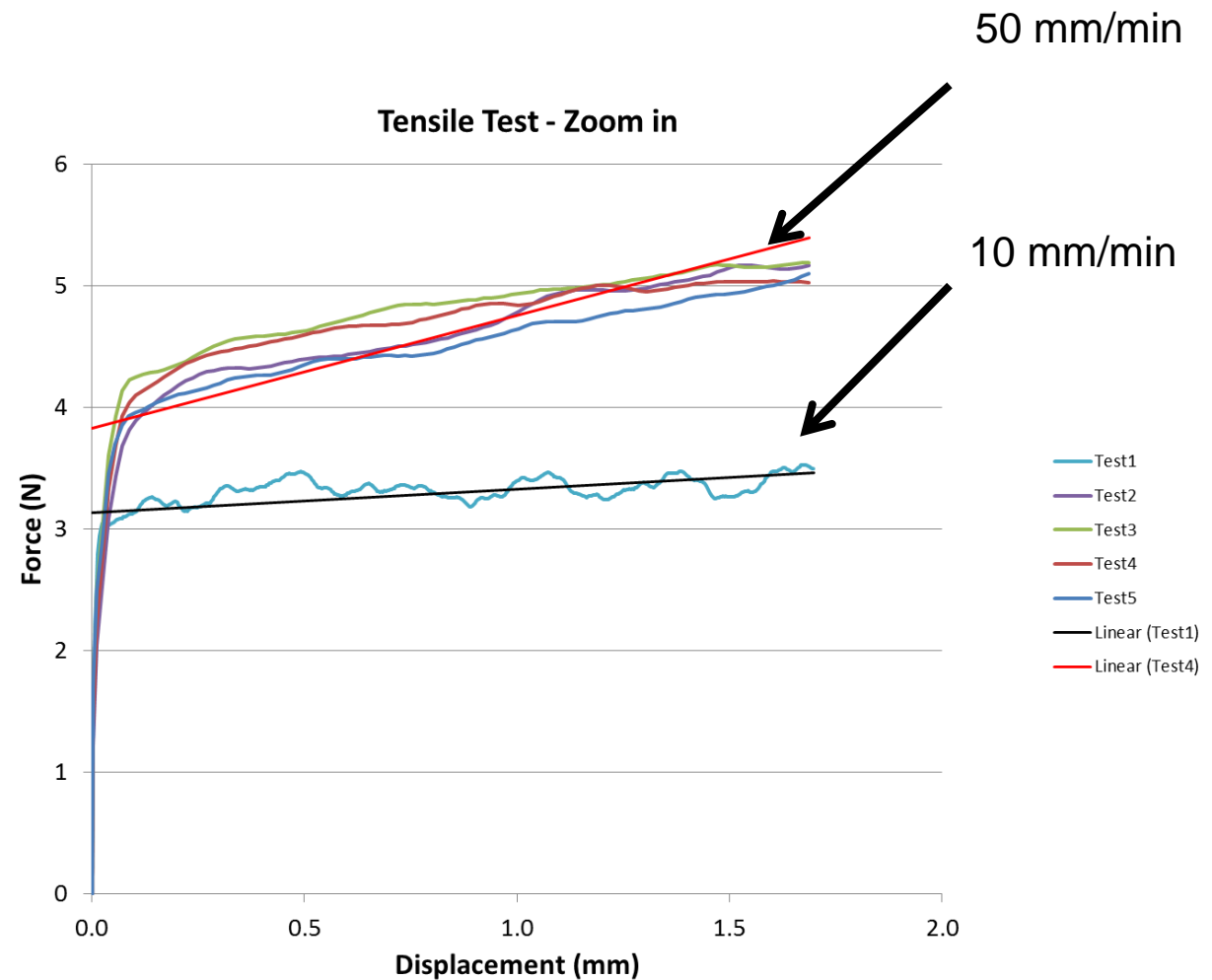
Woven Glass fibre PA6



Carbon Fiber Polypropylene woven fabric

Test Devices at TUM-LCC

Tensile test perpendicular to fibre direction - UD CF/PA6



Test Devices at TUM-LCC

Pre-impregnated composites

DMA system
TA Instruments Q800



Source: TA Instruments



Single cantilever



Double cantilever

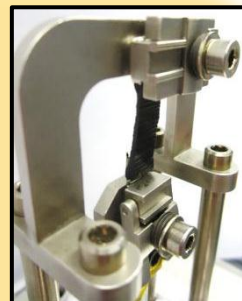
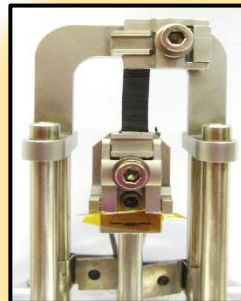


3 point bending
(20mm)



3 point bending
(50mm)

Bending tests

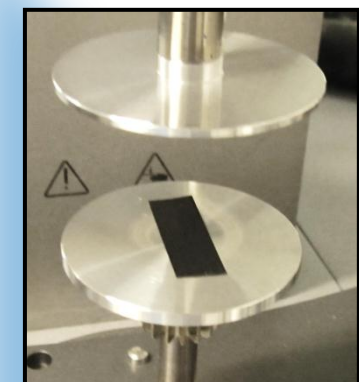


Tensile test

Rheometer
Anton Paar MCR302



Source: Anton Paar

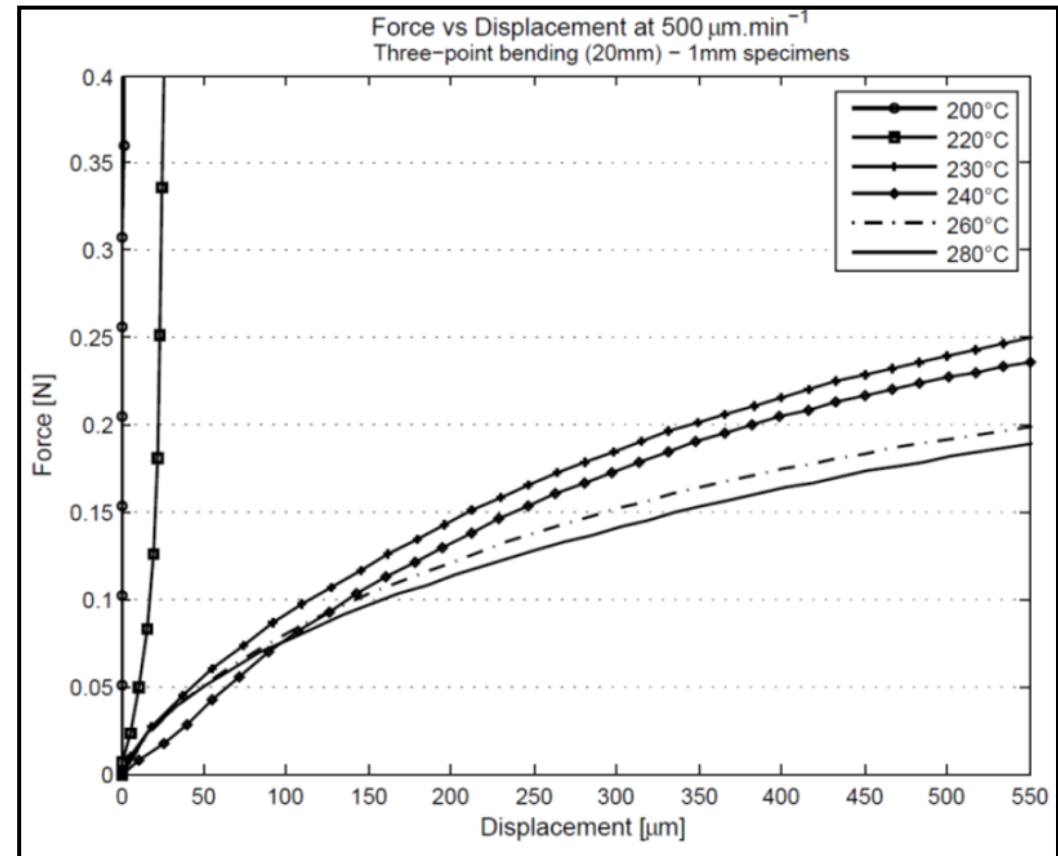
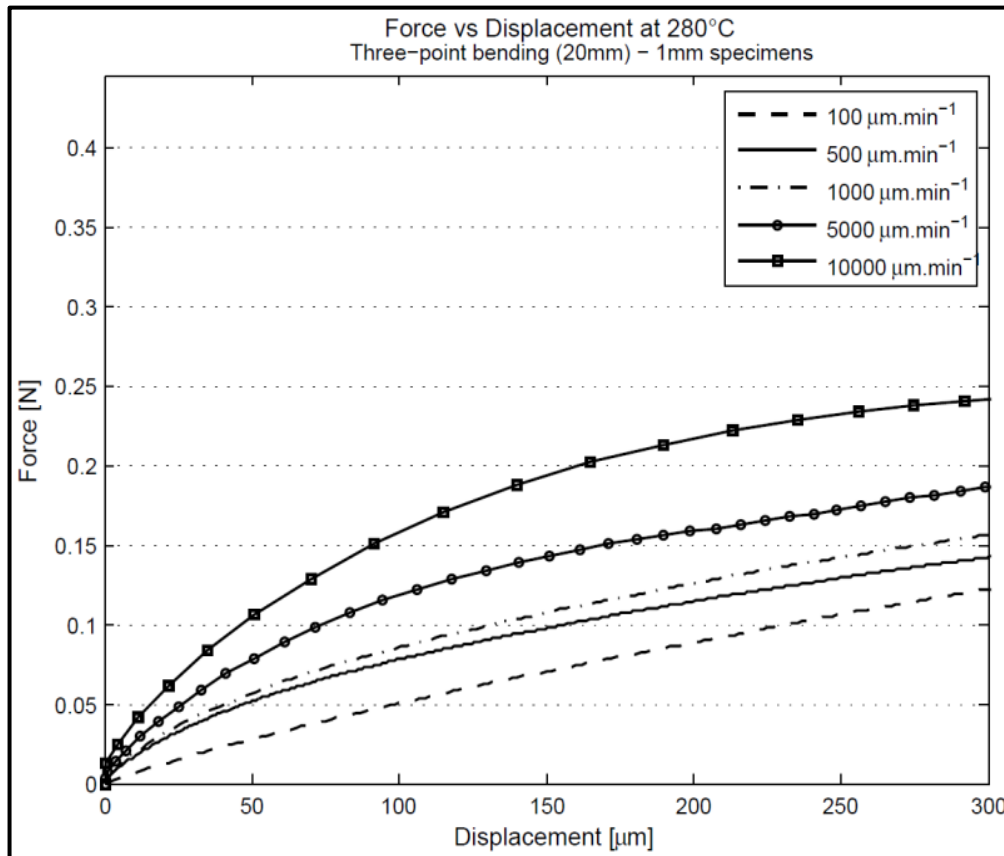


Shear test

Test Devices at TUM-LCC

Temperature and displacement rate dependencies (DMA - 3pt20)

- Quasi static, 3-point-bending (20mm), UD CF/PA6

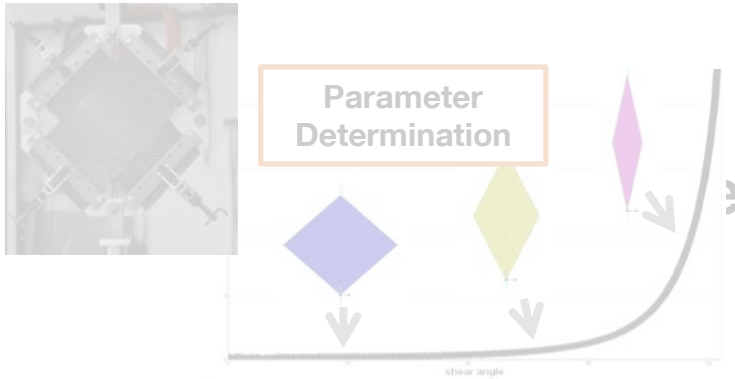


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Material characterization and material modelling

- Picture Frame Test
- ...

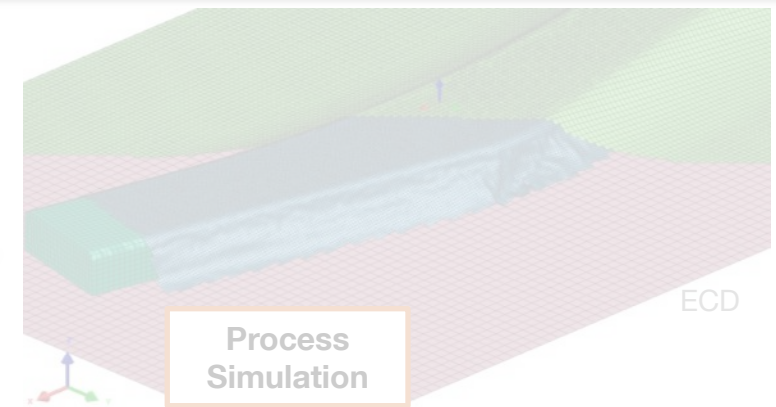
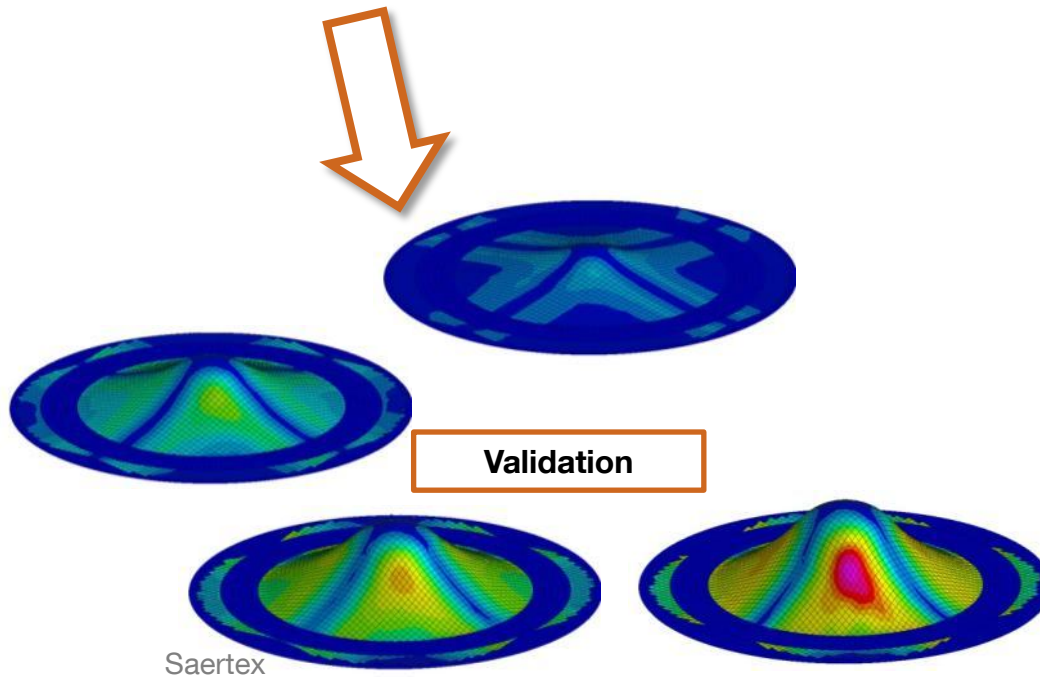


Validation on test geometry

- Hemisphere
- Double Dome
- ...

Process simulation (design and optimization)

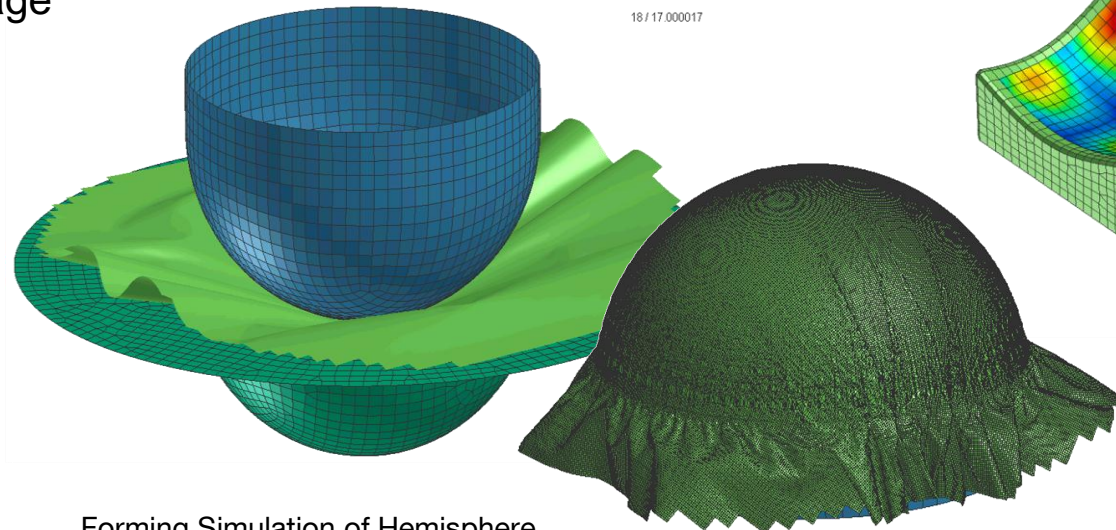
- Diaphragm draping
- Drape forming
- Hand lay-up
- ...



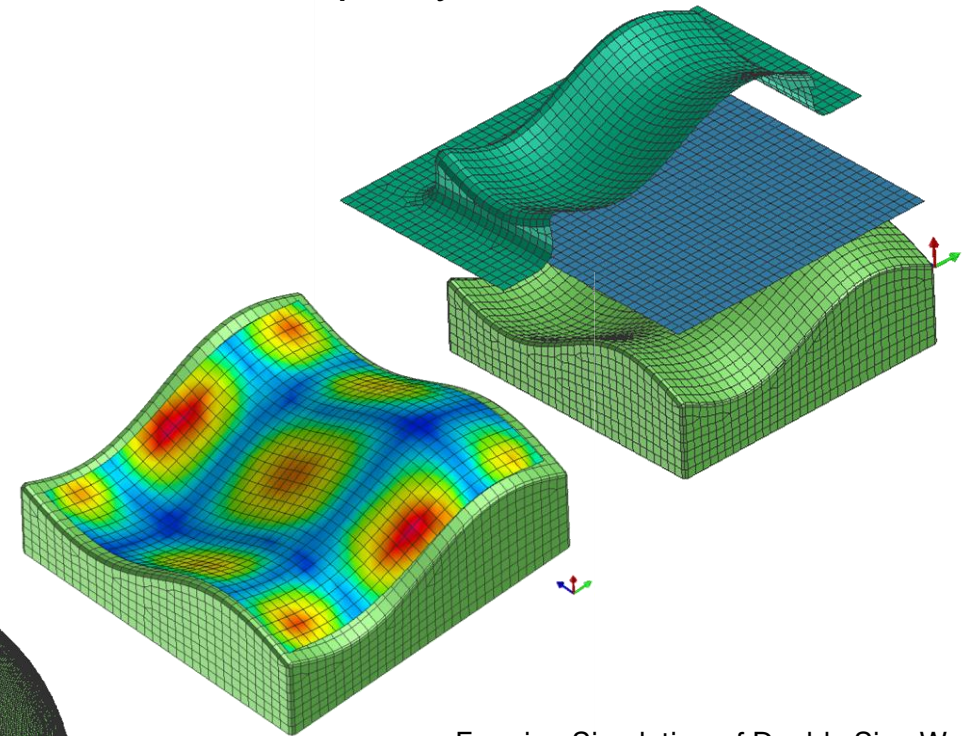
Validation Process on sub-component level

The stamp forming process is simulated to check for the simulation quality:

- Fiber alignment
- Defects (wrinkles, folds, gaps, etc.)
- Process / stamping forces
- Slippage
- ...



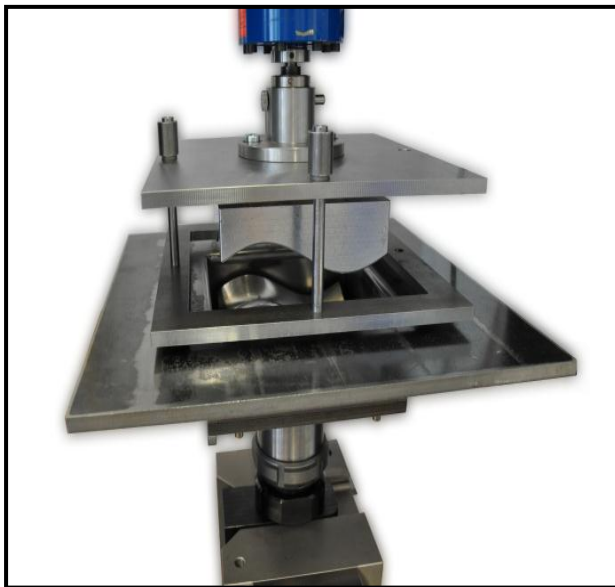
Forming Simulation of Hemisphere



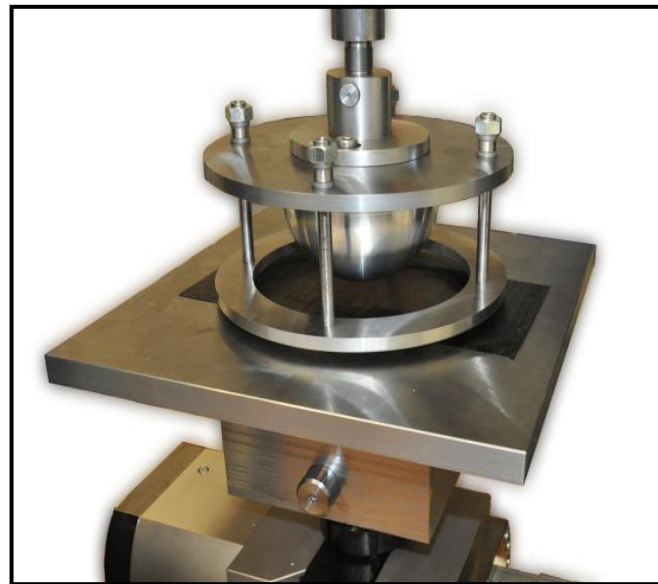
Forming Simulation of Double Sine Wave

Validation Process on sub-component level

Can be used within the environmental chamber
of the testing tensile machine



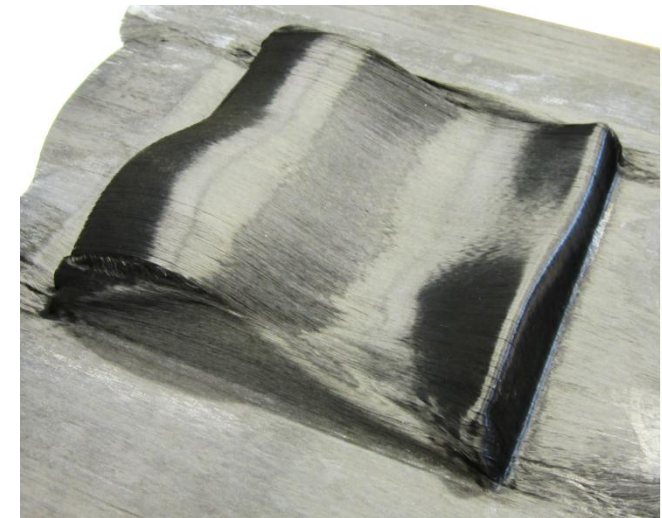
Double-wave test



Hemisphere test



Hemisphere stamping
UD CF/PA6 plate

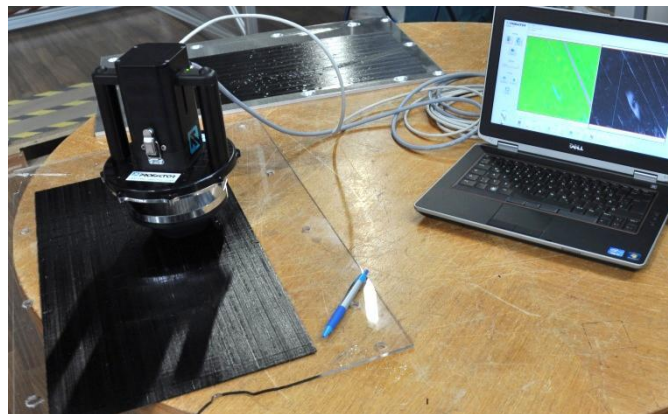
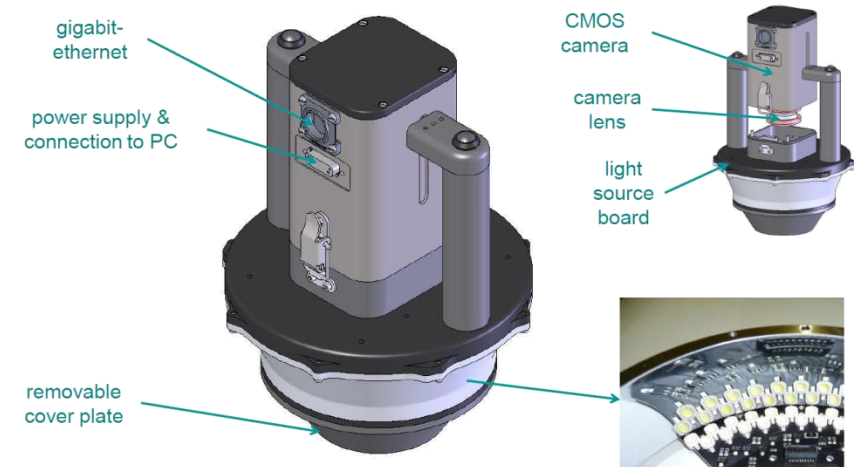


Double Sinus stamping
UD CF/PA6 plate

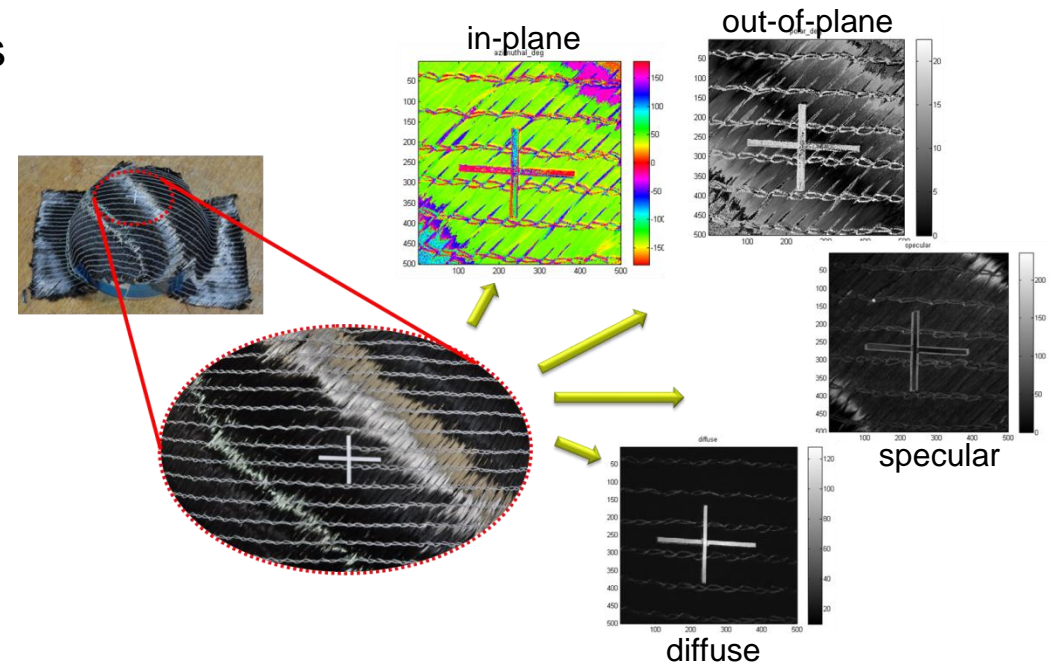
Analyzing the Test Results

Use of **PROFACTOR Fiber Angle Sensor** planned

- Optical sensor to measure
 - in-plane fiber angle
 - out-of-plane fiber angle
 - Live measurement
 - Manual mode
- to compare test results with simulation results



PROFACTOR Sensor Testing at LCC



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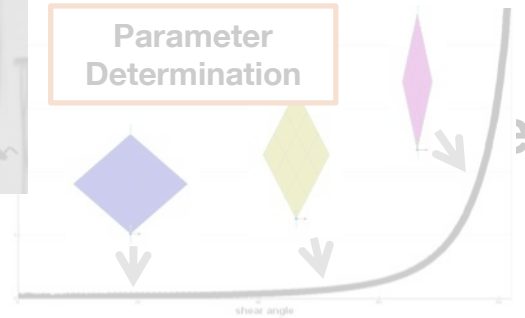
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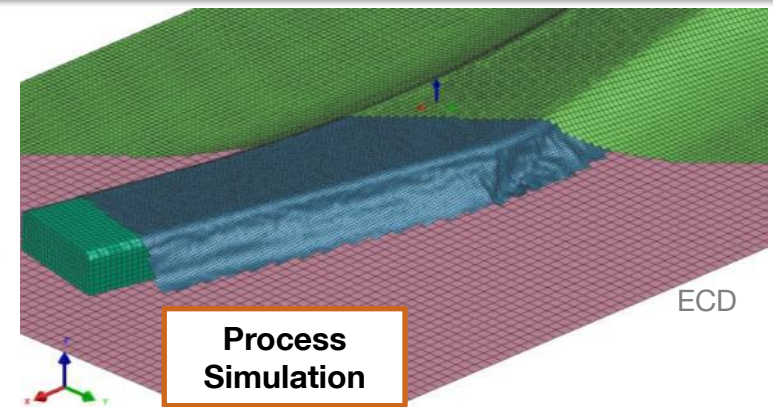
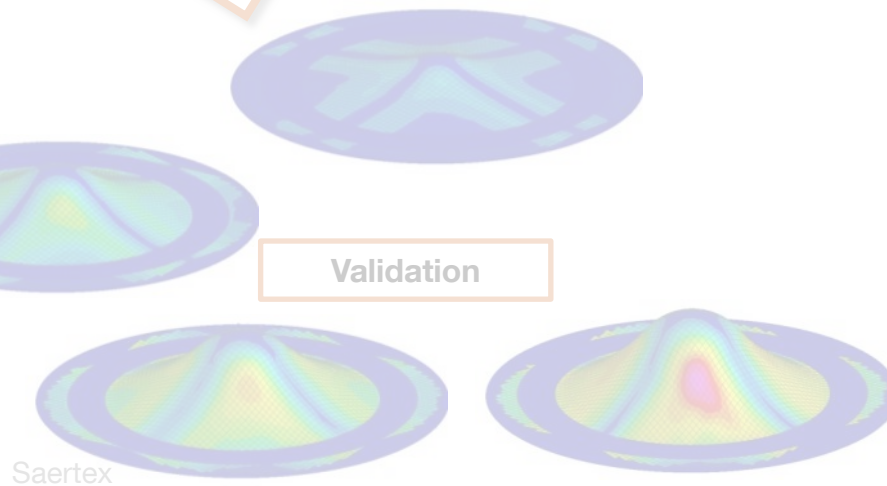
Process simulation (design and optimization)

- Diaphragm draping
- Drape forming
- Hand lay-up
- ...

Parameter Determination



Validation



Process Simulation

Draping simulation of dry NCF stacks

Case study 1

Work performed in collaboration with Airbus Helicopters Deutschland GmbH

Single Diaphragm Draping Process - Principle

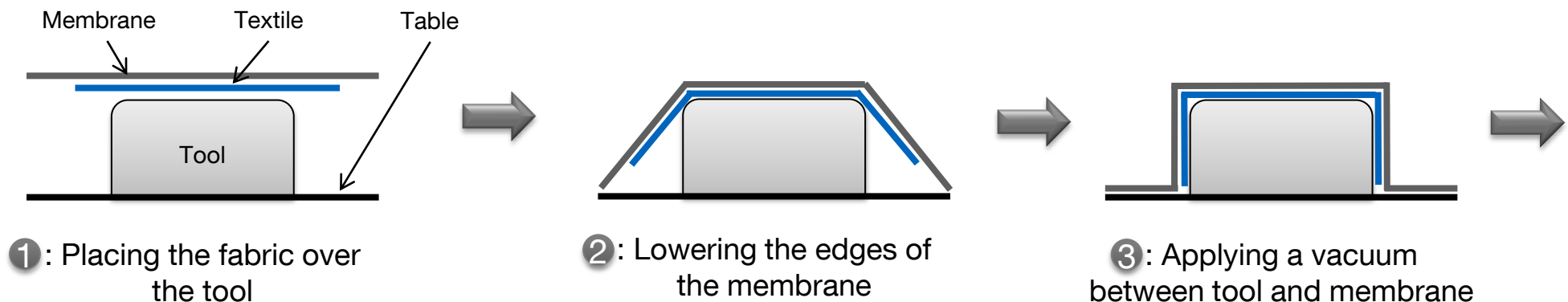
- Simulation of the diaphragm draping process on a generic helicopter frame with biaxial NCF



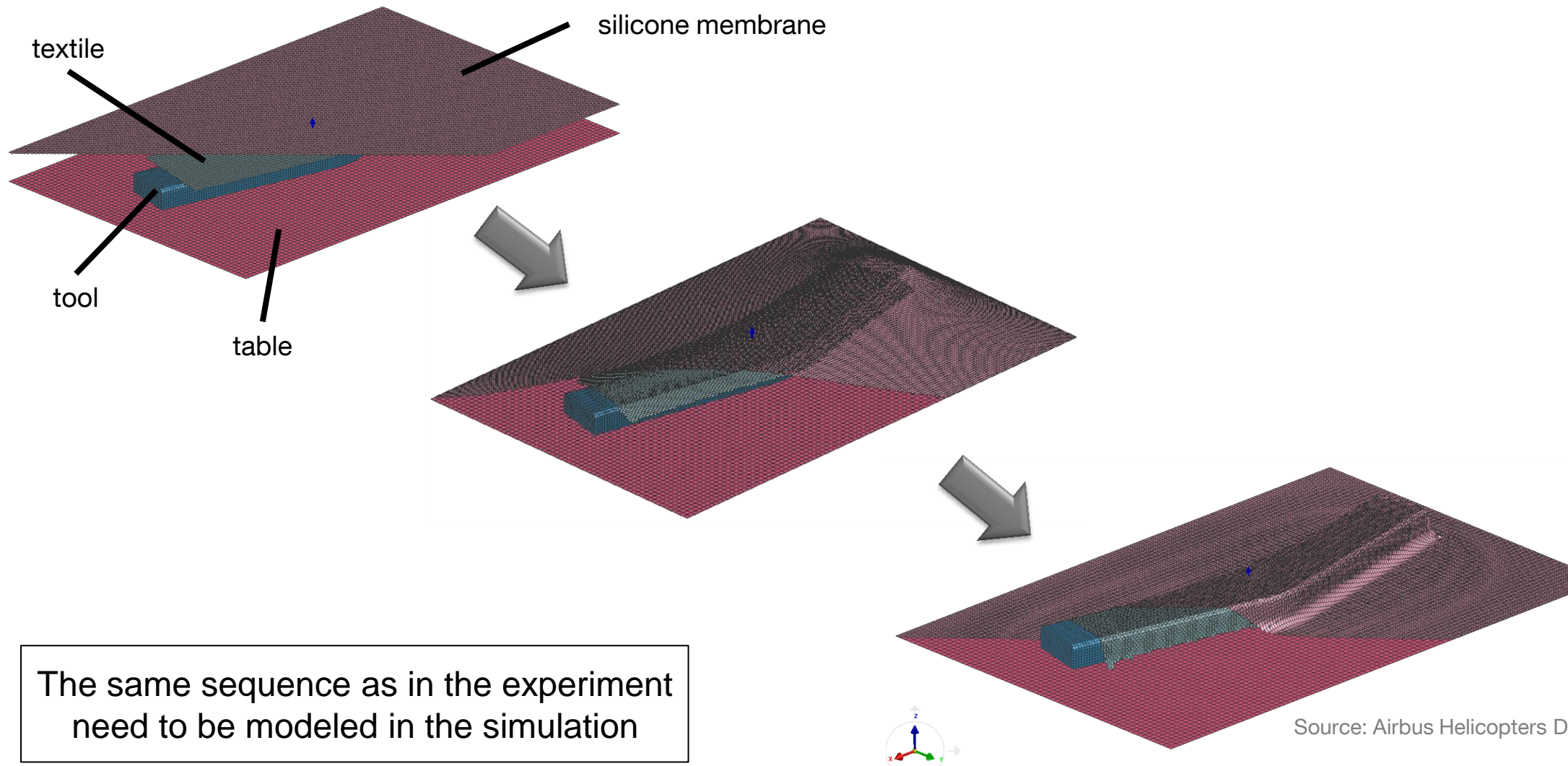
Source: Airbus Helicopters DE

Principle:

Draping of a textile with a silicone membrane (diaphragm)

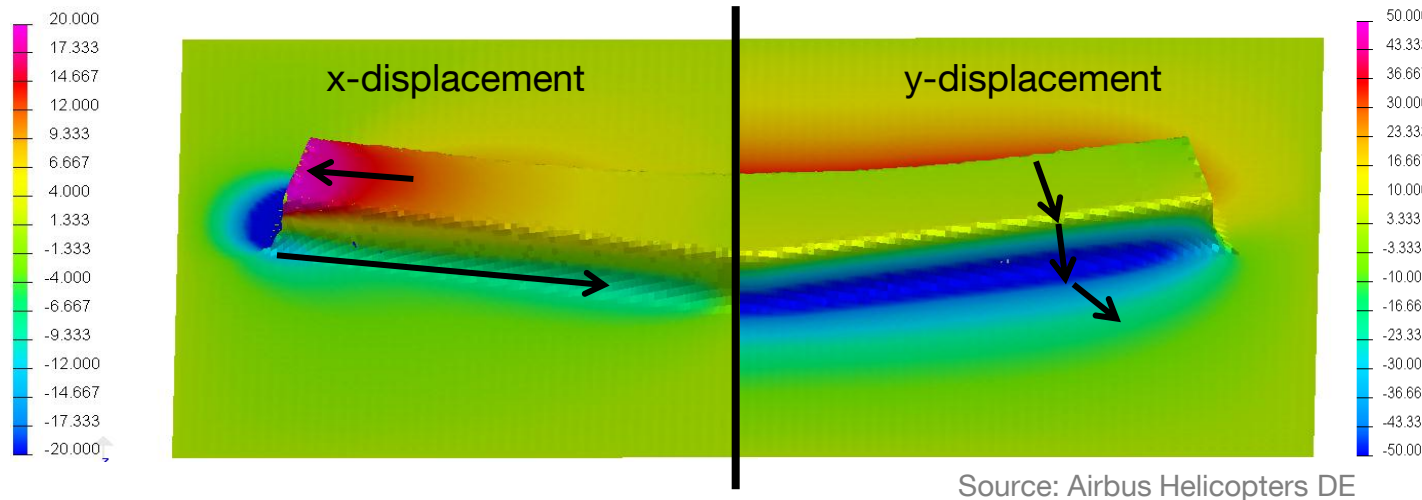


Diaphragm Draping Process – Macroscopic Model Setup

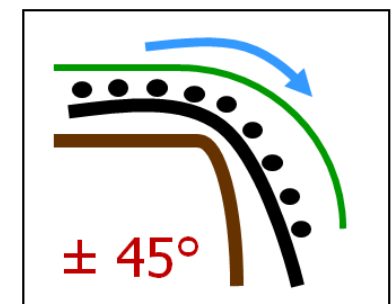
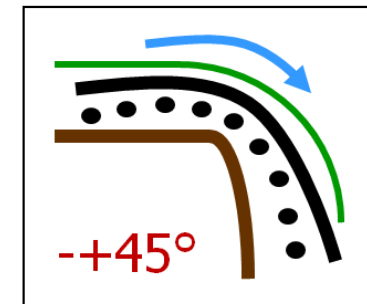


Diaphragm Draping Process - Effects

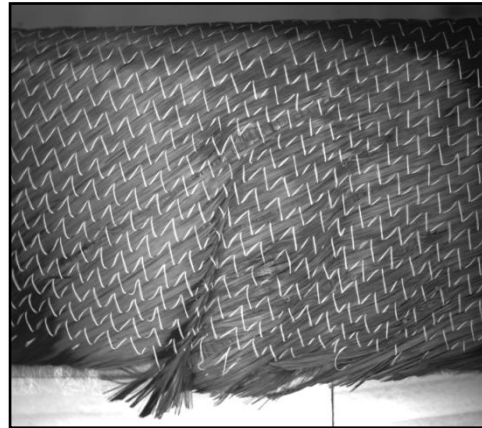
Relative movement between membrane and textile results in high friction forces



An anisotropic friction between membrane and textile needs to be defined

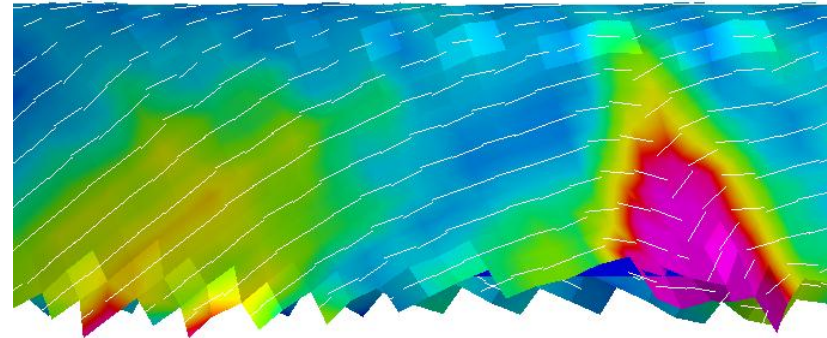
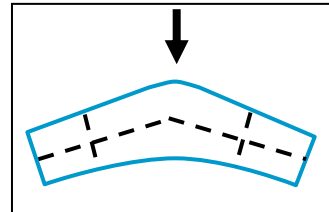


Diaphragm Draping Process – Simulation Results

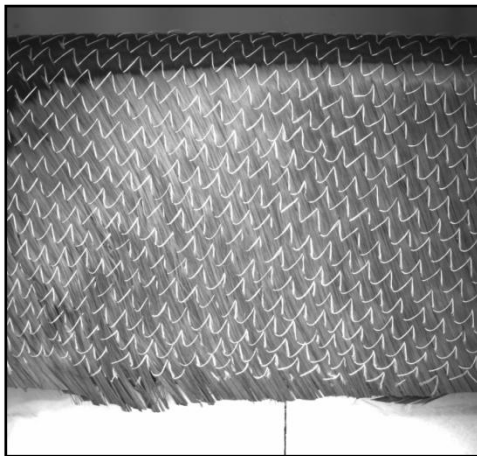


Experiment

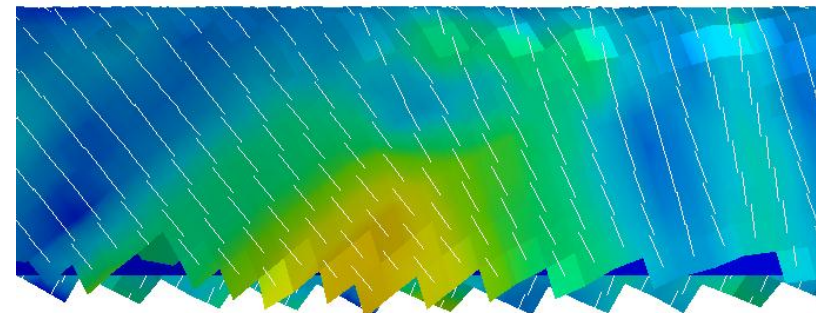
$\pm 45^\circ$ NCF



Simulation



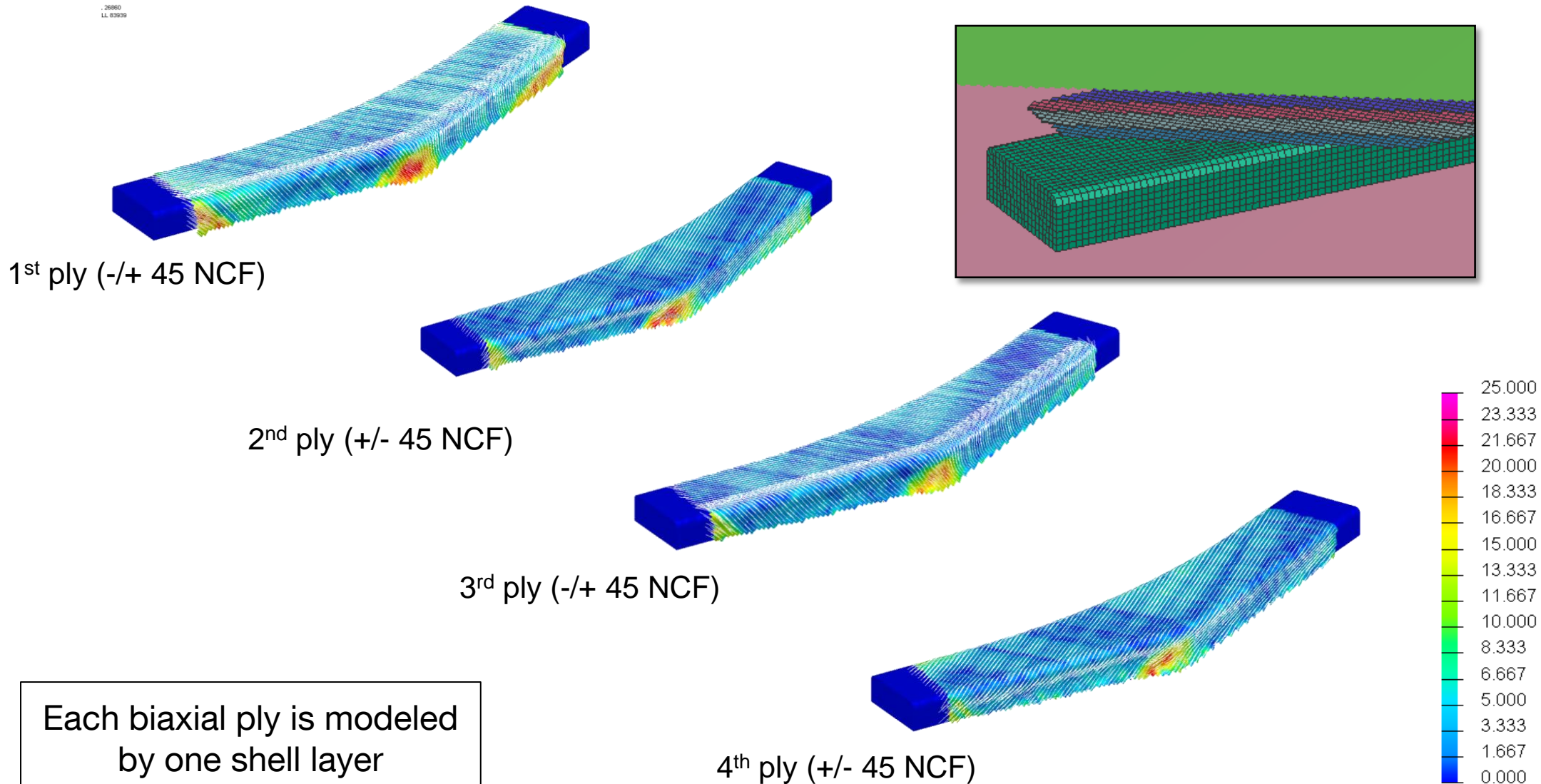
$\mp 45^\circ$ NCF



Contour plot: Fiber strain
Lines: Fiber direction

Source: Airbus Helicopters DE

Diaphragm Draping Process – Multilayer Draping



Draping simulation of stitched NCF stacks

Case study 2

Work published in Composites Part A: Applied Science and Manufacturing

A. Margossian, S. Bel, J.M. Balvers, D. Leutz, R. Freitas, R. Hinterhoelzl. Finite element forming simulation of locally stitched non-crimp fabrics. Composites Part A, 61:152–162, 2014.

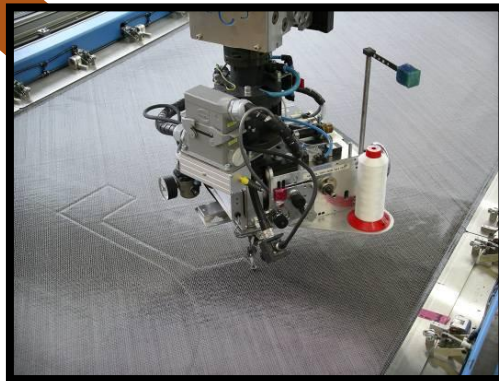
Initial Situation

NCF preform stacks are locally stitched together for better handling

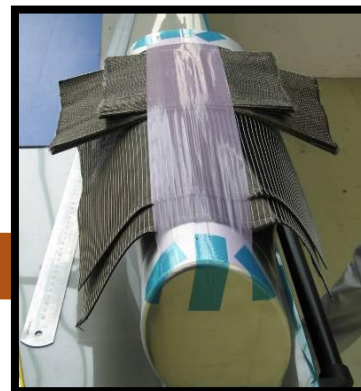
- Stitching can influence the draping result
- Influence of the local stitching needs to be investigated



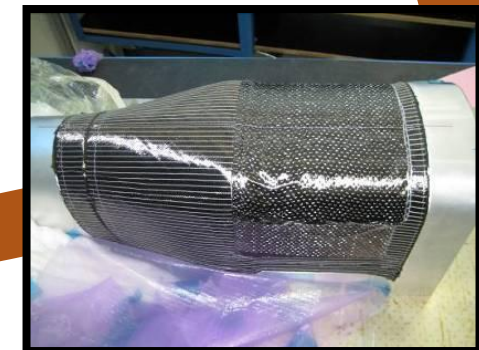
Final Part: Pitch Horn



Sewing of Preform Stack



Lay-up on Tool

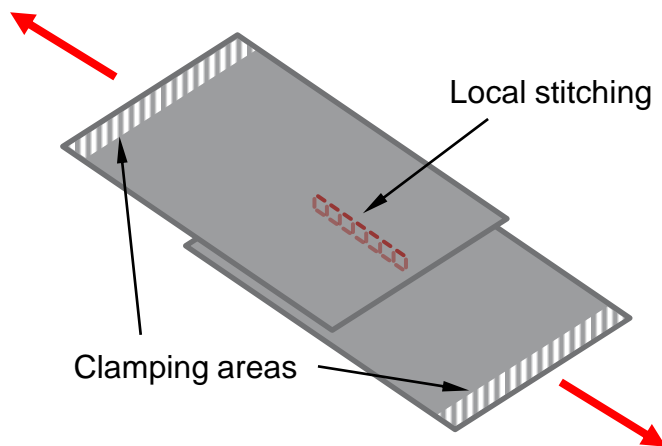


Draping of Stitched Preform Stack

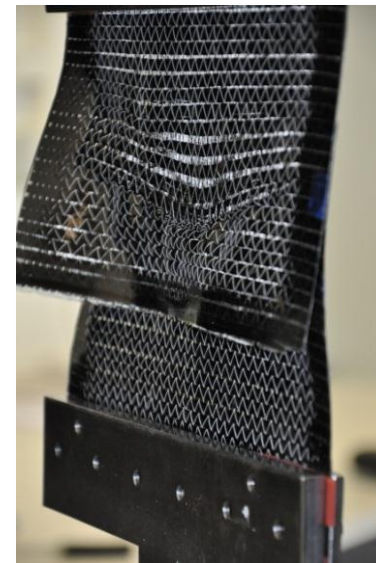
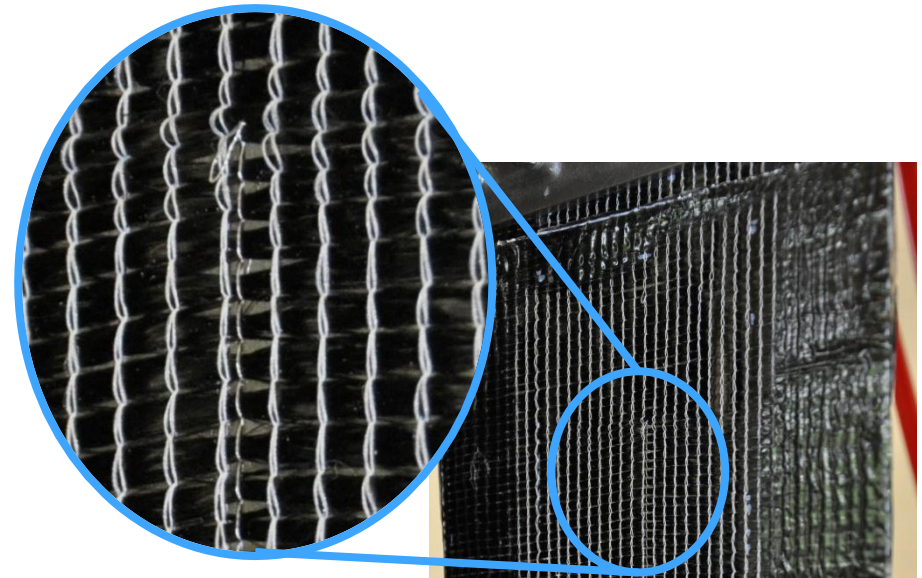
Single-Lap Shear Test

Purpose of test

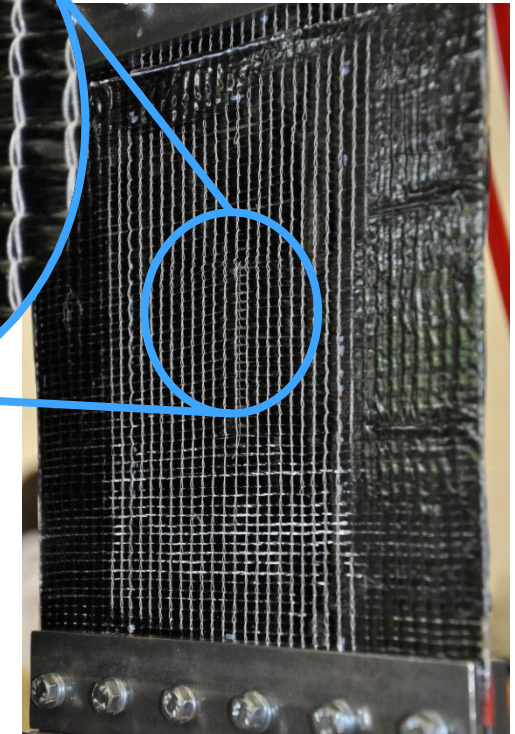
- Investigation of initial state: pretensed stitch <> slack in stitch
- Influence of the stitching on the textile
- Stress-Strain behavior of the textile in the stitching vicinity



Test Setup of Lap Shear Test



Tensile Force applied on Lap Shear Test



Lap Shear Test Setup

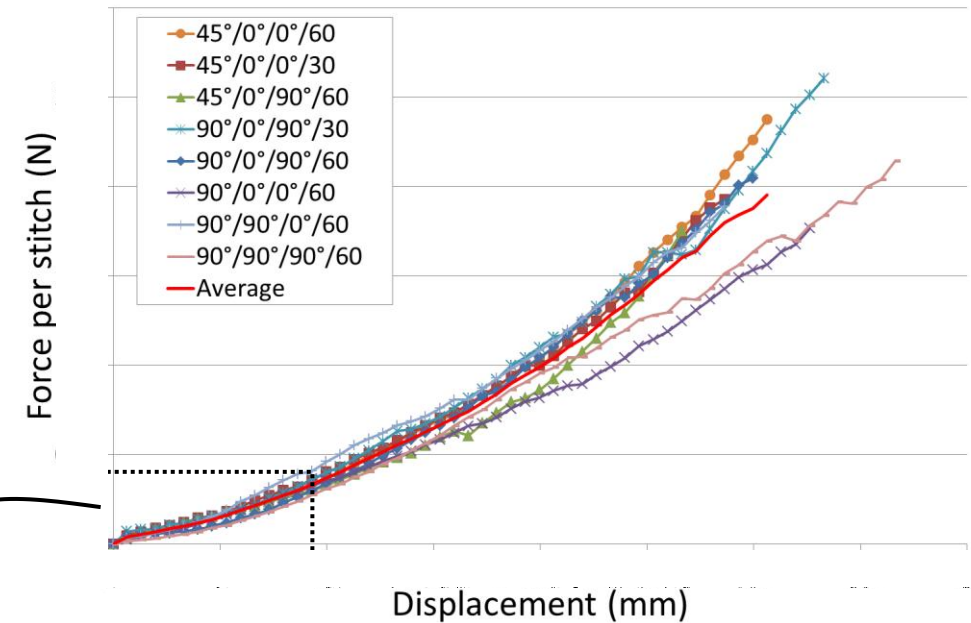
Single-Lap Shear Test - Results

Test results dependency on

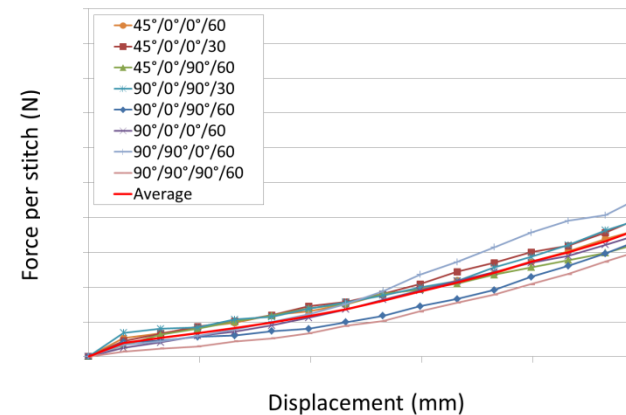
- Alignment of plies ($0^\circ/90^\circ$; $\pm 45^\circ$)
- Orientation of NCF stitching ($0^\circ/90^\circ$)
- Orientation of local seam
($0^\circ \rightarrow$ load direction; 90° perpendicular)
- Length of stitching (30/60 mm)

Examination

- starting behavior showed always the same characteristics \rightarrow slack in stitching
- measured displacement / strain is mainly caused by textile deformation



Force-Displacement Curve of Lap Shear Tests with varying configurations



Starting behavior \rightarrow Slack in Stitching



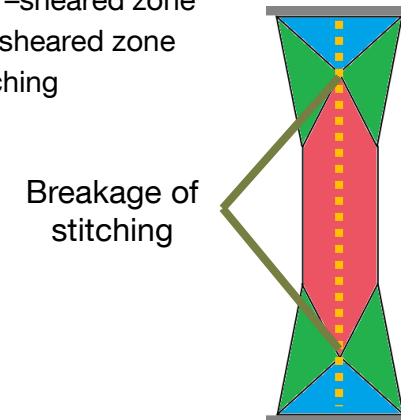
Main Deformation occurred in Textile

Bias Extension Test

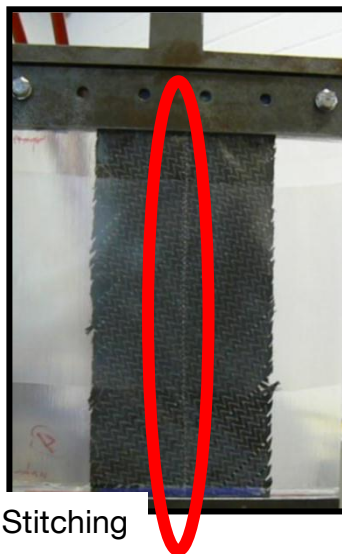
Purpose of test

- Stress-Strain behavior of the stitching
- Tensile modulus of the stitching

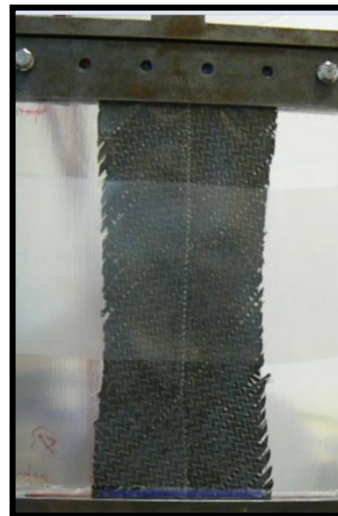
■ non-shear zone
■ half-sheared zone
■ full-sheared zone
--- stitching



Bias Extension Test with Stitching over the whole Length



Stitching

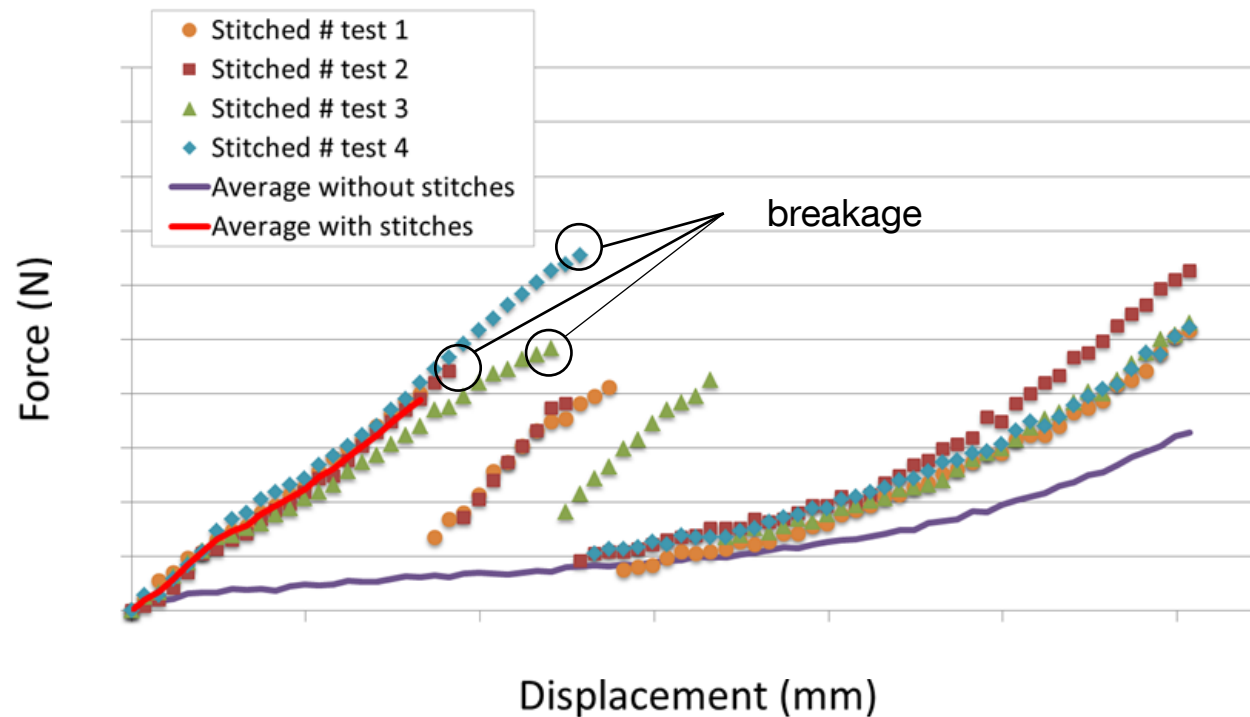


Bias Extension Test using a Single Ply with the Stitching running from Clamp to Clamp

Bias Extension Test - Results

Examination

- only stitching behavior is tested
- stitching does not influence shear behavior, fiber pull-out or bending behavior of the textile

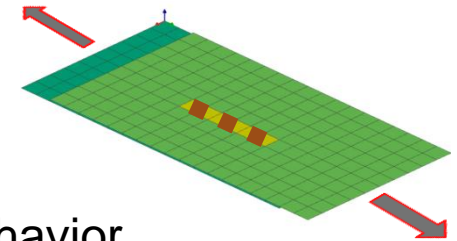


Load-Displacement Curve of Bias Extension Test showing the maximum bearable force and the stepwise breakage of the stitching. For comparison non-stitched bias extension tests result is also included.

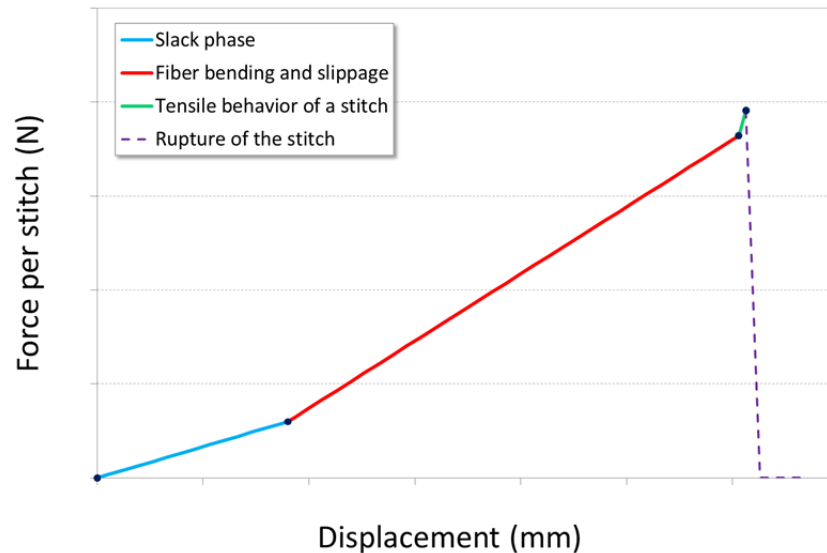
Simulation Results for Single-Lap Shear Test

Simulation results showed good correlations to the experiment

- Tri-linear force-displacement curve is a good approximation of the real behavior
- Rupture modeling of the PLINKS shows the same maximum force as in experiment

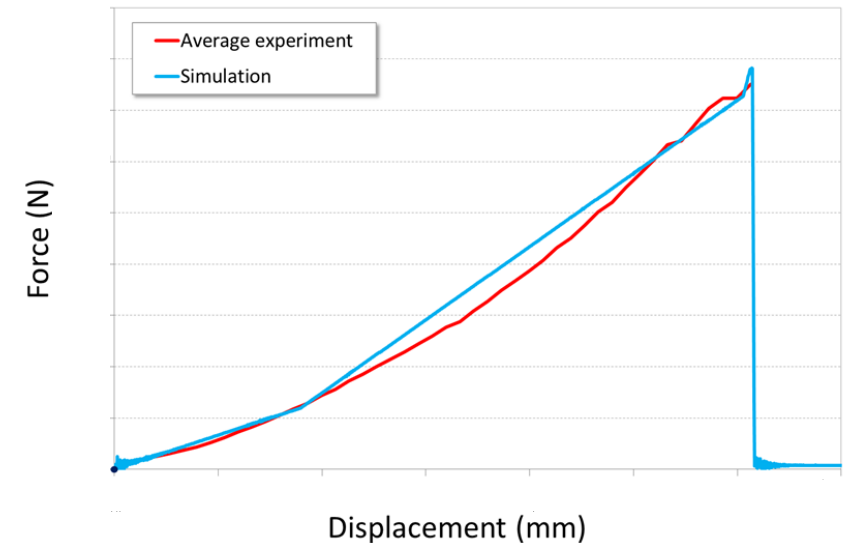


Simulation Input



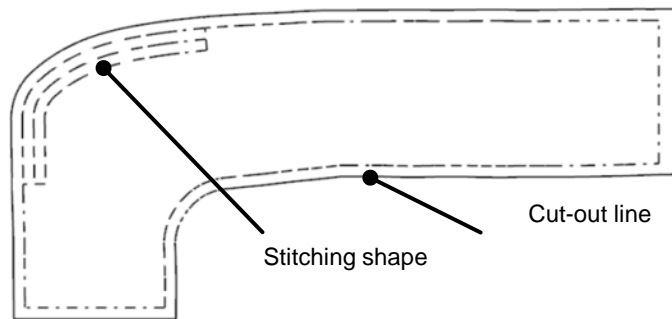
Load-Displacement curve for PLINKS elements

Simulation Output

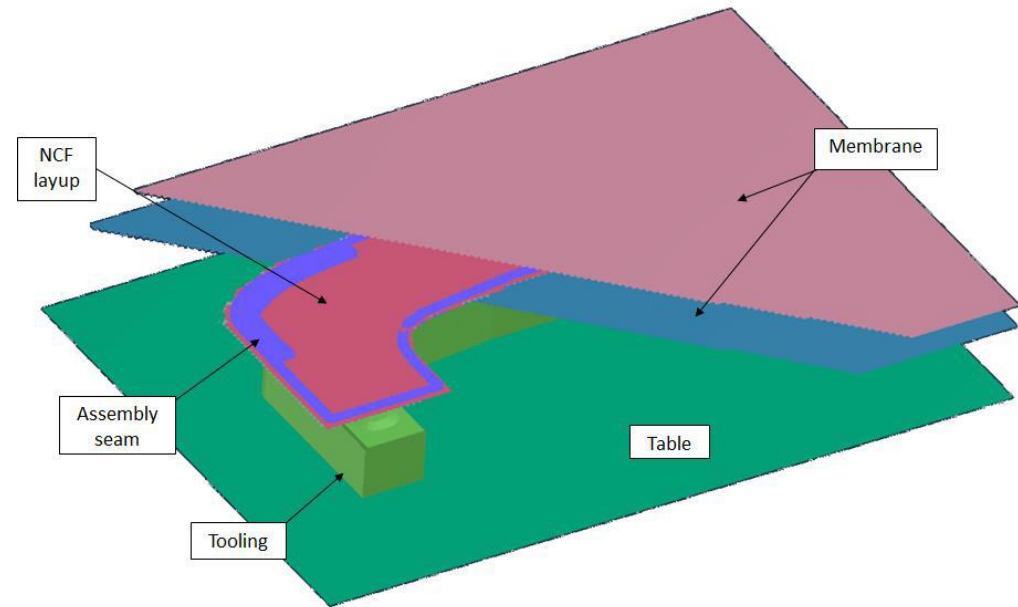


Load-Displacement curve for single lap shear test, comparison between experiments and simulation for a 60 mm seam

Simulation of double diaphragm forming process



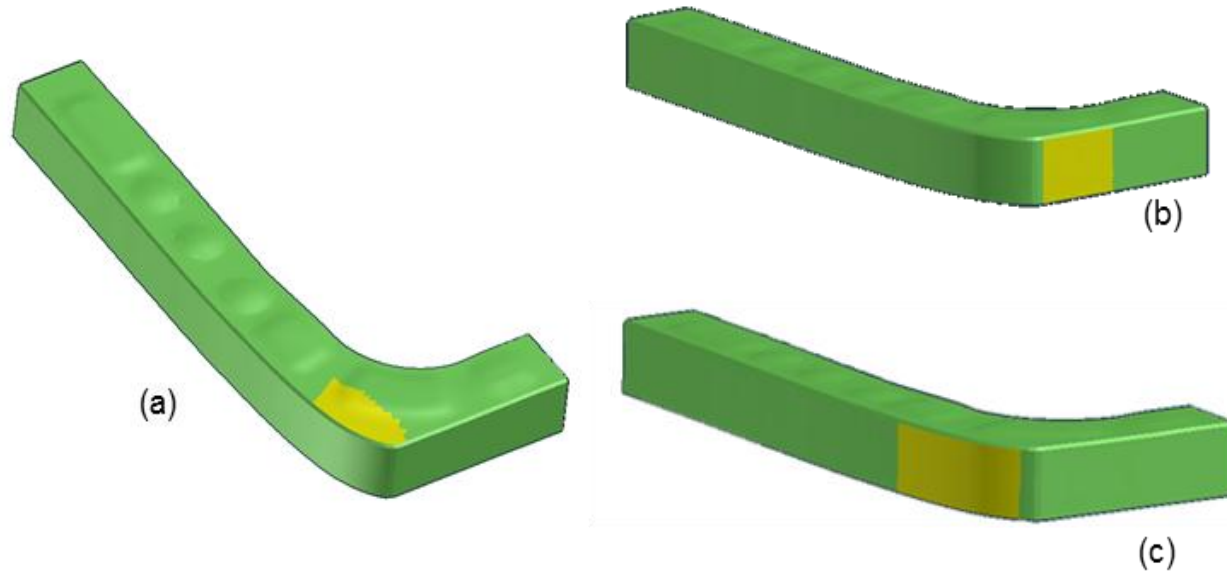
Stitching and cut-out lines



Overview of the simulation model

- Comparison on a real forming process : generic double curved helicopter frame
- FE meshing automatically created from CAD data

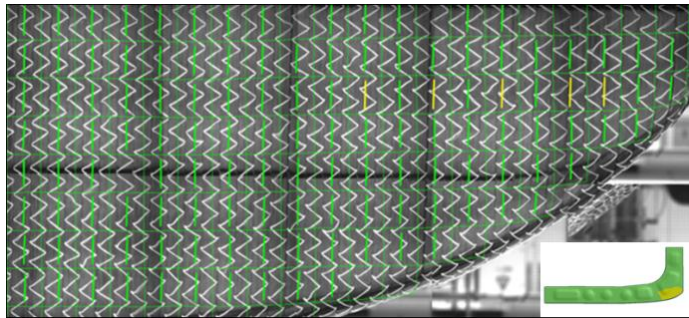
Measurement system



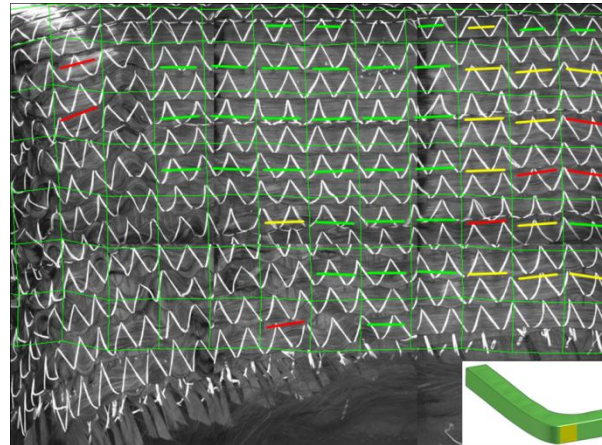
Regions of Interest (ROI), (a) web, (b) short outer flange, (c) long outer flange

- Comparison between fiber orientation of the outer layer of experiment and simulation
- Optical measurement : **EuroPAS** (Eurocopter Preform Analysis System)
- 3 regions of interest: web (a, reference), short outer flange (b) and long outer flange (c)

Comparison



Region a



Region b



Region c

- ROI a : reference, few differences
- ROI b : overall good correlation
- ROI c: Not satisfying → simulation needs to be improved

Layup	Part	Average angle difference	Standard deviation
[0/90 // -/+45]	ROI a	1,89°	1,07
	ROI b	4,7°	5,28
	ROI c	13,15°	6,85

Comparison



ROI c : Comparison with stitched model



ROI c : Comparison with unstitched model

	Good correlation [%]	Fair correlation [%]	Bad correlation [%]	Undetected [%]
ROI c (Comparison with unstitched model)	29,70	35,64	34,65	21,09
ROI c	53,57 (+80,3 %)	18,75 (-47,3 %)	27,68 (-20,1 %)	10,40 (-49,3 %)

Agenda

- 1** Introduction
- 2** Kinematic and Finite Element draping methods
- 3** Macroscopic Finite Element simulations
- 4** Conclusion

Conclusion

- Draping Simulation is used
 - to develop the draping process
 - to shorten the development cycle of composite parts
 - to predict potential draping effects (fiber waviness, gaps etc.)
- Forming determines the fibre orientation of final components
- Material characterization tests must be performed in the same conditions as forming occurs
- Simulation results showed good correlations to experiments.

Contact



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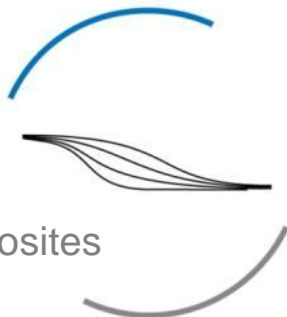
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