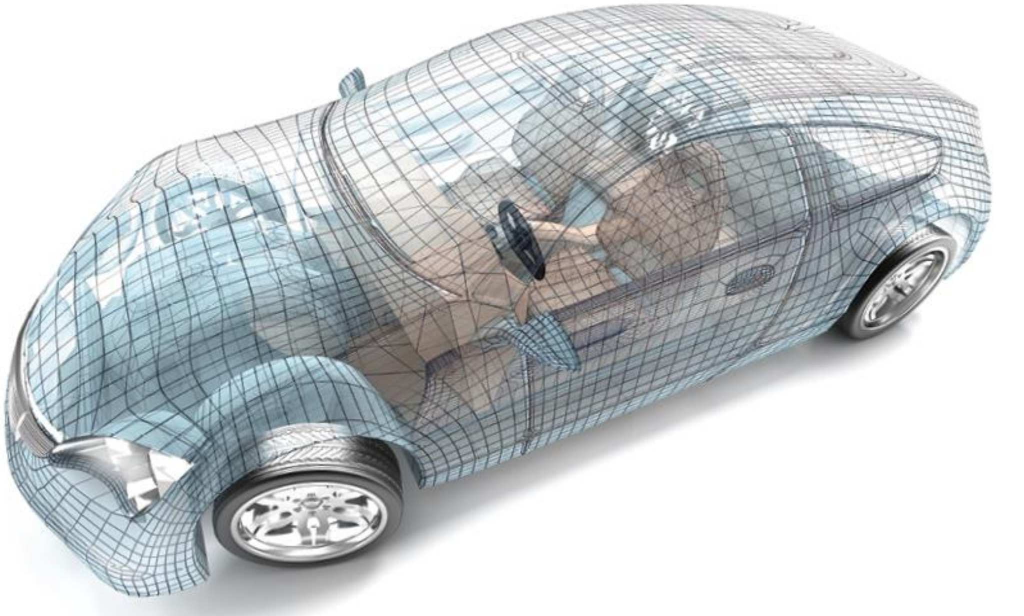
TCC 2020

THERMOPLASTIC COMPOSITES CONFERENCE

A VIRTUAL EVENT

APRIL 29 – MAY 1, 2020



Using process simulation for the advanced forming of a thermoplastic composite part

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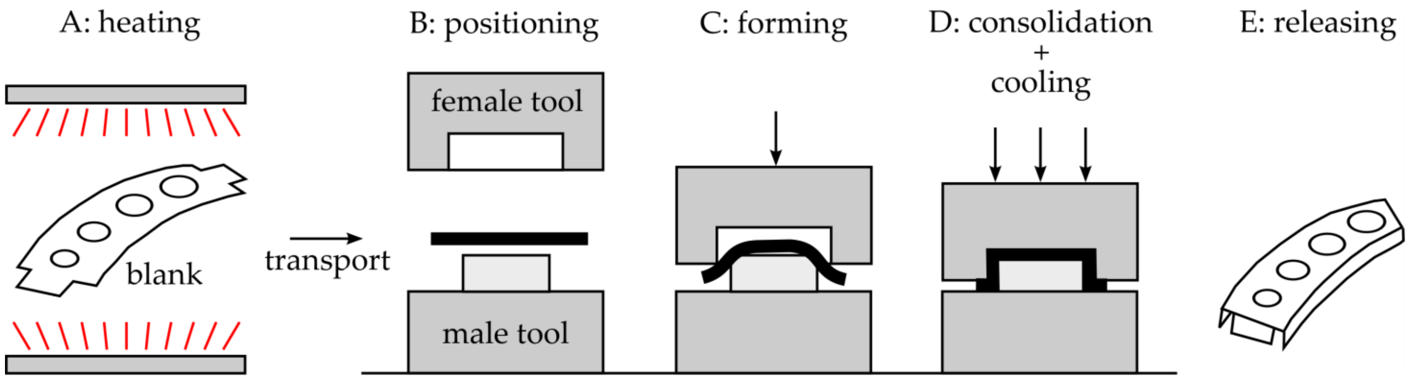
In collaboration with: Noushin Bahramshahi, Collins Aerospace

Introduction

Stamp forming process

- Pre-consolidated laminate heated in IR oven
- Laminate transport to press
- Tool closes to form and (re)-consolidation the product



- Short cycle times
- High mechanical performance
- Cost reduction via high volume production and automation

Introduction

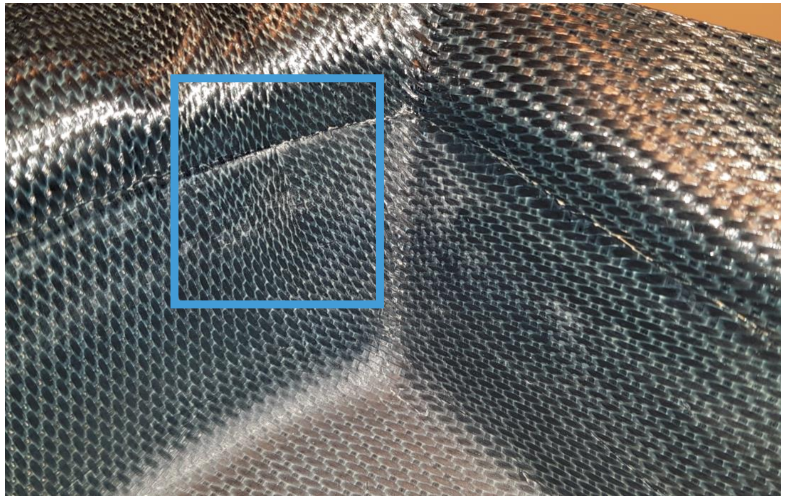
Typical challenges for composite stamp forming:

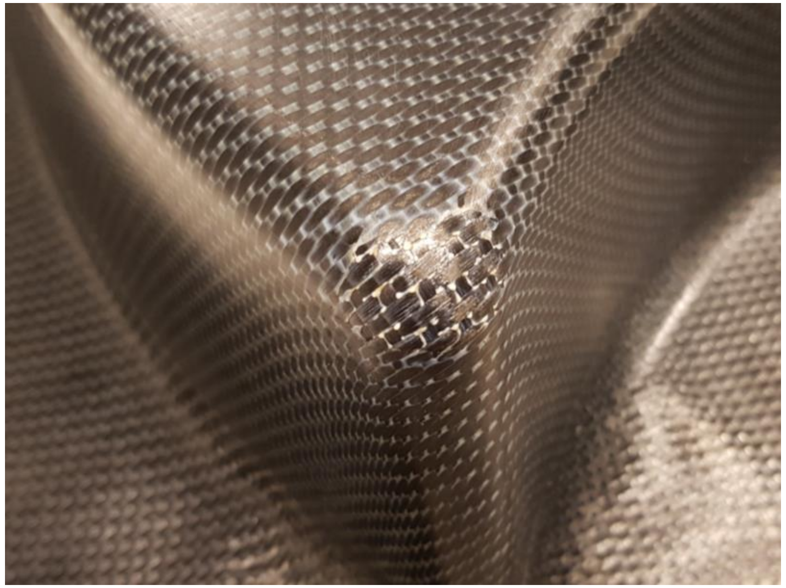
- forming-induced deformation and resulting thickness change;
- wrinkle formation as a result of excessive shearing and/or fiber compression;
- consolidation issues because of fiber tensioning and thickness changes;
- blank misalignment issues and laminate contour optimization for formability.

State-of-the-art simulation techniques:

- provide a better understanding of frequently occurring adverse phenomena in the forming process;
- enable efficiently the study of potentially resolving process configurations;
- contribute to finding the optimal process solution.

ANIFORM's simulation technology supports these design efforts





Case study overview

Demonstrate state-of-the-art technology by:

Case 1 - Large aerospace part

- Study the formability and forming-induced effects as a function of part-size

Case 2 - Overmolding demonstrator

- Determine near net-shape laminate contour and identify potential blank alignment issues in a closed cavity

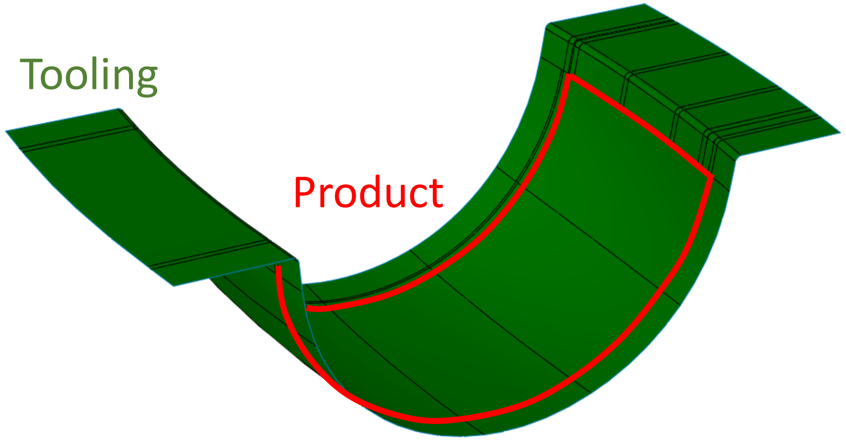
Case 3 – Deep box with concave & convex flanges

- Optimize for minimal wrinkle formation

Case study 1 – Large aerospace part

Goal
- Study the formability and forming-induced effects as a function of part-size

Simulation setup
- Toray Cetex® TC1225 (carbon fiber/PAEK) unidirectional tape
- Laminate
  - 11 plies, quasi-isotropic layup
  - Dimensions 5800 x 2500 mm
- Closing speed 1000 mm/s

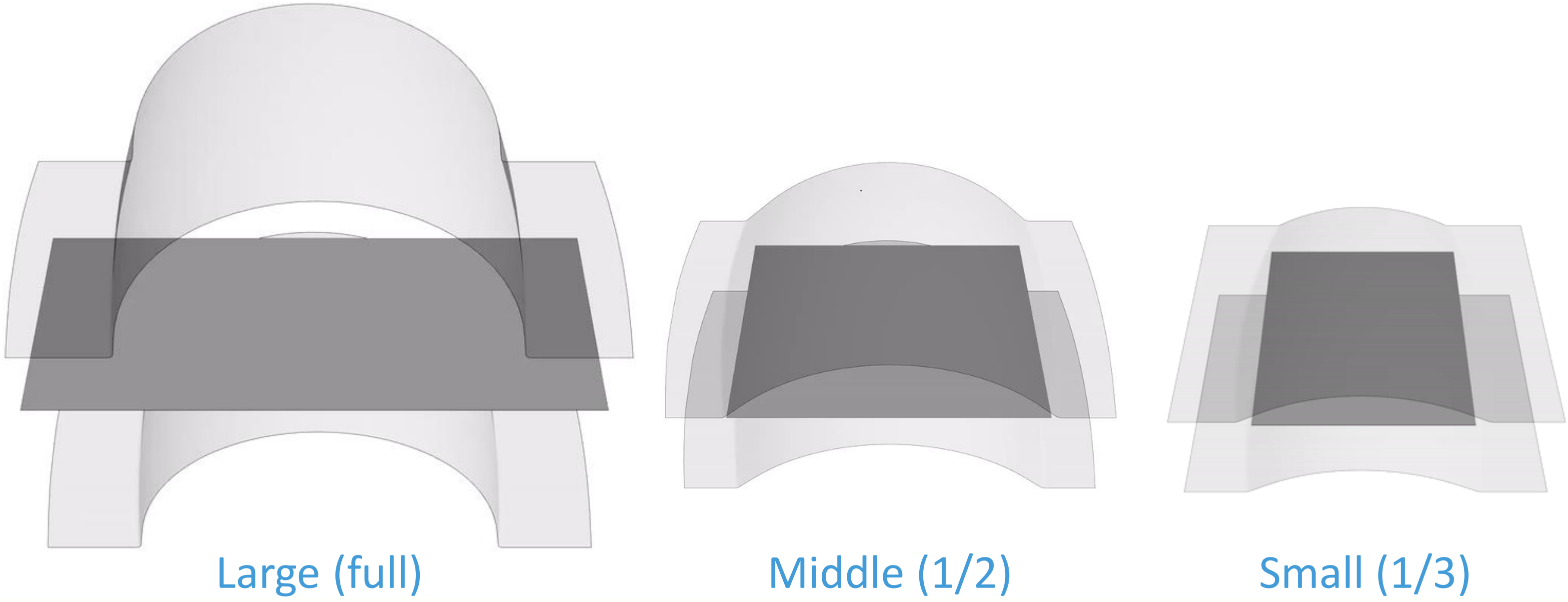


Case study 1 – Large aerospace part

Scalability study

- How does the deformation and resulting fiber stress scale with the product dimension?

- Deformation of laminate is primarily single curved (cylinder–like)
- Double curvature is introduced in the last steps



Case study 1 – Large aerospace part

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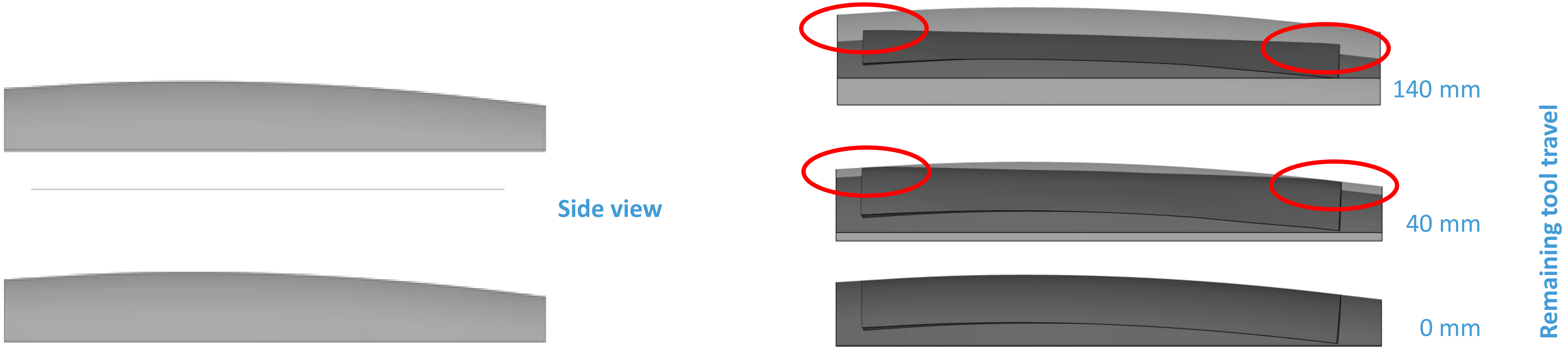
Scalability study

- Near the edge of the laminate excess material is present
    - In-plane shear might resolve the excess material



Case study 1 – Large aerospace part

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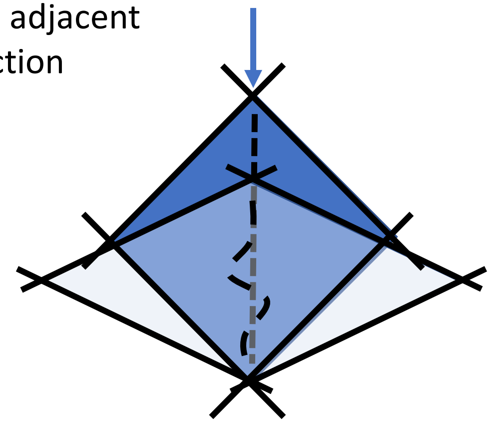
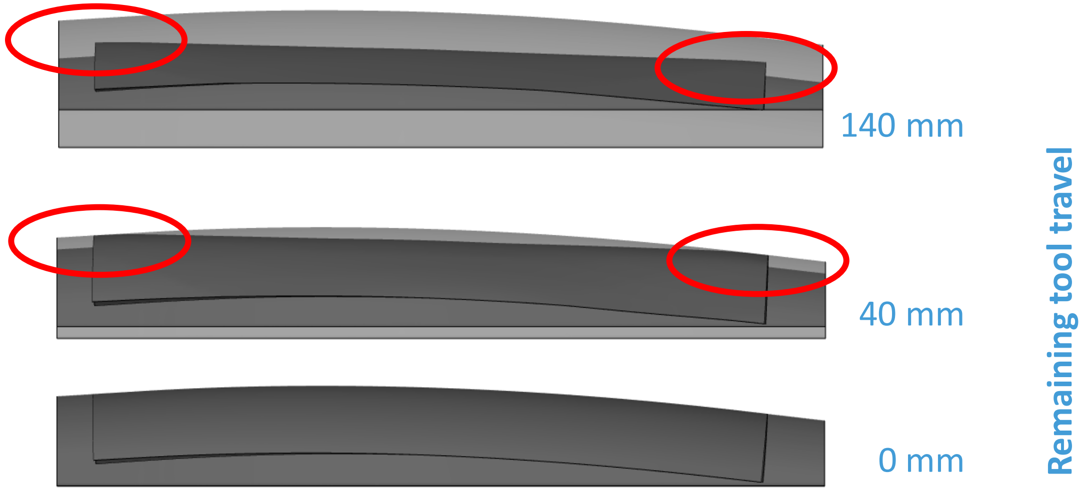
Scalability study

- Near the edge of the laminate excess material is present
    - In-plane shear might resolve the excess material
        - Quasi-isotropic impedes mobility since a fiber direction is present in the shearing direction
    - Compressive stresses arise in this region, which indicates the possible formation of wrinkles

Fiber compaction in adjacent ply in shearing direction





Case study 1 – Large aerospace part

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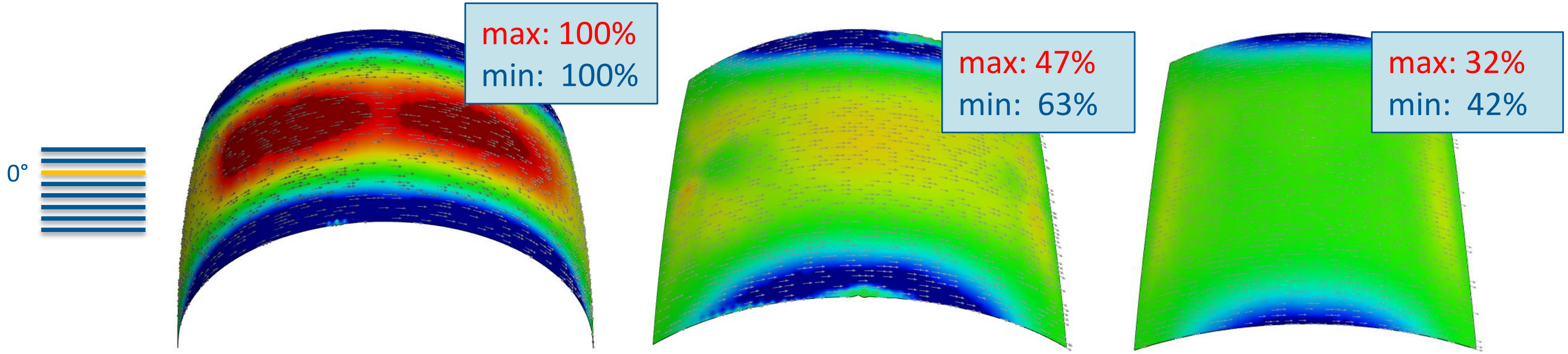
Scalability study

- Compressive stresses reduce with decreasing part size; however they are still high and indicate possible wrinkling
- High fiber tensile stresses are observed in the third (0°), which indicate possible consolidation issues (fiber migration)
    - Decreasing the part size results in a large reduction of fiber tensioning
    - Thickness increase due to surface traction (and consequent in-plane shear) is reduced, thereby increasing the mobility of the laminate



Large (full) | Middle (1/2) | Small (1/3)

Fiber stress
Red: tension
Blue: compression

Case study 1 – Large aerospace part

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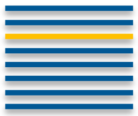
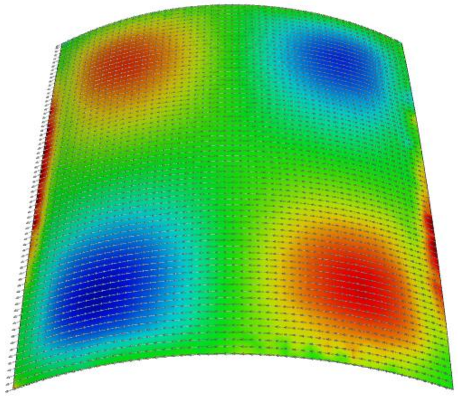
Formability improvements

- Compressive fiber stresses could be resolved by tensioning the laminate using springs
  - High mass of the laminate would require very stiff springs, which might tear the laminate in melt
  - Suitable handling system needs to be investigated
- Promote in-plane shearing in the laminate
  - Decoupling of the fiber directions: two 0° plies translate into two off-axis plies
  - Shear strain increases near the edge, which indicates improvement of mobility

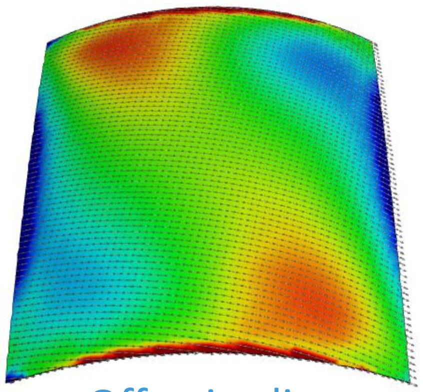
0°





Nominal layup

Small (1/3)



Off-axis plies

In-plane shear strain
Red: positive shear strain
Blue: negative shear strain

Case study 1 – Large aerospace part

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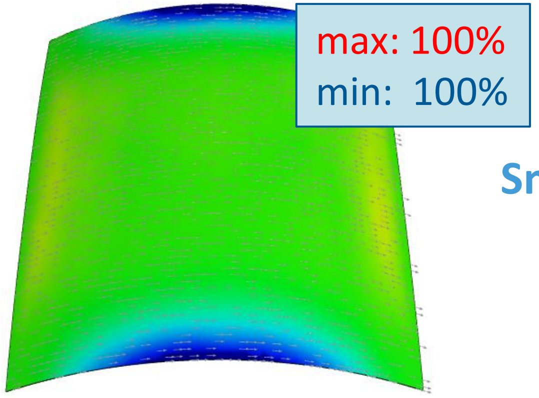
- Promote in-plane shearing in the laminate
    - Decoupling of the fiber directions: two 0° plies translate into two off-axis plies
    - Shear strain increases near the edge, which indicates improvement of mobility
    - Resulting compressive fiber stress is still high however



Nominal layup

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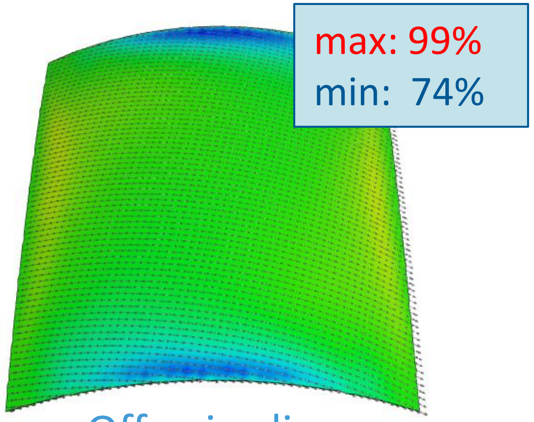


Off-axis plies

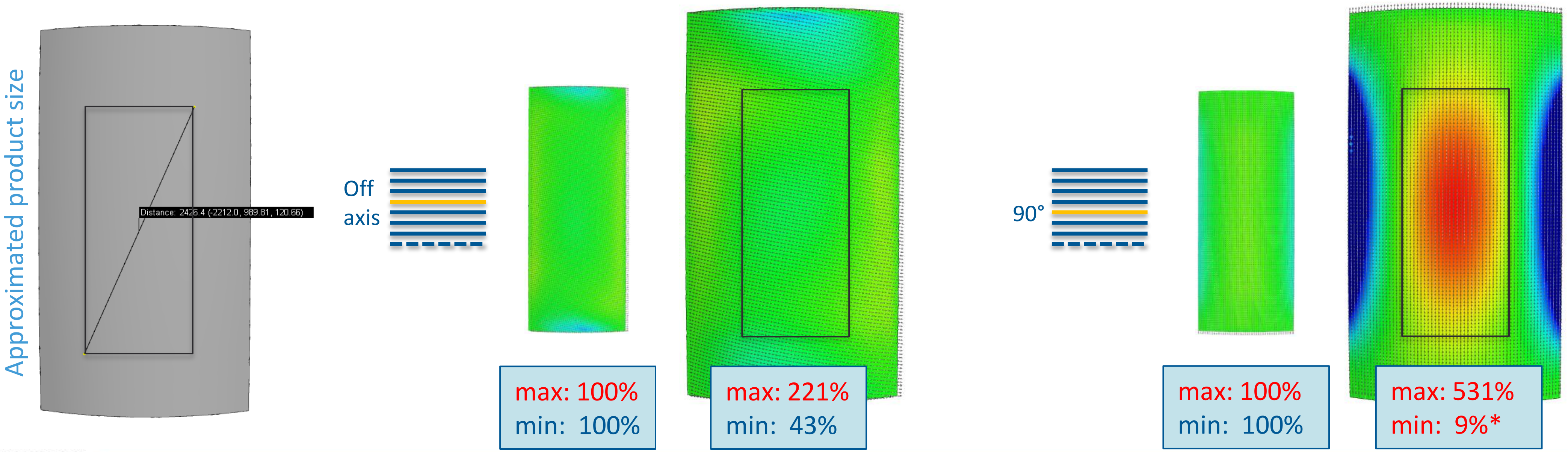
Fiber stress
Red: tension
Blue: compression

Case study 1 – Large aerospace part

TPRC THERMOPLASTIC COMPOSITES RESEARCH CENTER Collins Aerospace

Formability improvements

- Increasing laminate size such that compressive stress are outside the product area
    - Significantly decreases the compressive stress in the plies, however tensile fiber stresses increase which indicate possible consolidation issues
- Optimize laminate dimensions is possible via the usage of simulation tools



Fiber stress in product
Red: tension
Blue: compression

*tensile load

Case study 1 – Large aerospace part

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Simulation tool supported

- Identification of potential critical fiber tensioning and compression
- Its sensitivity to part-size

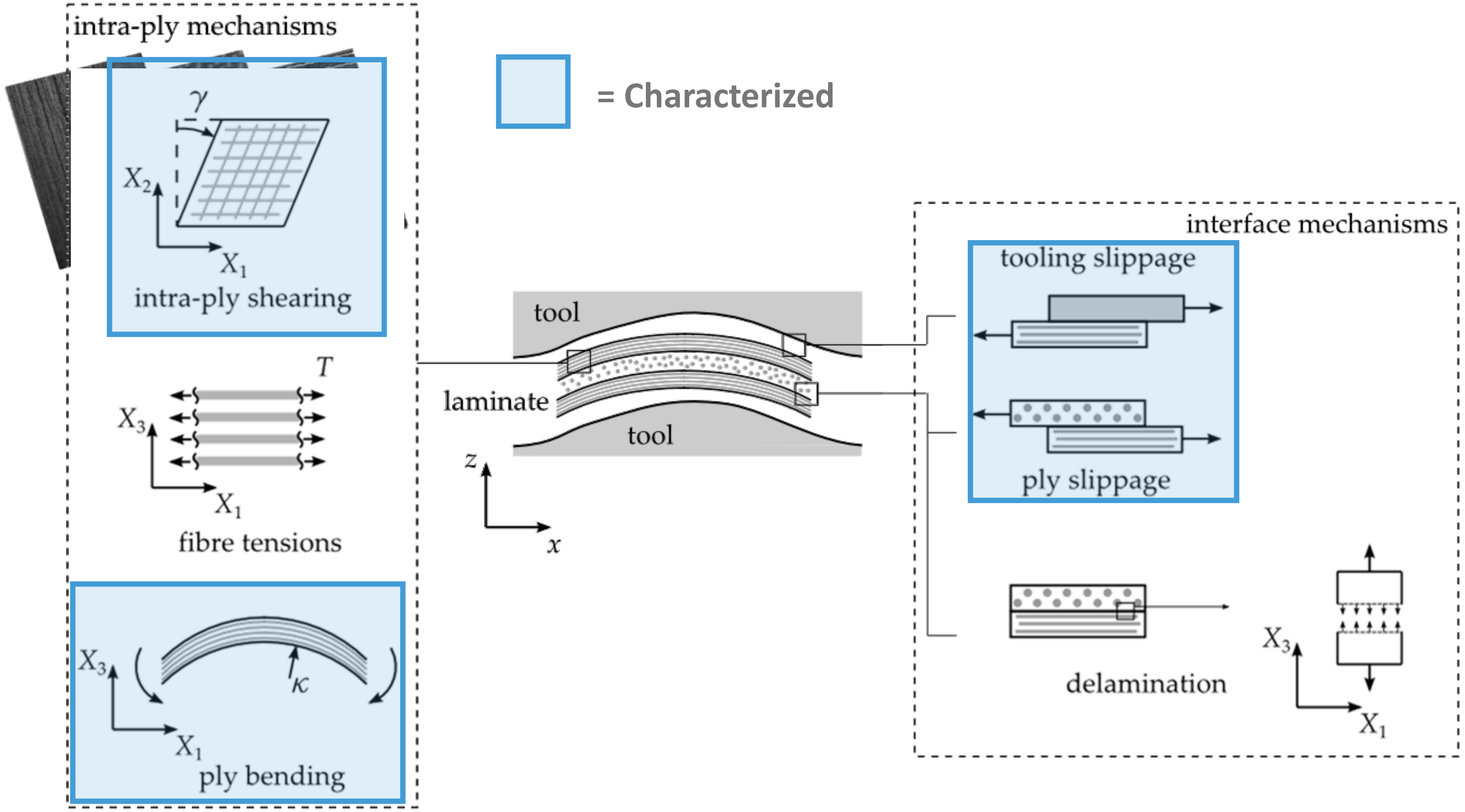
Sound understanding to support future steps

Material characterization

Various composite material types

- Unidirectional tapes
- Woven fabrics
  - Dry or thermoplastic/thermoset matrix
- Non-Crimp Fabrics

Deformation mechanisms of fiber reinforced laminated composites



Material characterization

Characterization methods developed in collaboration with the University of Twente and TPRC

- Conditions relevant to the process
- Elevated temperatures typically above the melting temperature
- Various strain-rates relevant for the process

UNIVERSITY OF TWENTE.

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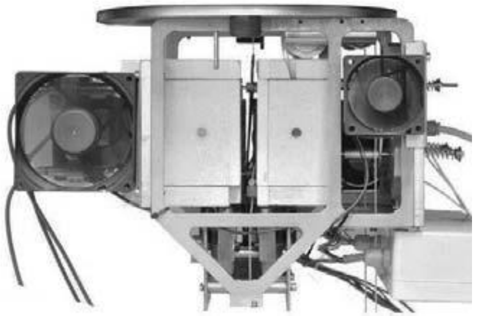
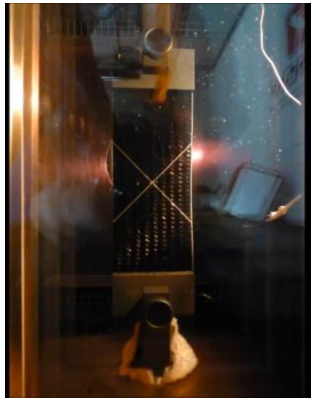
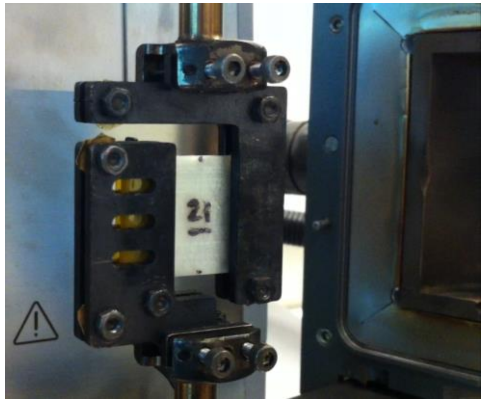


Friction



Fabric shear

Tape shear



Bending

Case study 2 – Overmolding demonstrator

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Overmolding project at TPRC (COMPeTE)

- Combined stamp forming and injection molding
- Function integration & net-shape manufacturing

Goal

- Determine near net-shape laminate contour and identify potential blank alignment issues in a closed cavity

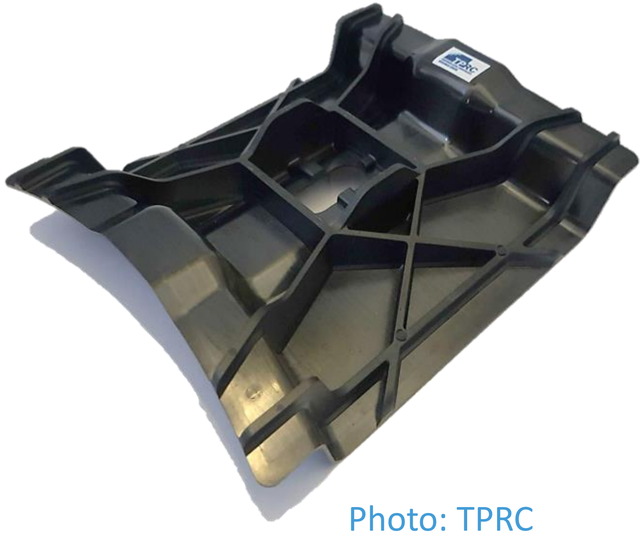
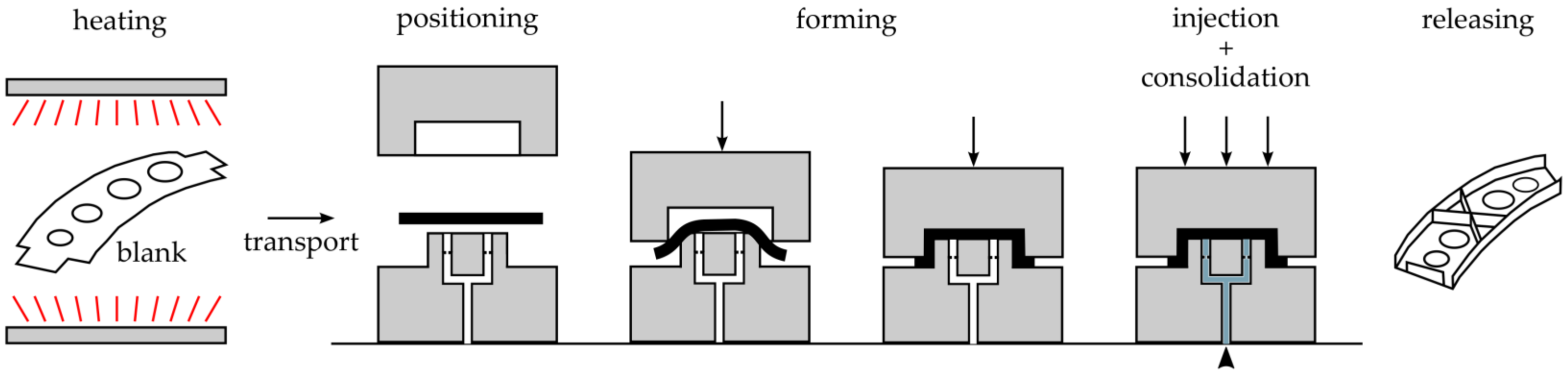


Photo: TPRC



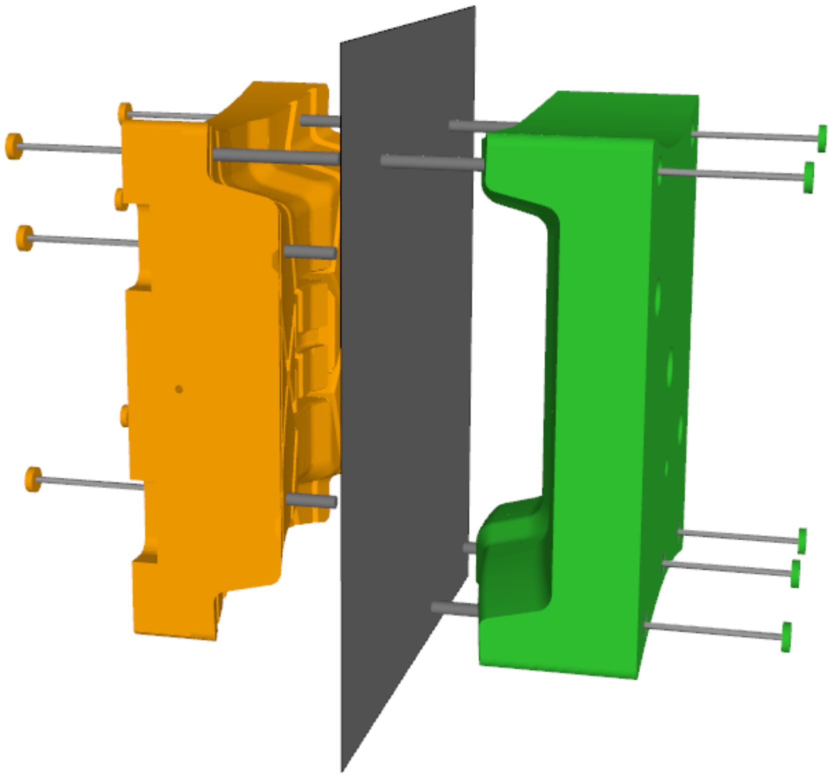
Case study 2 – Overmolding demonstrator

Laminate

- Toray Cetex® TC1225 (carbon fiber/PAEK) unidirectional tape
- Cross-ply layup $[[0/90]_4/0]$

Identification of laminate contour

- Dimensions limited by injection molding cavity
- Rectangular laminate to determine deformed shape



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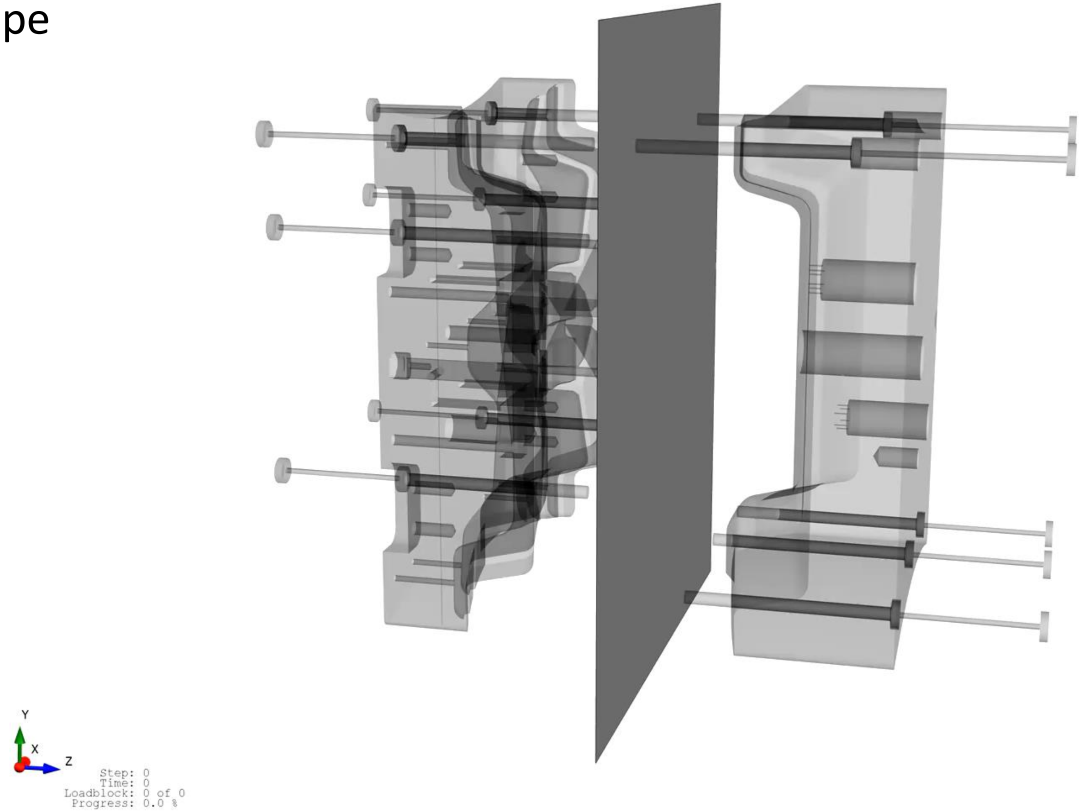

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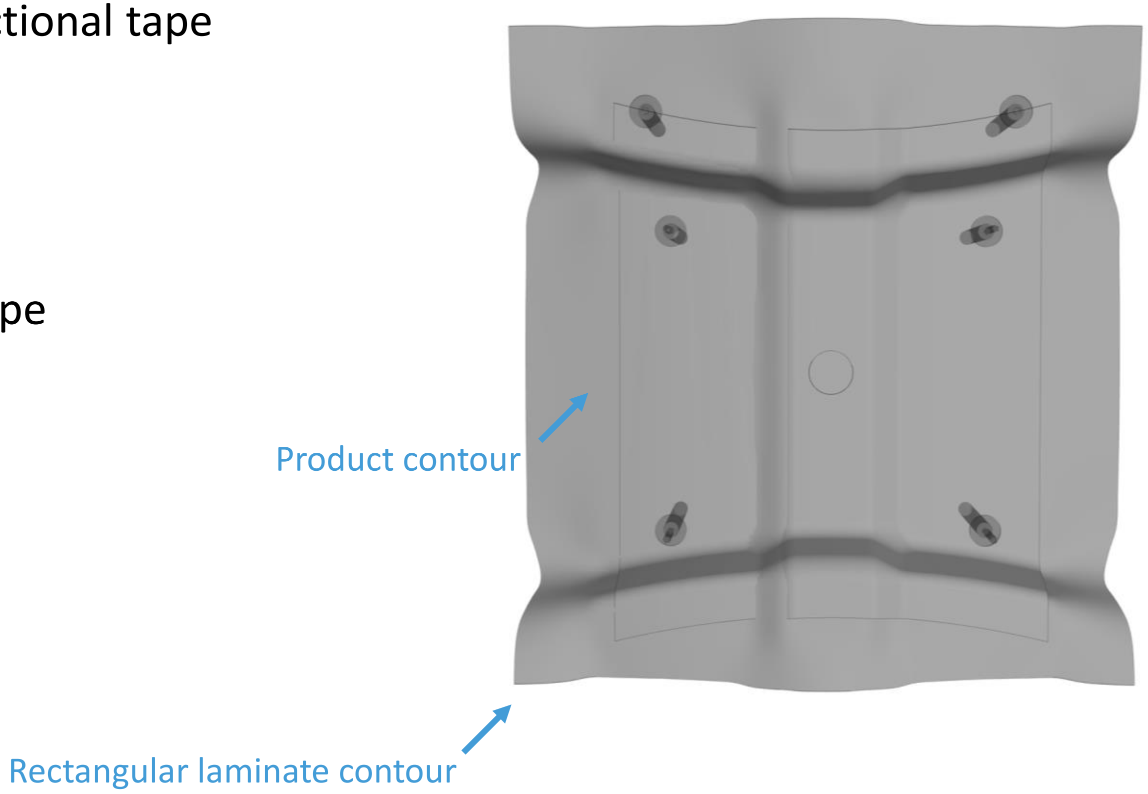

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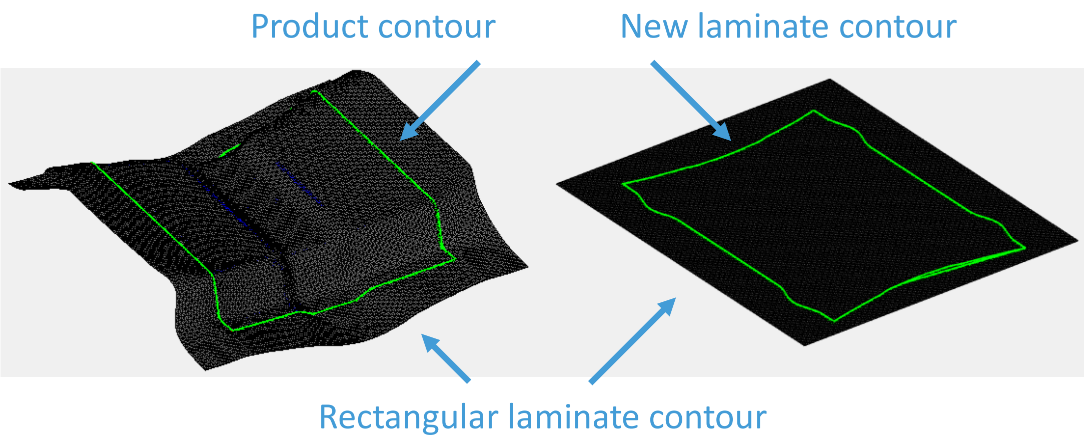
- AniForm InverseDrape add-on
  - Export of newly created laminate contour



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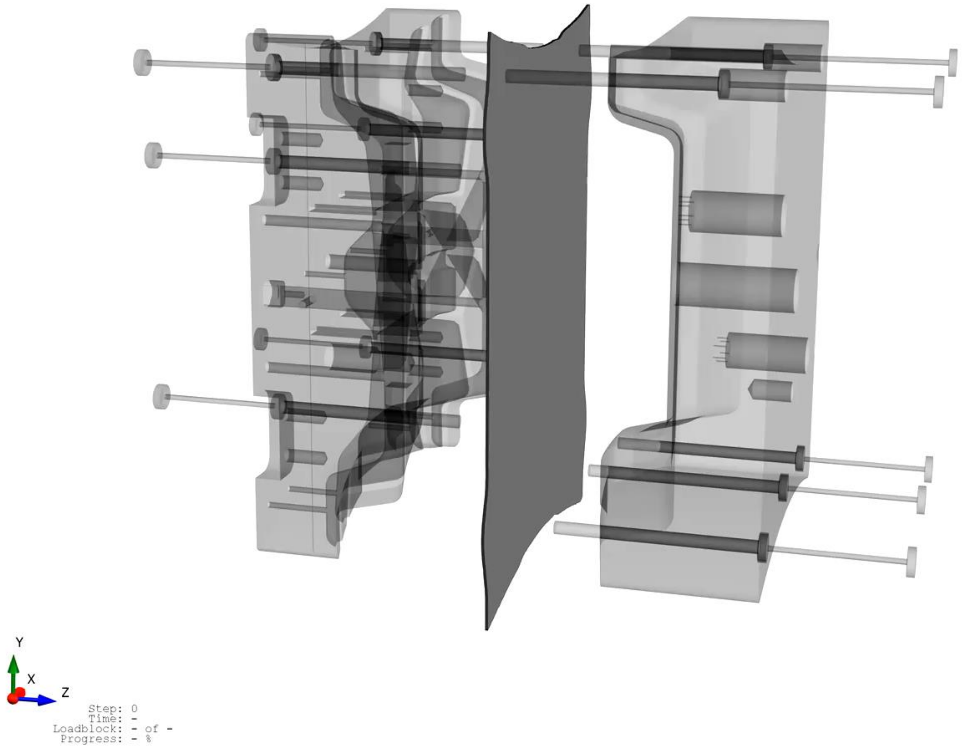

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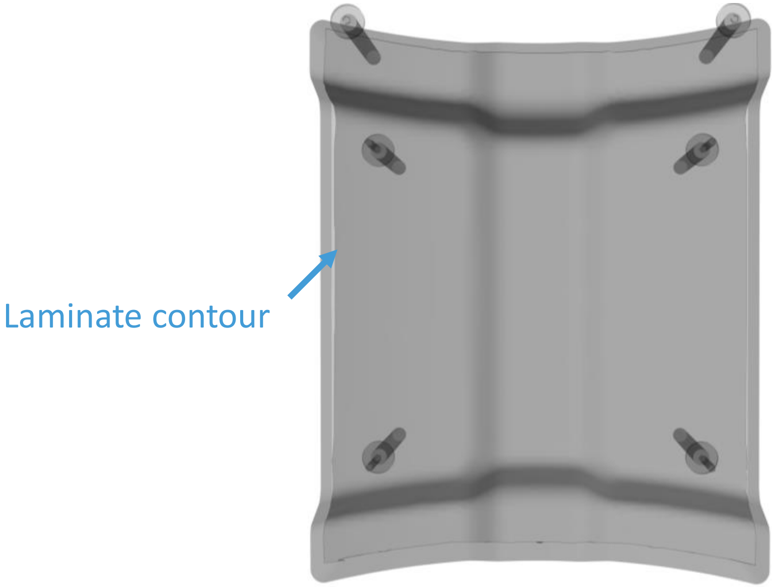


Case study 2 – Overmolding demonstrator

Required accuracy for blank alignment prior to tool closure

- Laminate cutting by tooling
- Obstruction of polymer flow can result in inadequate filling

Nominal | 5 mm horizontal translation | 3° rotation around product normal axis

Case study 3 – Deep box with concave & convex flanges

Goal

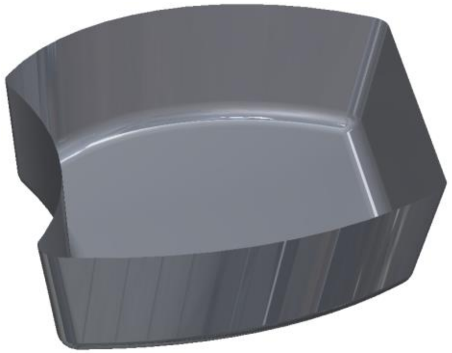
- Optimize for minimal wrinkle formation

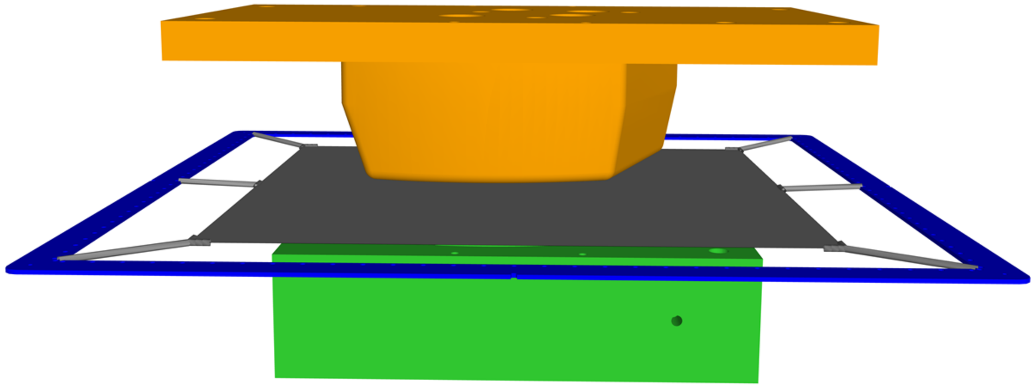
Laminate

- Woven carbon fiber/PPS (Toray Cetex® TC1100 T300J-5HS/PPS)
- Four plies quasi-isotropic $[(45/-45), (0/90)]_s$ & cross-ply $[(0/90)]_{2s}$
- 470 x 470 mm

Boundary conditions

- Male (moving) and female (fixed) tooling
- Handling system via edge grippers and tensioners (springs)

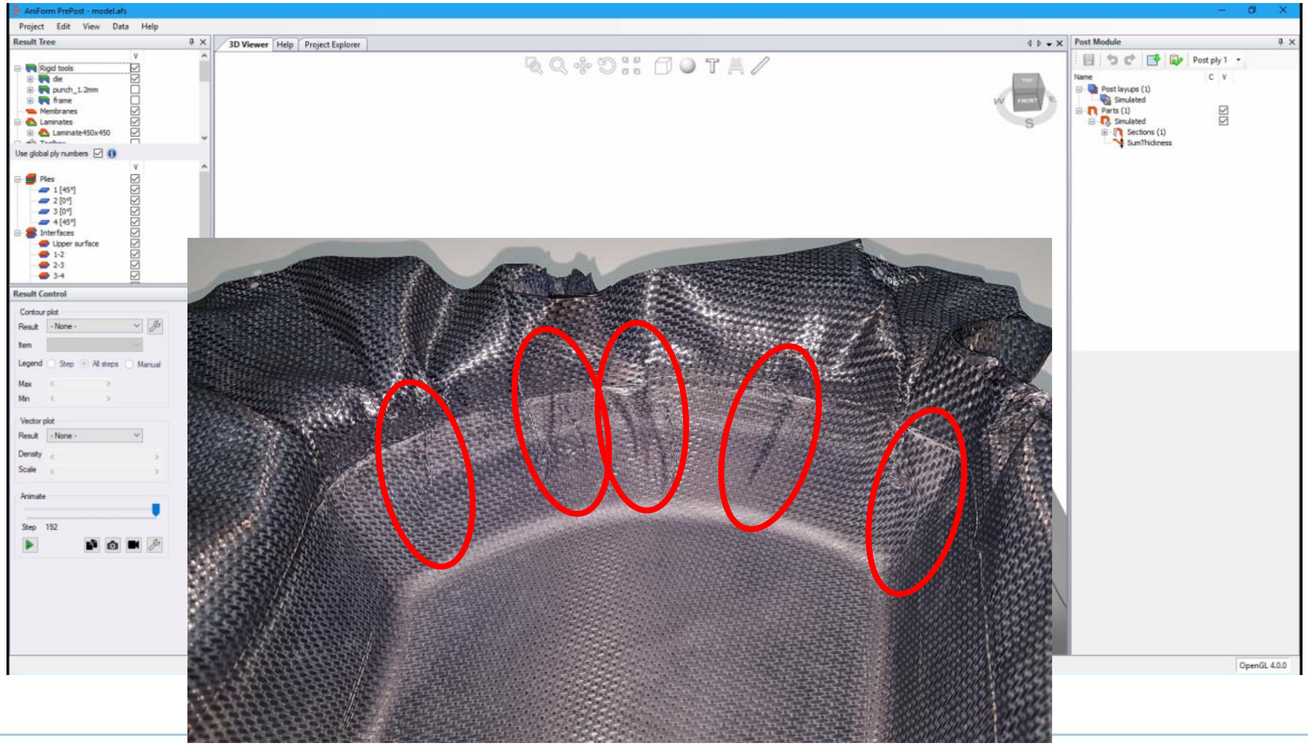




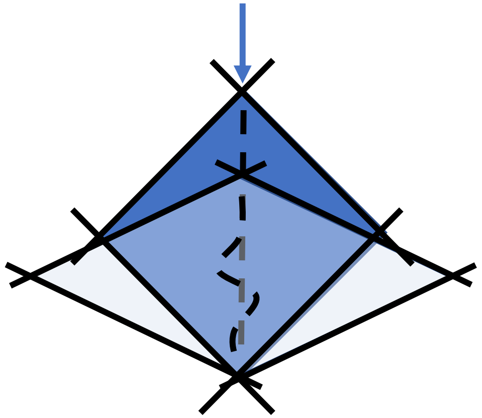
Case study 3 – Deep box with concave & convex flanges

Results

- Wrinkle formation near edge for quasi-isotropic [(45/-45), (0/90)]$_s$ laminate
  - Impediment of in-plane shearing due to presence of adjacent fibers



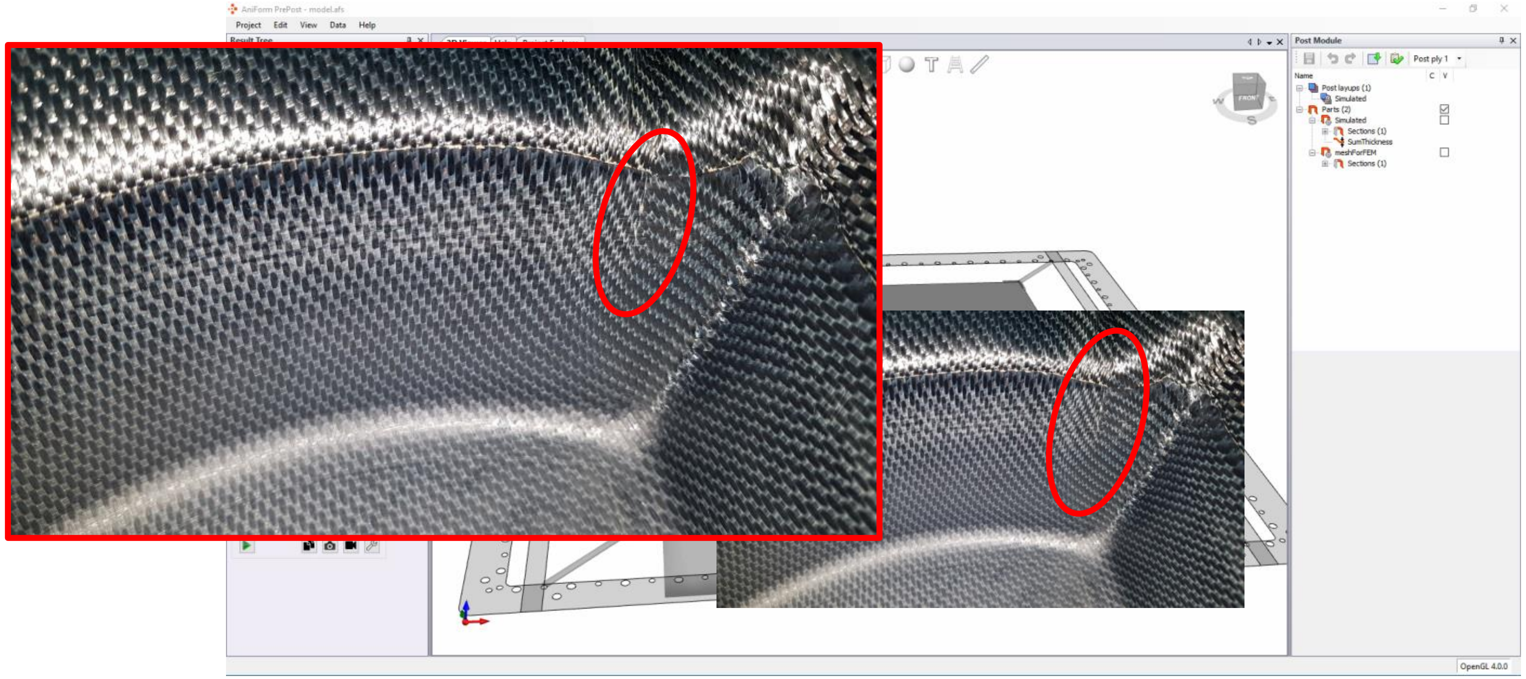
Fiber compression in adjacent ply in shearing direction



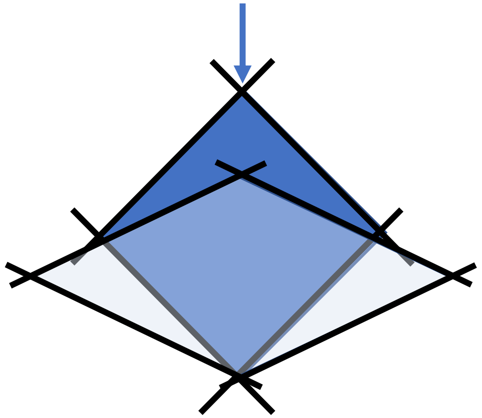
Case study 3 – Deep box with concave & convex flanges

Results

- Wrinkle reduction for cross-ply $[(0/90)]_{2s}$ however not fully resolved
  - In-plane shear deformation is promoted



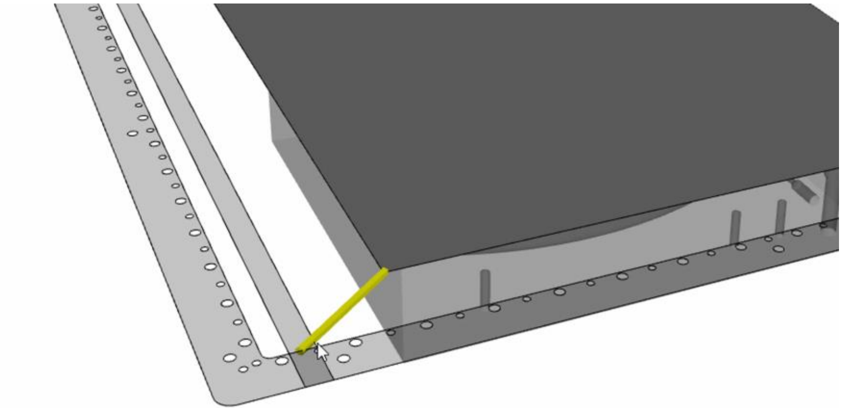
No fiber compression in adjacent ply in shearing direction

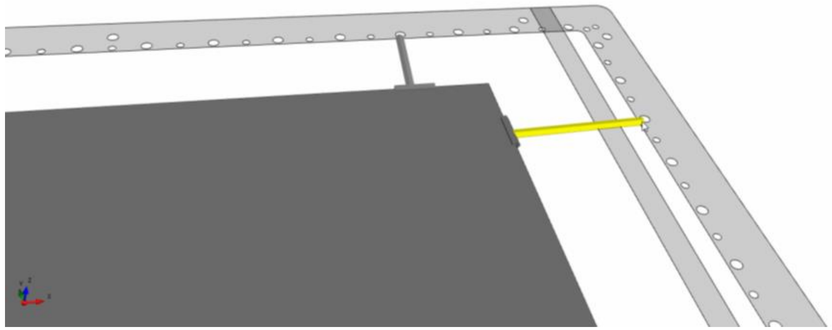


Case study 3 – Deep box with concave & convex flanges

Results

- Change handling system to minimize localization of shear
  - Decoupling the tensioners introduces shear over a larger area





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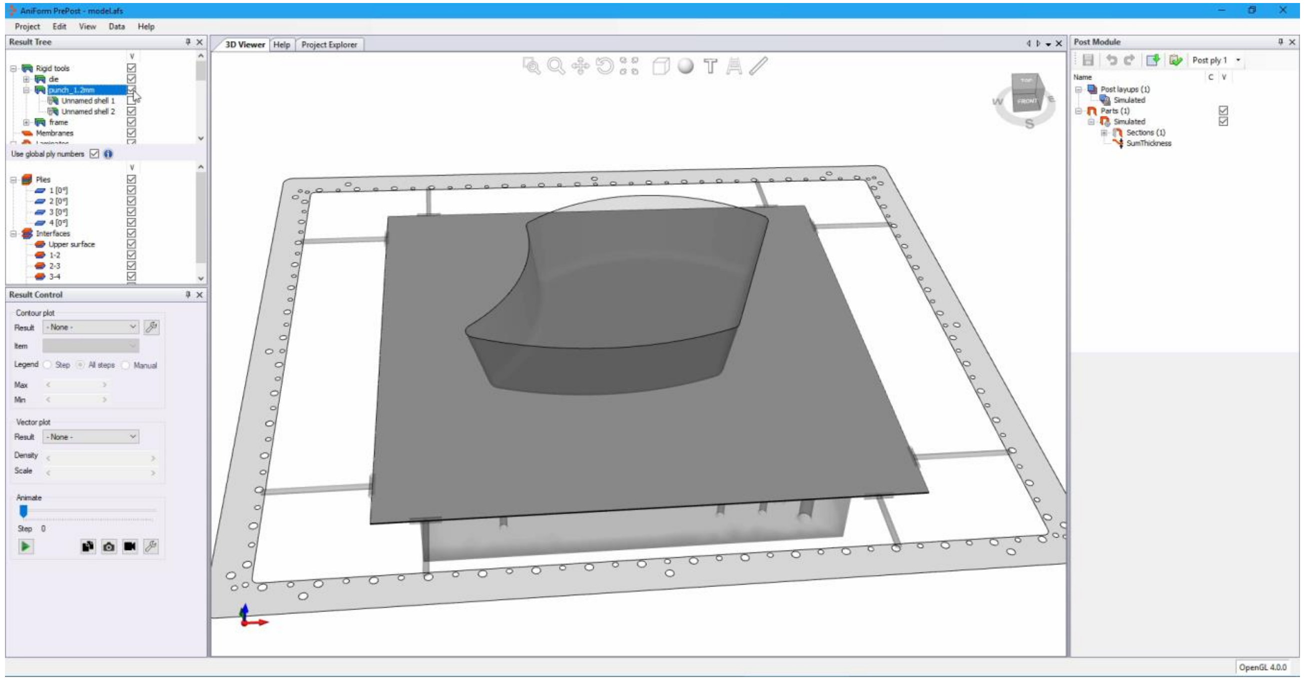

Case study 3 – Deep box with concave & convex flanges

Summary

The following was achieved in the cases discussed:

- identify regions prone to fiber tensioning and compression and their relation to part-size;
- determine near net-shape laminate contour and identify potential blank alignment issues;
- optimize for minimal wrinkle formation.

State-of-the-art simulation techniques:

- provide useful insights of forming-induced phenomena;
- enable investigation of their sensitivity to various process configurations;
- and eventually contribute to finding the optimal solution.

Thank you for your attention

Questions?

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