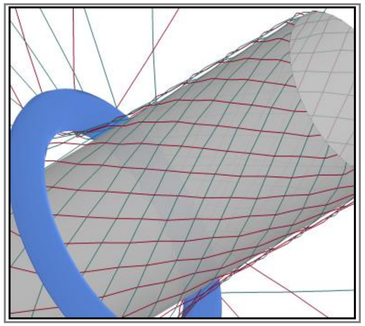
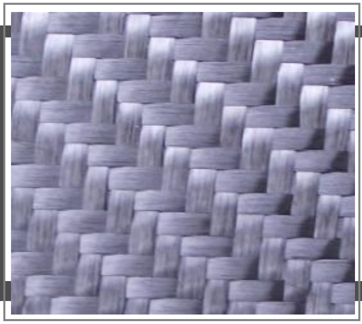


AFBW Fellbach



Die Simulationsprozesskette für faserbasierte Werkstoffe: Von der Herstellungssimulation zu Aussagen der Gebrauchstauglichkeit

Dr. Andre Haufe, Dr. Thomas Klöppel, Christian Liebold

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Stuttgart

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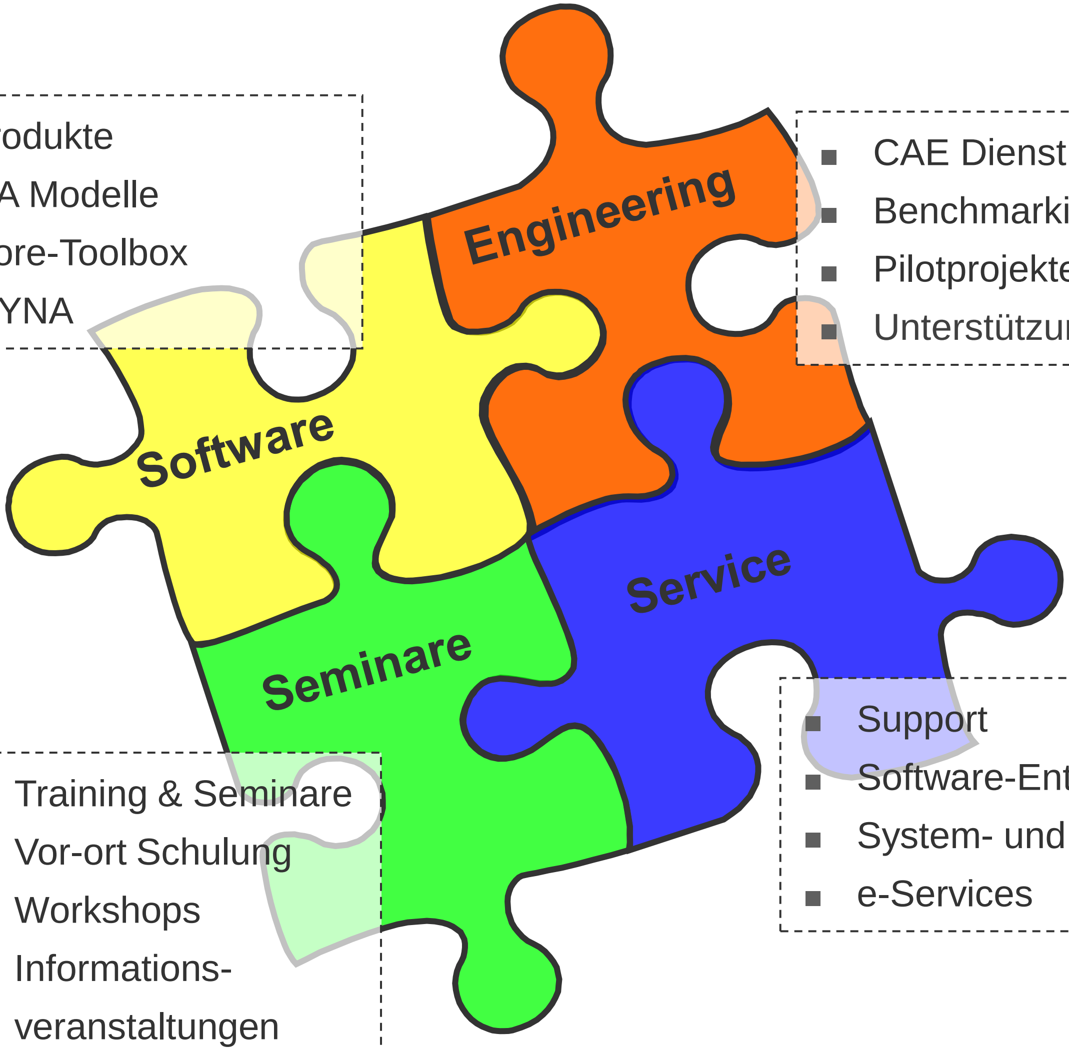
Portfolio

- LSTC Produkte
- LS-DYNA Modelle
- DYNAmore-Toolbox für LS-DYNA

- CAE Dienstleistungen
- Benchmarking
- Pilotprojekte
- Unterstützung vor Ort



- Training & Seminare
- Vor-ort Schulung
- Workshops
- Informations-veranstaltungen

- Support
- Software-Entwicklung
- System- und Prozessintegration
- e-Services

LS-DYNA 2013

9th European Users' Conference

2.-4. Juni 2013 in Manchester, UK

Themen:

- Crash
- Insassensicherheit
- Optimierung
- Airbag, Dummy
- Metallumformung
- Impact und Falltest
- Herstellungsprozesse
- Fluid-Struktur-Interaktion
- Automotive
- Schiffbau
- Luft- und Raumfahrt
- Offshore
- Transportation
- Biomechanik
- Bauwesen
- ...

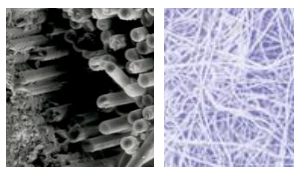
Courtesy of Dr. Ing. h.c. F. Porsche AG

Introduction

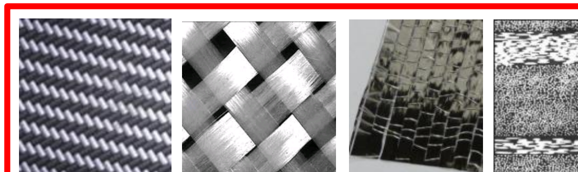




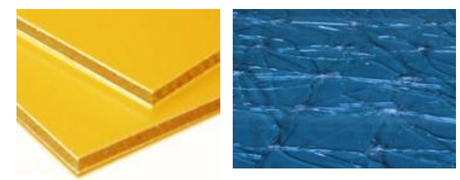
Concrete
(cement/stone/steel)



Short/long fiber
reinforced polymers
(glass/PP)



Endless fiber
reinforced polymers
(glass/carbon/PA/PP/EP)

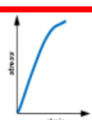


Sandwich/Laminates
(alloy/polymer/..glass/PVB/…)

 &  **Weight & CO_2**

 **Production issue**

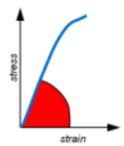
 **Part complexity**

 **Stiffness & strength**

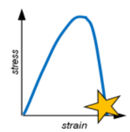
 **Economic issue**

Target: Predict serviceability in crashworthiness

Status:

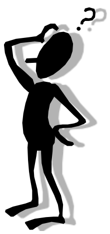


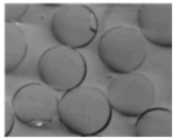
Mostly shell like structures.
Stiffness and/or deformation prediction possible
IF fiber content and/or orientation is known.

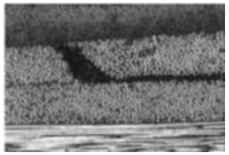


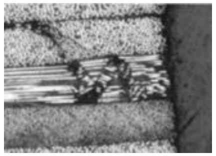
Failure prediction may be possible if failure mode can be engineered to be **ductile**.

Brittle failure is hard to predict, because
many different failure modes may exist
due to mechanisms on different length scales:







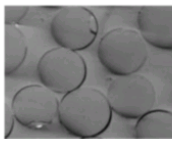
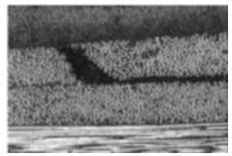
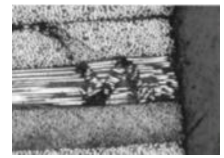


[μm] [mm] [cm] Length scale

micro sub-ply meso macro

Target: Predict serviceability in crashworthiness

➡ Crushing/cracking/delamination/buckling on different length scales…

[μm] micro — sub-ply — [mm] meso — [cm] macro — Length scale

➡ Optimal product design? New approaches in CAE necessary!

Steel/Aloy

Isotropic

Elasto plastic

Ductile

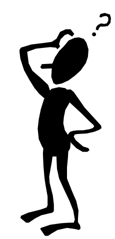
CFRP

Anisotropic

Stacked laminate

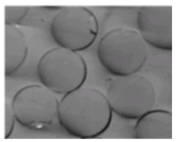
Elastic

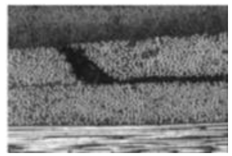
Brittle failure

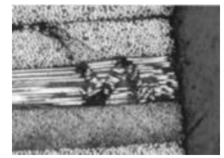


Target: Predict serviceability in crashworthiness

➡ Crushing/cracking/delamination/buckling on different length scales…

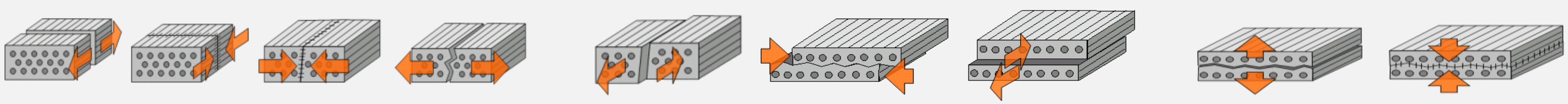




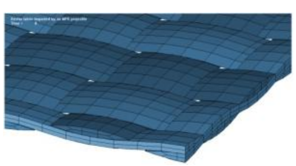


[μm] micro — sub-ply — [mm] — meso — [cm] macro — Length scale

T/C in plane — Shear — T/C out of plane

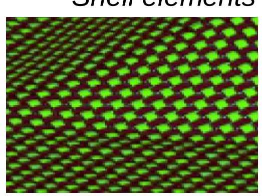


Meso-model to capture structural effects

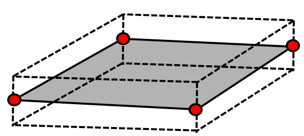


Solid elements

Shell elements

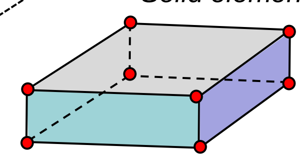


Macro-model (smeared out properties



Shell element

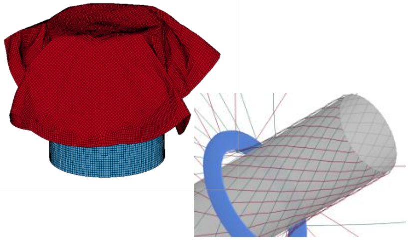
Solid element



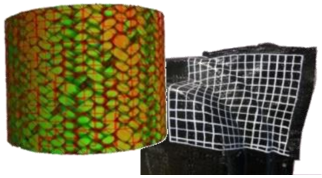
Charact. element length: 3mm

Main issues to solve:

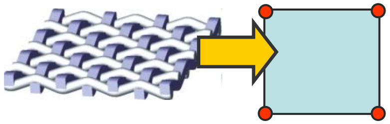
- Know fiber influence (orientation) and matrix properties on relevant length scale



  - producibility simulation
  - Measurements



- Homogenize and map data to target length scale

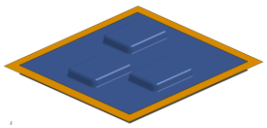


- Find suitable (predictive) models on that scale!

Composite process chain: Producibility2Servicability

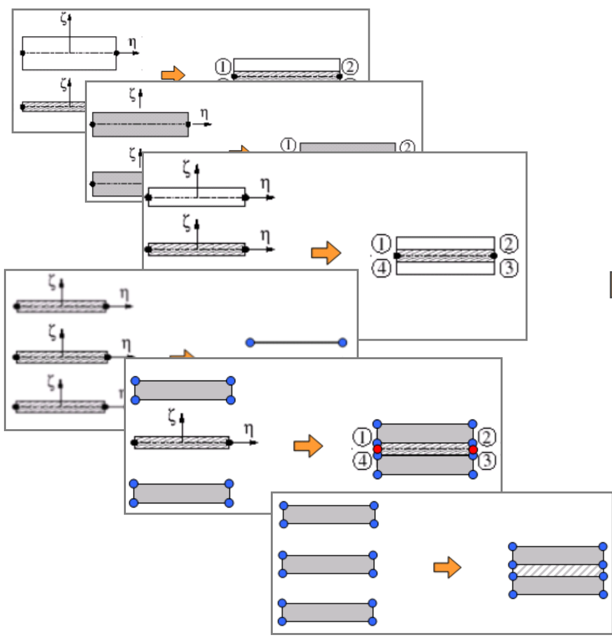
Problem: Different applications use different modeling techniques, constitutive models, standards and validation procedures.

Producibility



GMT, SMC, BMC
LMC or Prepreg??

Anisotropy and inhomogeneity



Modeling technique

Const. model mapping

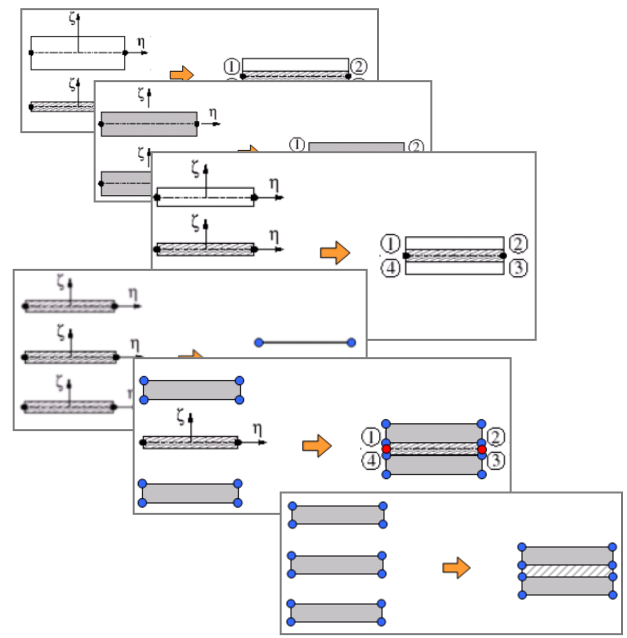
Geometrical mapping

LSTC
Livermore Software Technology Corp.

Fraunhofer
SCAI
Institute Algorithms and Scientific Computing

Serviceability

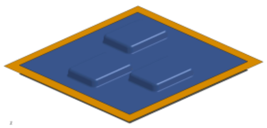
Anisotropy and inhomogeneity



Composite process chain: Producibility2Servicability

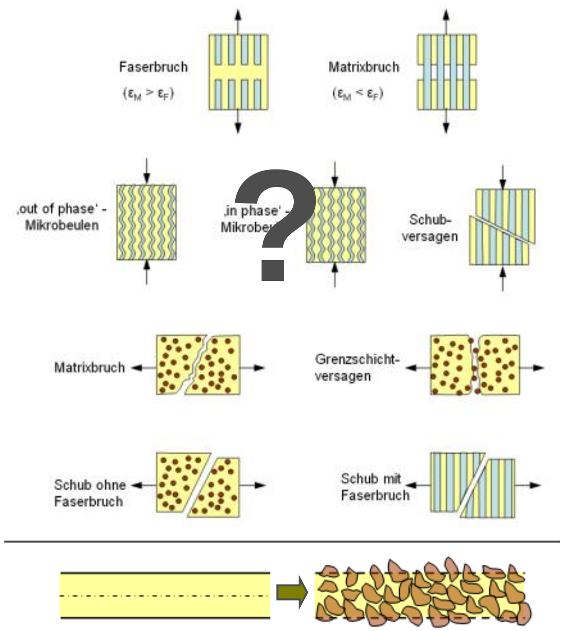
Problem: Different applications use different modeling techniques, constitutive models, standards and validation procedures.

Producibility



GMT, SMC, BMC
LMC or Prepreg??

Anisotropy and inhomogeneity



Length scale?

Const. model mapping

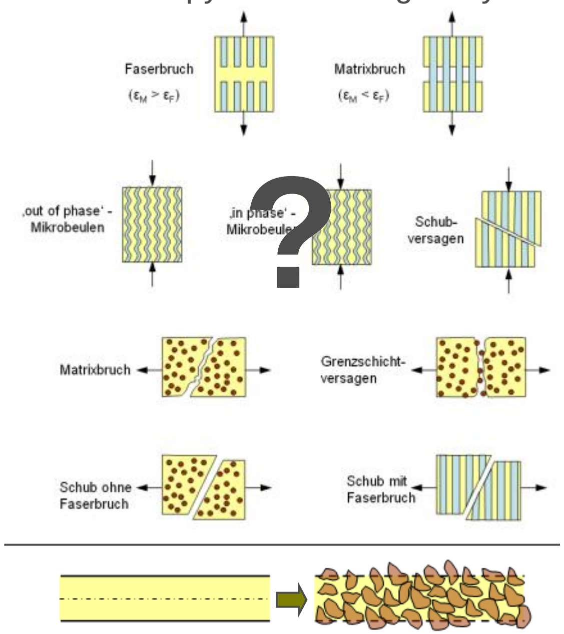
Geometrical mapping

LSTC Livermore Software Technology Corp.

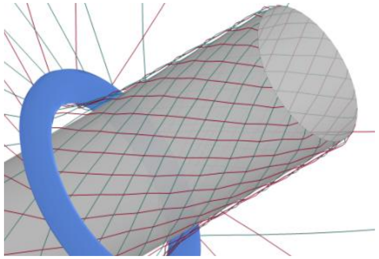
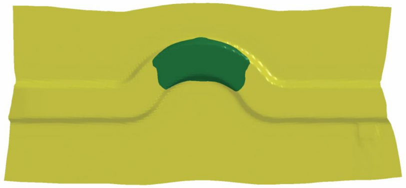
Fraunhofer Institute Algorithms and Scientific Computing

Serviceability

Anisotropy and inhomogeneity



Producibility

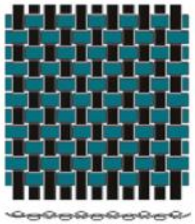
   

Producibility

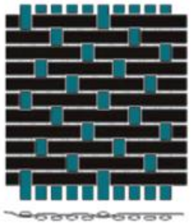
Draping

Process simulation: Draping with strong anisotropy

Some fabrics (preforms) show extreme orthotropic behavior. Here modeling with shell elements using different constitutive models is possible:

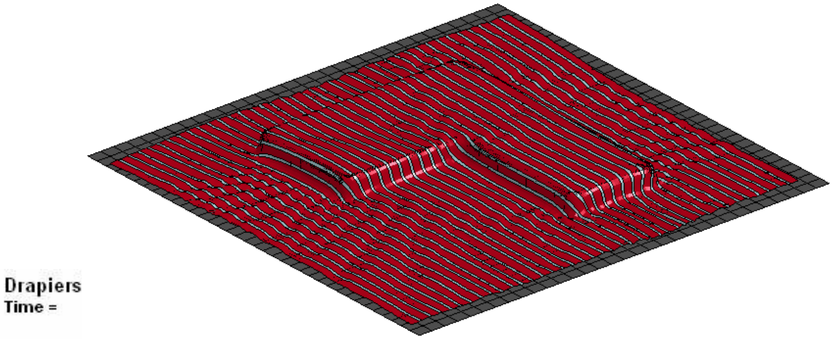


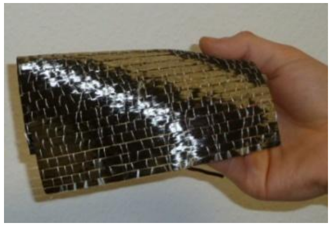
plain weave

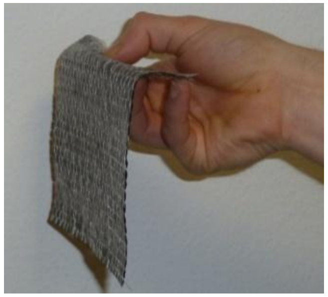


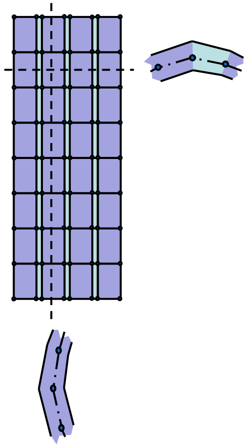
5 harness weave

●●● and more…

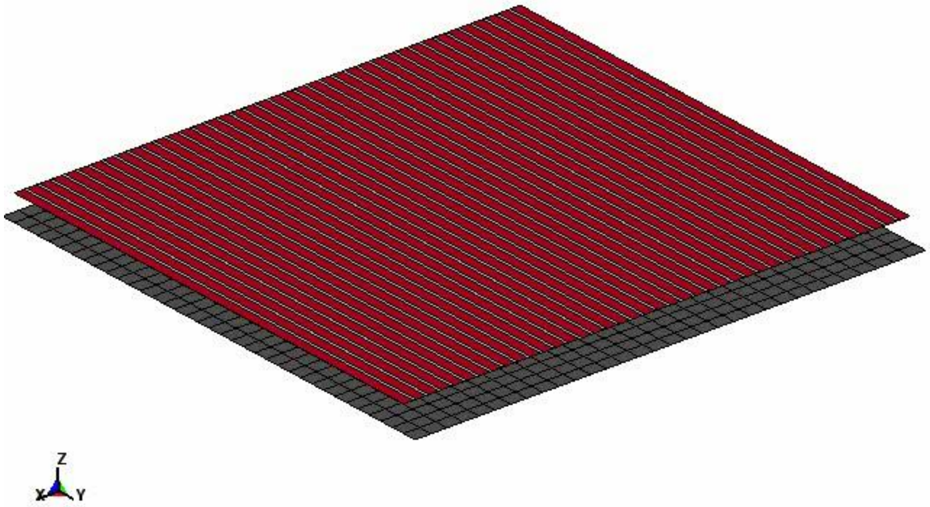








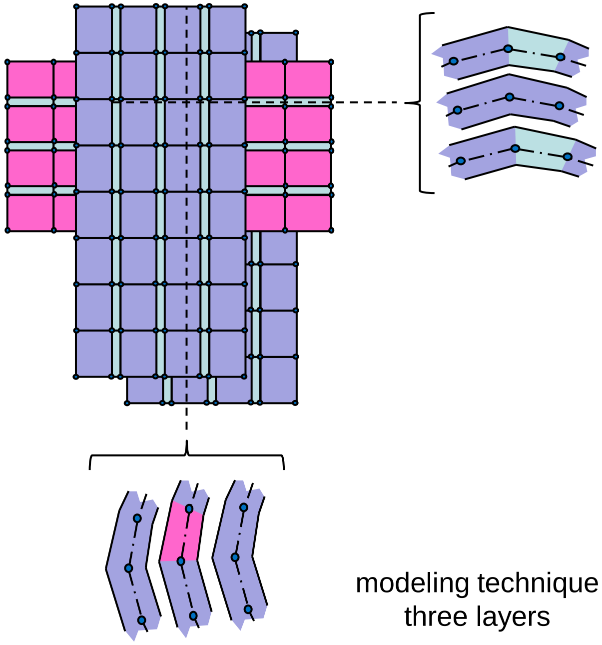
modeling technique
single layer



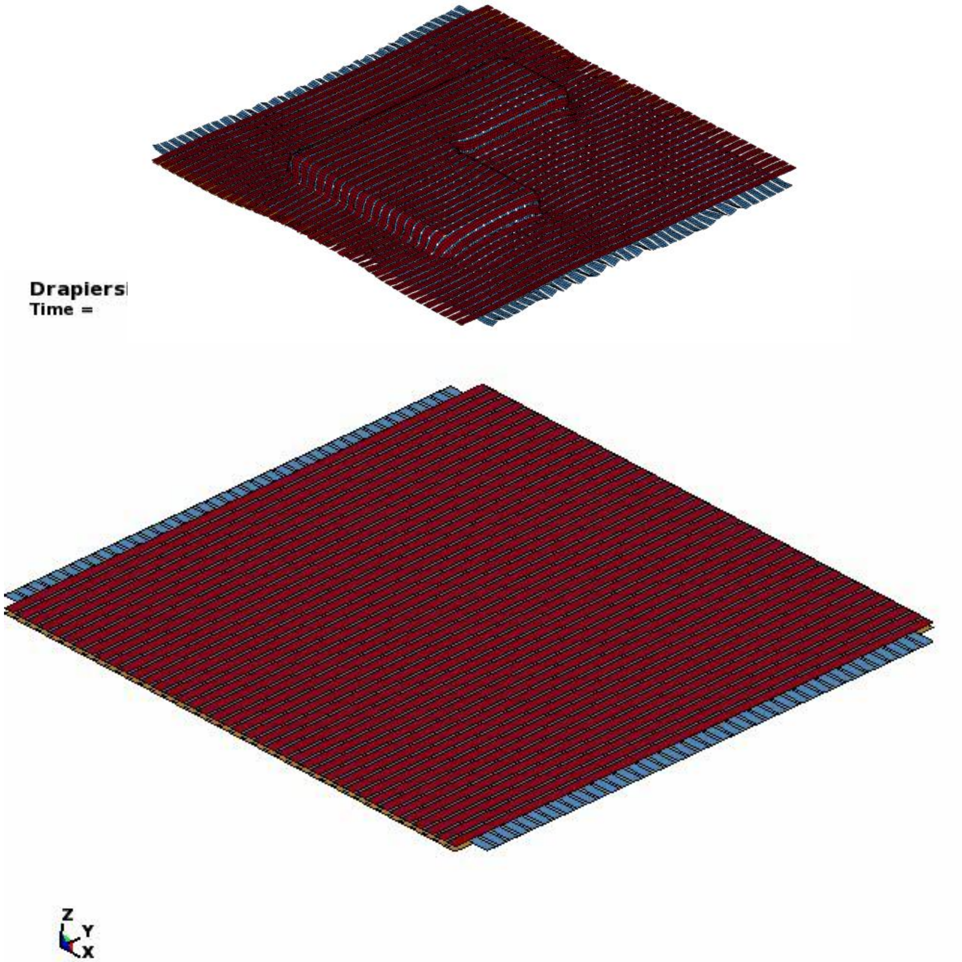
Process simulation: Draping with strong anisotropy

Some fabrics (preforms) show extreme orthotropic behavior.
Here modeling with shell elements using different constitutive models is possible.

For stacked preforms a similar approach in finite element modeling is of course possible: Multiple layers of shell elements.



modeling technique
three layers

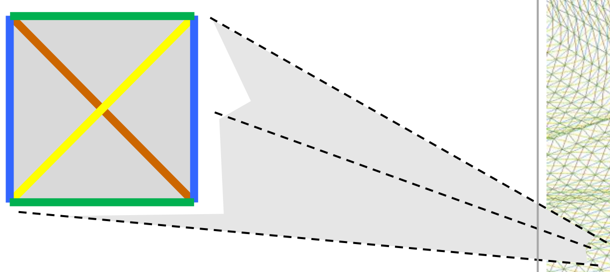


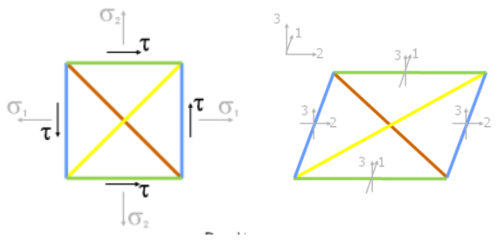
Draping: Using discrete elements for strong anisotropy

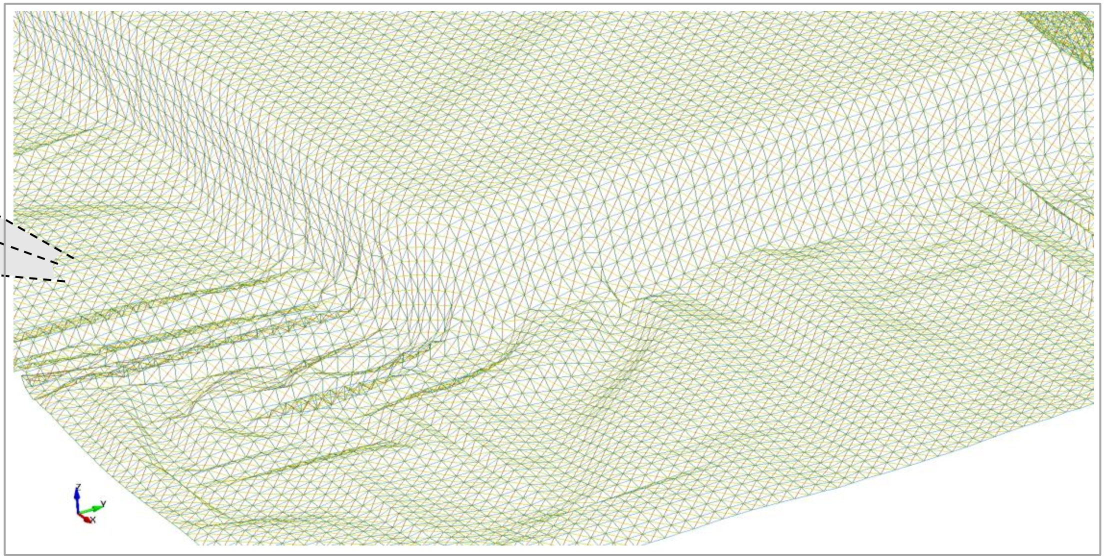
Modeling woven fabrics with beam elements:

Warp and weft direction *MAT_LINEAR_ELASTIC_DISCRETE_BEAM (MAT_066)

Diagonal behavior modeled with *MAT_CABLE_DISCRETE_BEAM (MAT_071)







This approach allows also to model positive and negative shear loading.

Optional matrix may be represented with shell elements and elastic/plastic material.

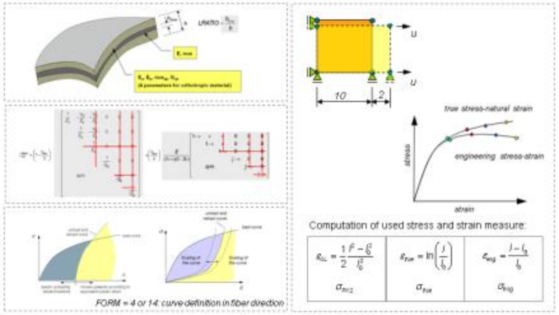
Modeling techniques on cm-scale:

Fabric materials available for draping simulation in LS-DYNA

MAT_34

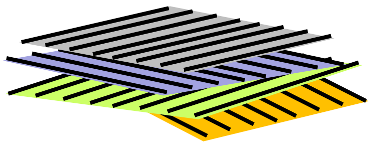
Simulation on cm-scale: MAT_FABRIC (#34)

A special membrane formulation is automatically invoked



New in R7.0: bending stiffness

New: ACMD



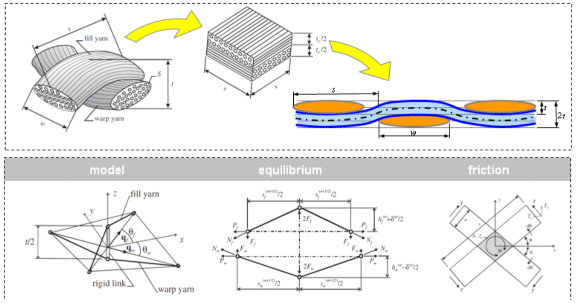
Anisotropic unidirectional layered constitutive model for draping

NEW in future release.

MAT_234

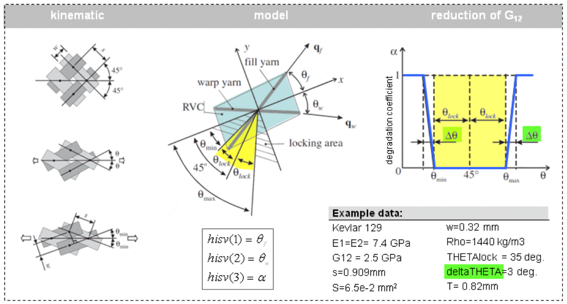
Simulation on cm-scale:
MAT_VISCOELASTIC_LOOSE_FABRIC (#234)

Micro-mechanical approach :
Mathematical description of geometry and kinematic of symmetrical woven fabric



Simulation on cm-scale:
MAT_VISCOELASTIC_LOOSE_FABRIC (#234)

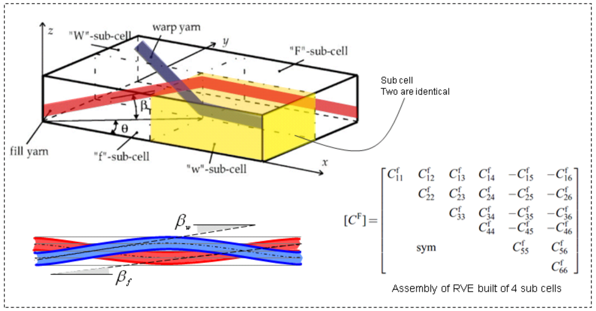
Taking locking angle through reduction factor for G_{12} into account
Visco-elastic enhancement for higher strain rates



MAT_235

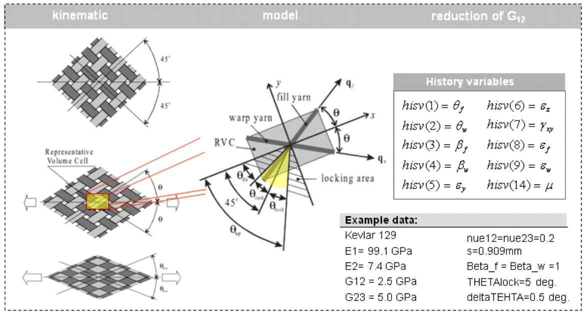
Simulation on cm-scale:
MAT_MICROMECHANICS_DRY_FABRIC (#235)

Micro-mechanical approach with homogenization strategy (RVE):
Mathematical description of symmetrically woven fabric



Simulation on cm-scale:
MAT_MICROMECHANICS_DRY_FABRIC (#235)

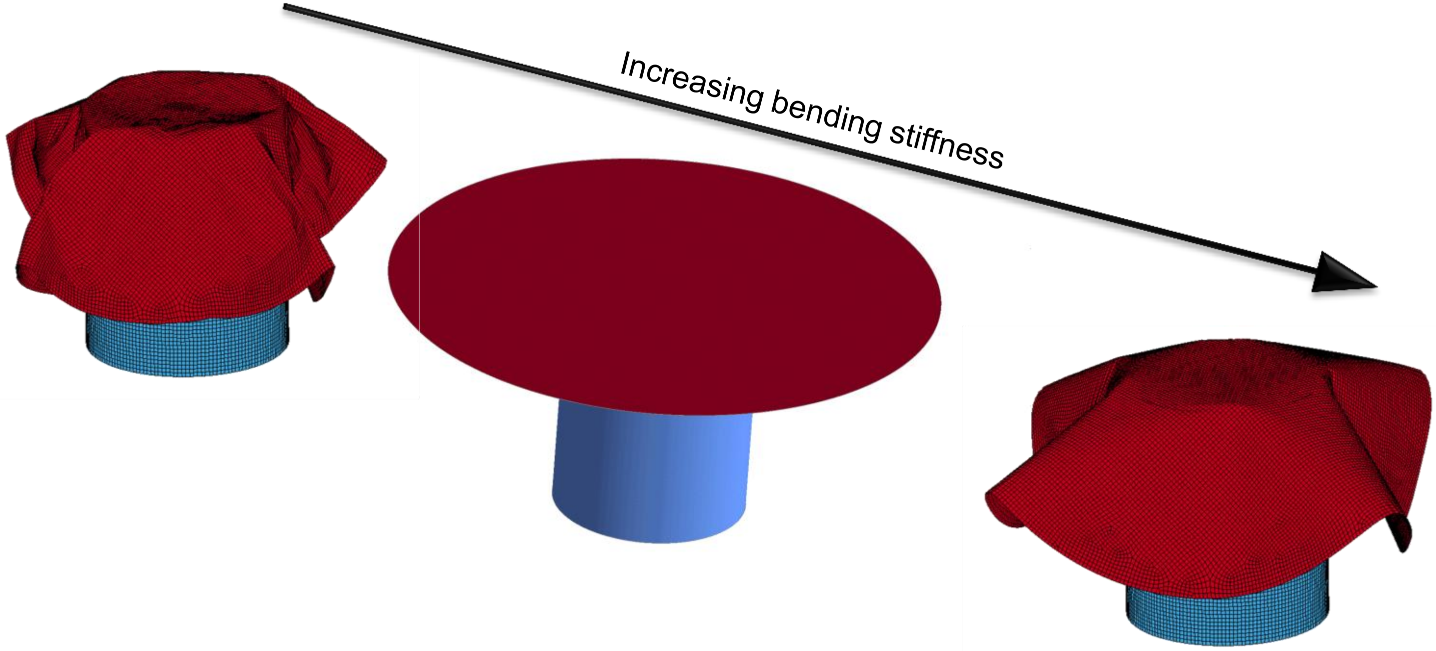
Micro-mechanical approach with homogenization strategy (RVE):
Mathematical description of symmetrically woven fabric

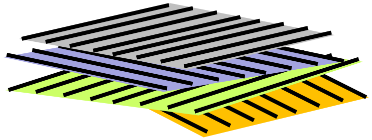


Enhancements in MAT_FABRIC (MAT34) starting with LS-DYNA R7.0

- Material describes an orthotropic material behavior
- Requires discretization with membrane elements
- Allows to add a bending resistance by defining an additional elastic coating in the material card

Example: Tablecloth with varying coating stiffness

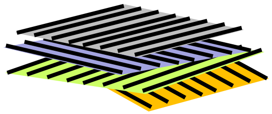




New model for draping: ACMD

(beta status)

New anisotropic constitutive model for draping (ACMD)



- Hyperelastic, anisotropic material formulation, accounting for *n* discrete fiber families in *each* integration point
- Normalized initial fiber directions $\vec{m}_i^0$ are defined w.r.t. to material direction
- Current state of fiber $\vec{m}_i$ is given by $\vec{m}_i = \underline{F}\vec{m}_i^0$ with length λ_i
- Response of the fibers according to a function $f(\lambda_i)$ of current length $\vec{m}_i$ of the fiber defined by a load curve
- Stresses due to elongation of the individual fibers families are then computed as

$$\underline{\sigma} = \sum_{i=1}^{n} \tfrac{1}{J} f(\lambda_i) \underline{F} \left(\vec{m}_i^0 \otimes \vec{m}_i^0 \right) \underline{F}^T$$

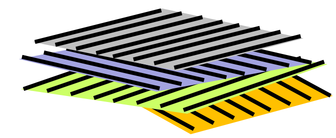
- Interaction between neighboring fiber families can be accounted for by

$$\underline{\sigma} = \sum_{\substack{i,j \\ i \neq j}} \tfrac{1}{J} g(\vec{m}_i \cdot \vec{m}_j) \underline{F} \left(\vec{m}_i^0 \otimes \vec{m}_j^0 \right) \underline{F}^T$$

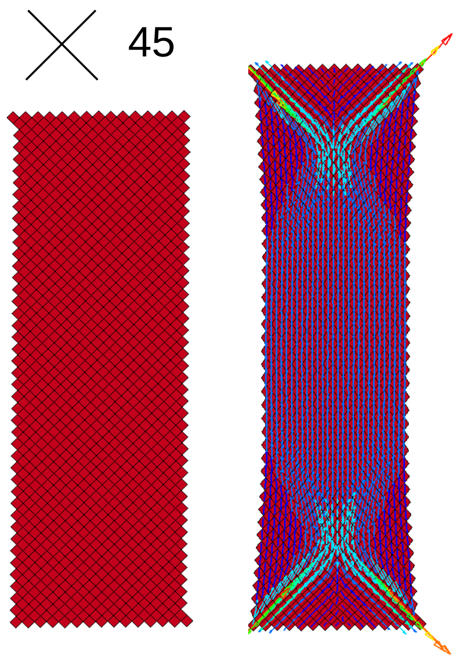
where function g can again be provided as a load curve

- For the sake of stability, a linear relation between transverse shear stresses σ_{31}, σ_{32} and the corresponding components of the bulk strain tensor is additionally assumed

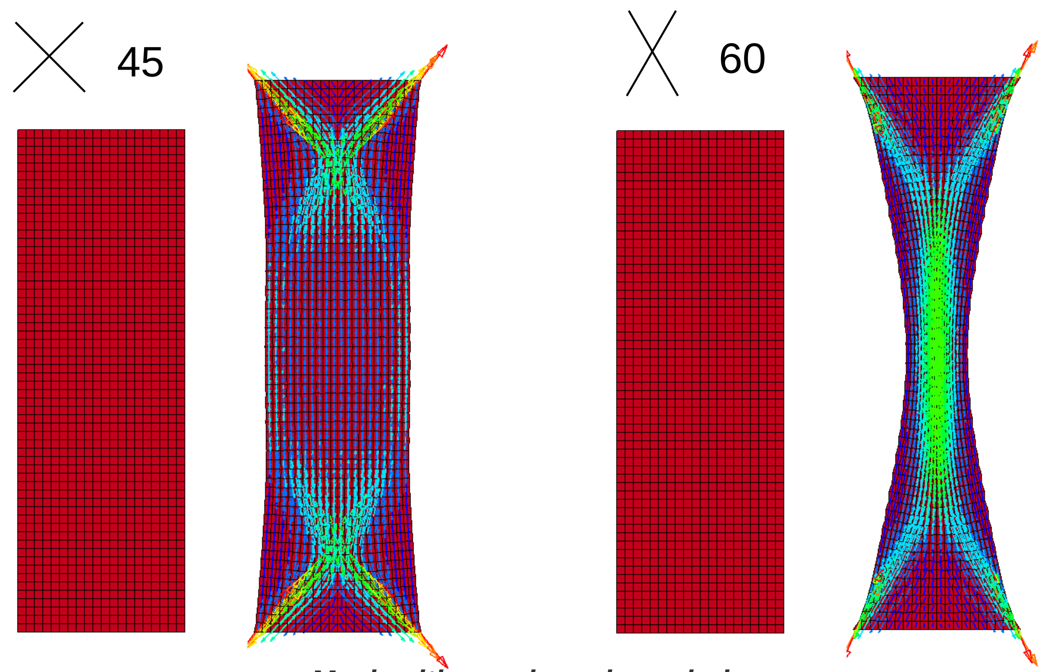
Example: tensile test specimen (ACMD)



- Prescribed motion of top nodes
- Arrows indicate the principal stresses



Mesh aligned with fiber directions

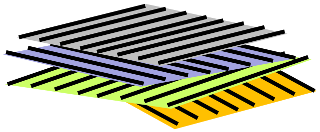


Mesh with specimen boundaries

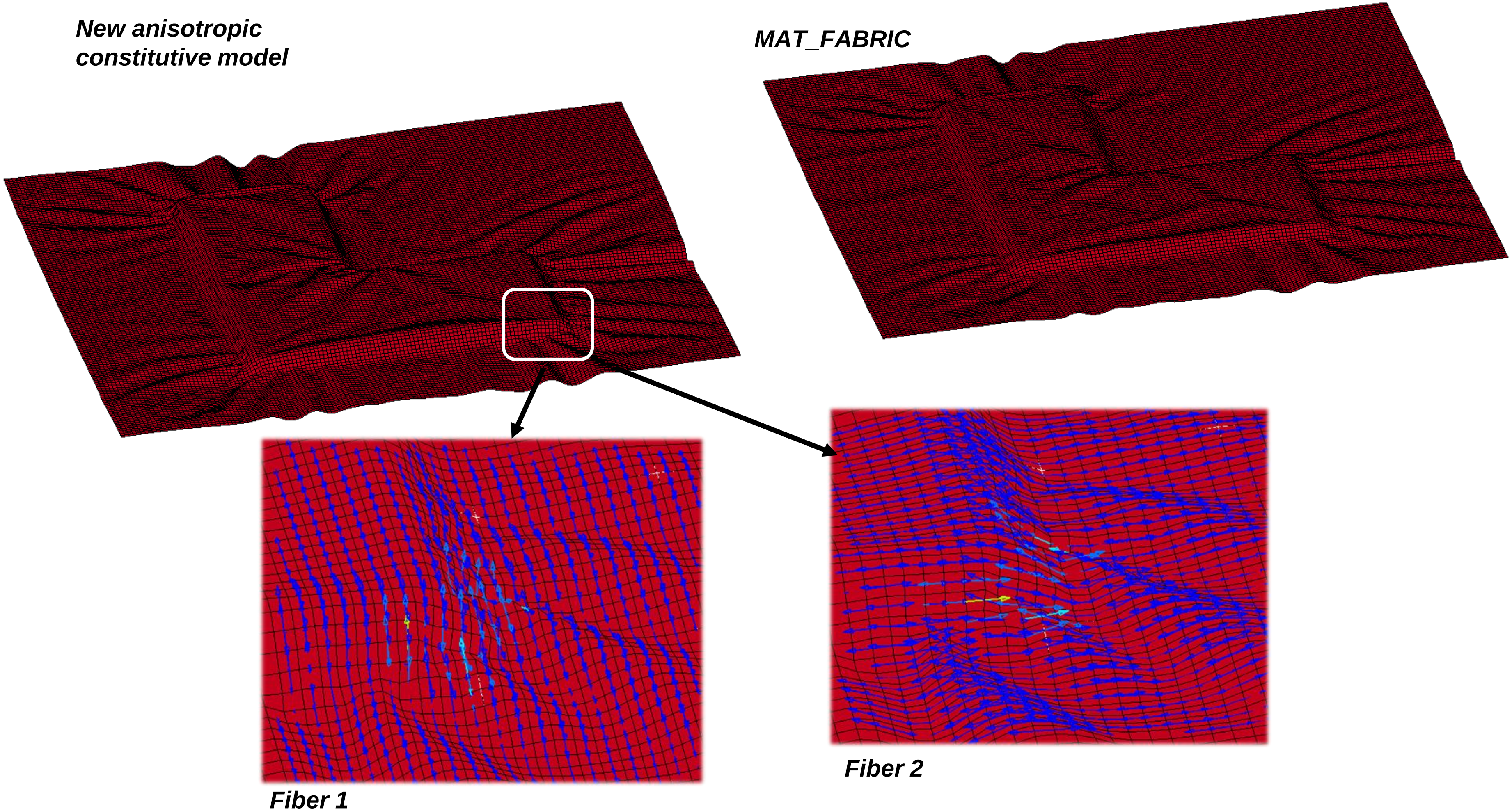
Results show that

- stress orientations are independent of element orientations
- material definition accounts correctly for anisotropic (non-orthotropic) material behavior

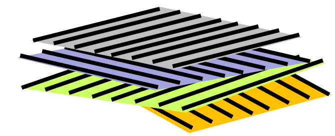
Example ACMD: Draping simulation (0 /90)



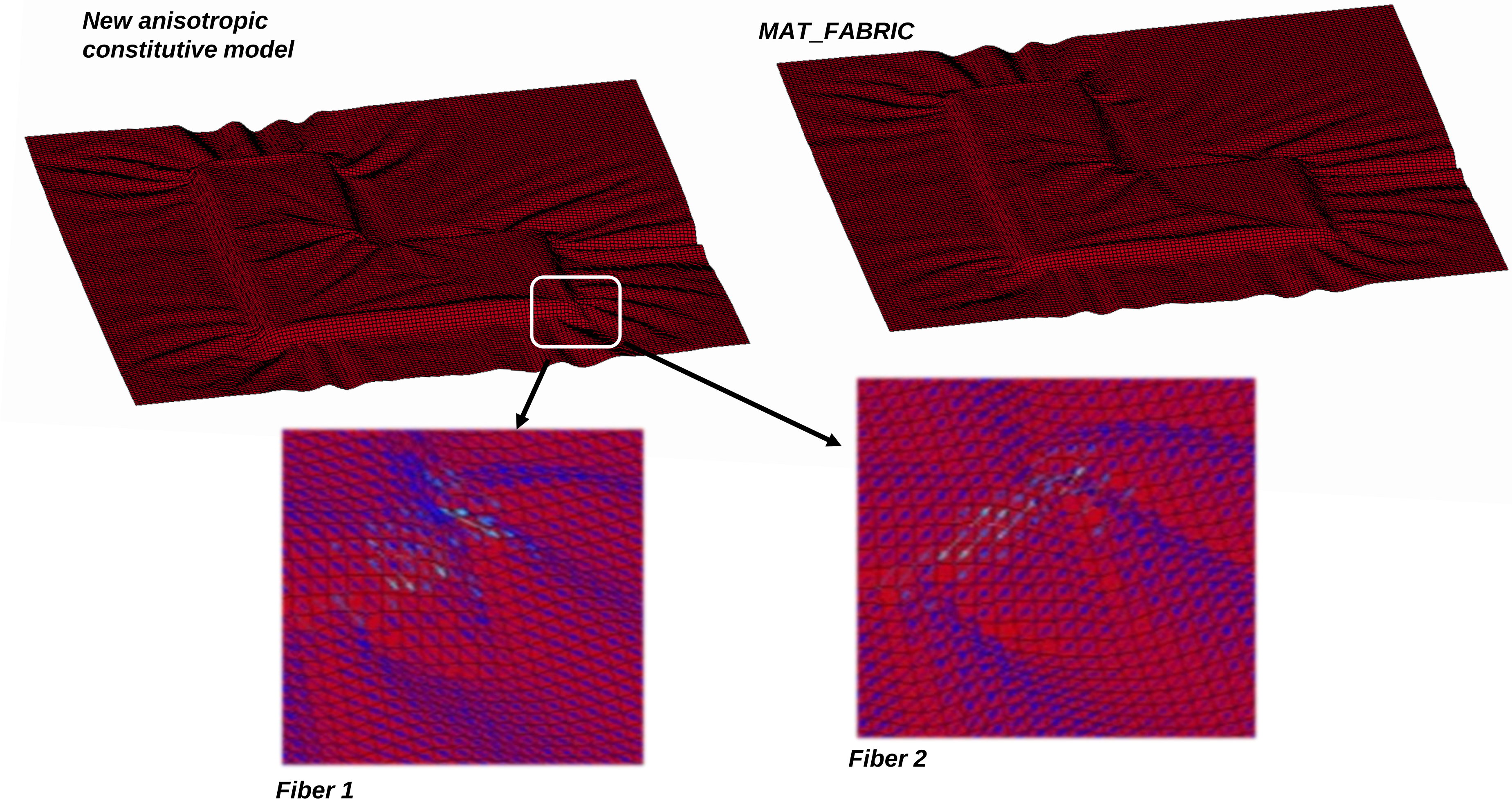
Comparison with LS-DYNA standard material MAT FABRIC (MAT 034)



Example ACMD: Draping simulation (-45 /+45)

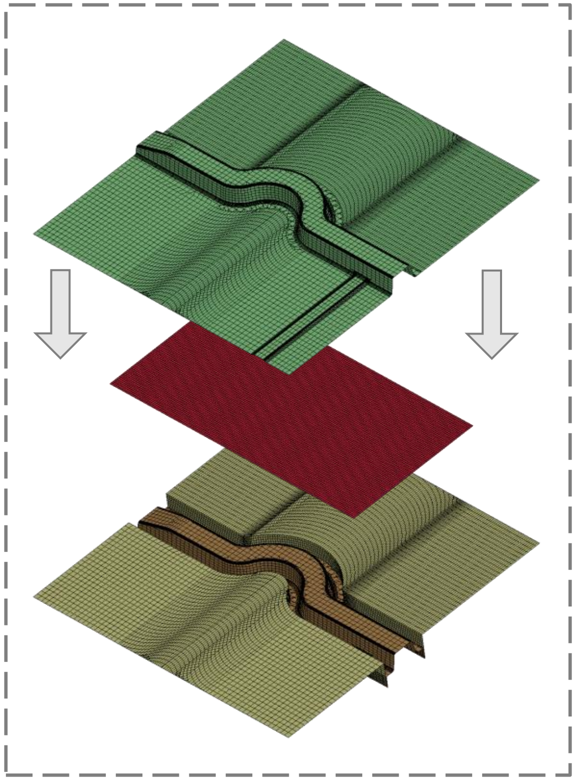


Comparison with LS-DYNA standard material MAT_FABRIC (MAT_034)

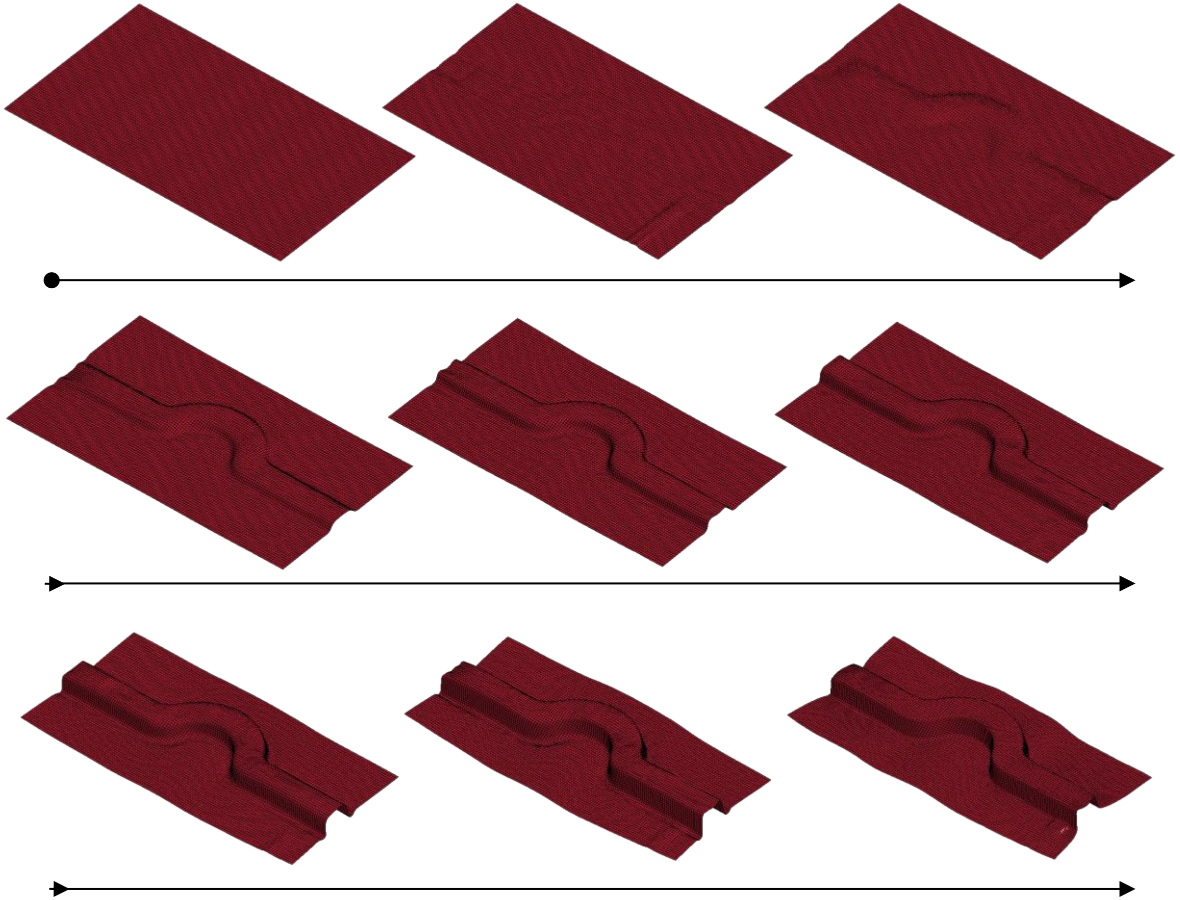


Draping example: Rail

Process simulation

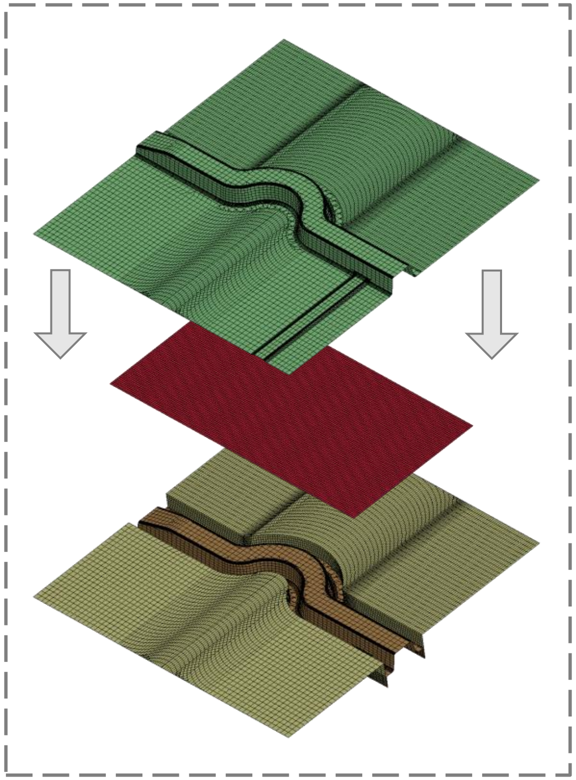


[geometry provided by Benteler-SGL]

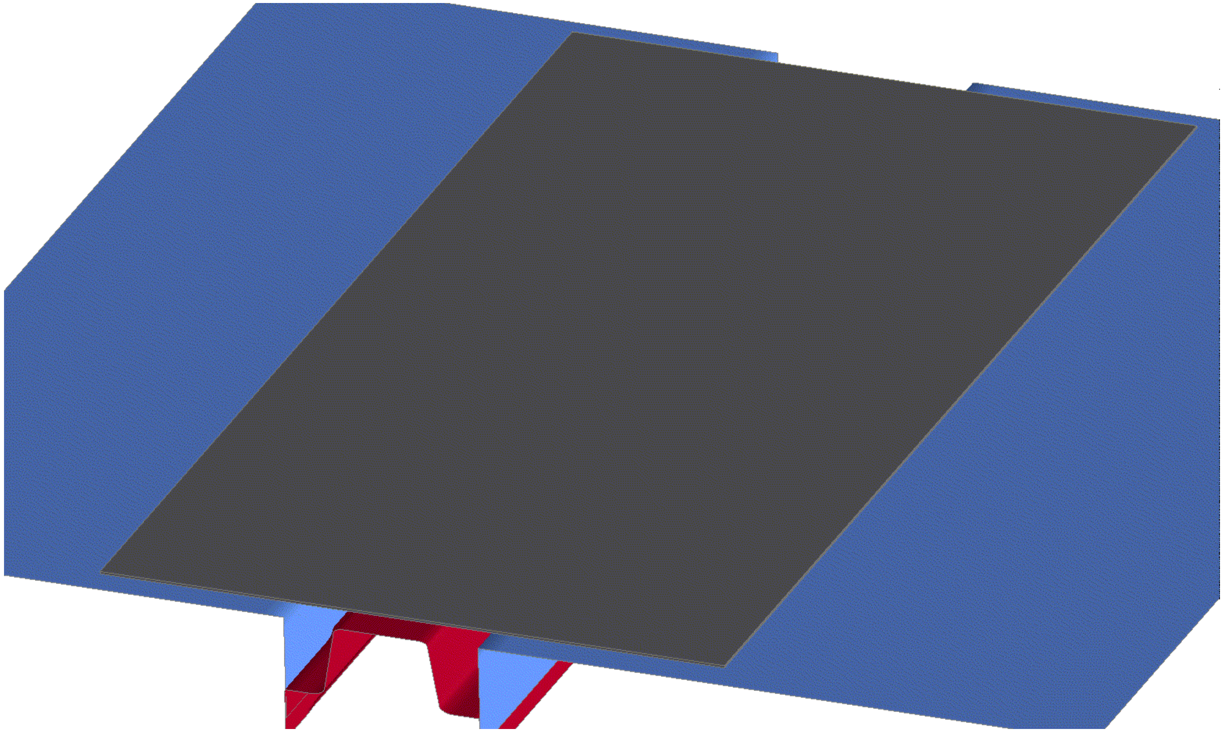


Draping example: Rail

Process simulation



[geometry provided by Benteler-SGL]



Draping example: S-Rail

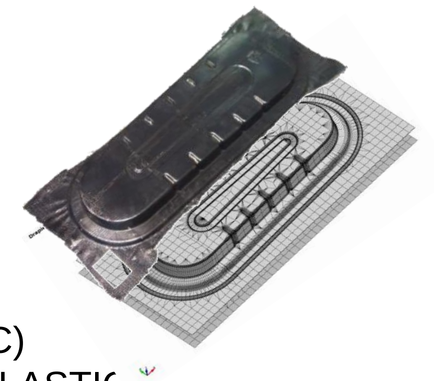
Fiber angle ±45°, final state

Fiber angle ±60°, final state

Producibility

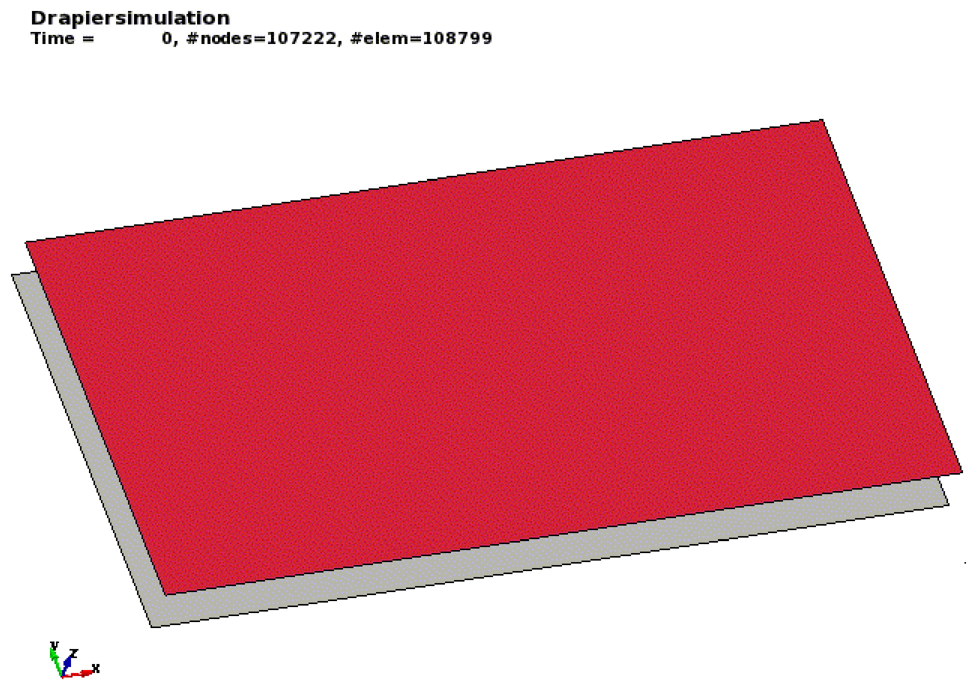
Organo sheet

Process simulation: Organo sheet



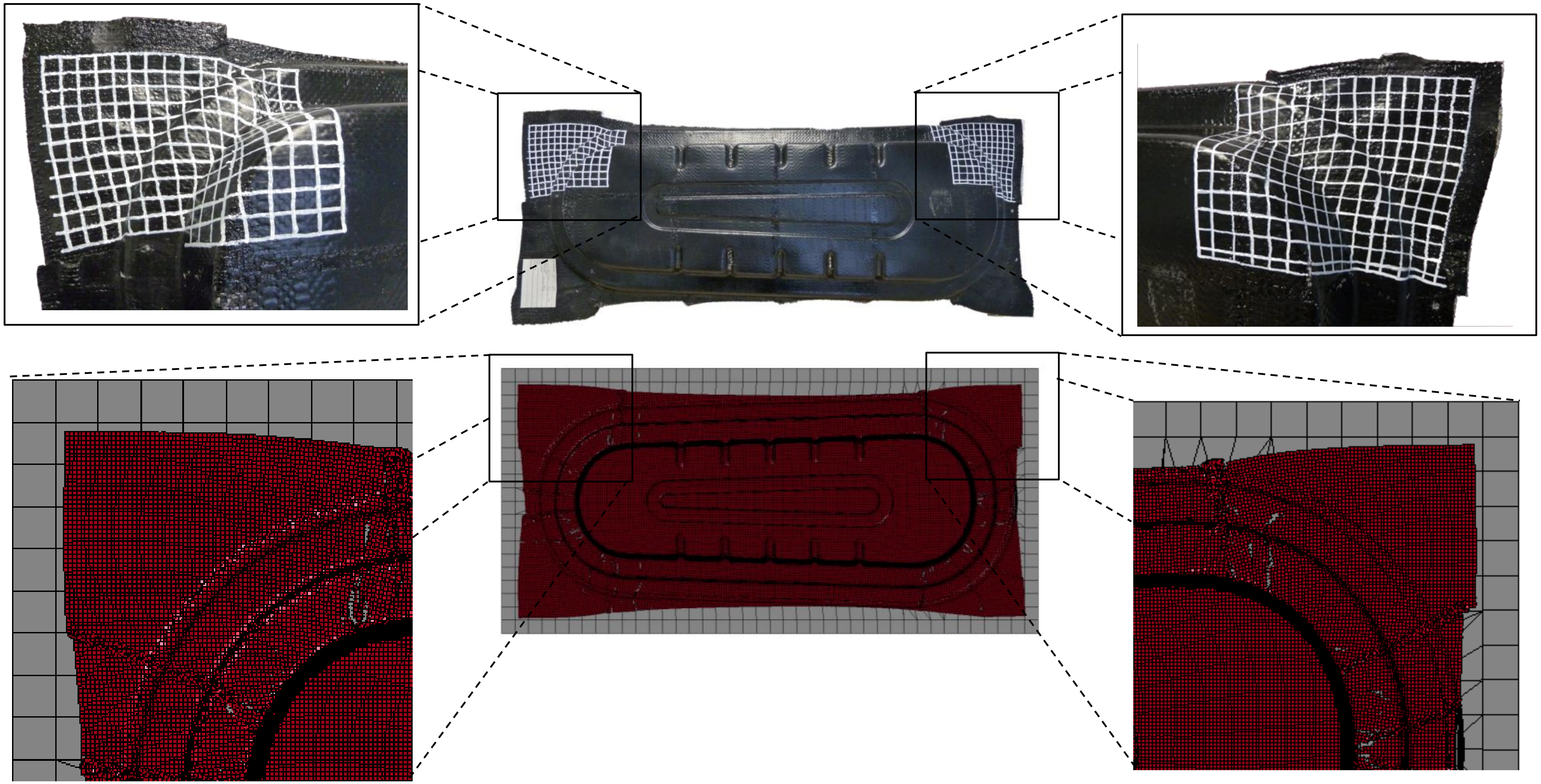
- Single layer of woven fabric that is coated on both sides with PA6, t=1.5mm
- The forming process is done at 250-300 C.

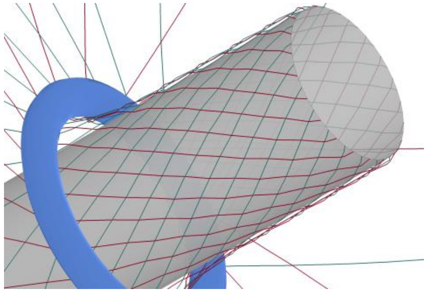
Modeling: Layered shell with *PART_COMPOSITE defining
plastic material for PA6 at the outsides (*MAT_PLASTIC_KINEMATIC)
and orthotropic material for woven fabric (*MAT_ORTHOTROPIC_ELASTIC)



Process simulation: Organo sheet

Optical comparison of fiber directions (aligned with mesh)



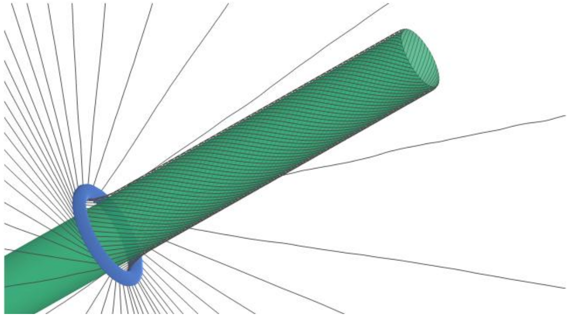


Producibility

Braiding

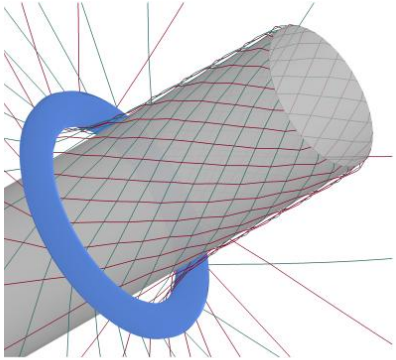
T-Pult: First steps into the process simulation

Filament winding simulation:



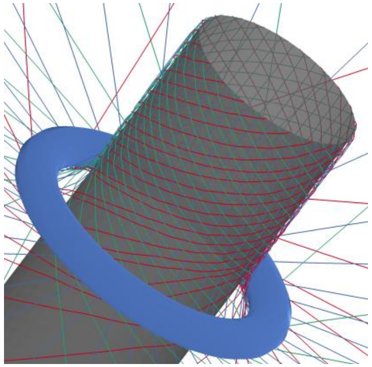
- 21 yarns
- 21543 Beam elements, 1 part
- Simple rotation of the fibers and pushing of the braiding core through the braiding ring
- Simple filament winding

Simple braiding simulation:



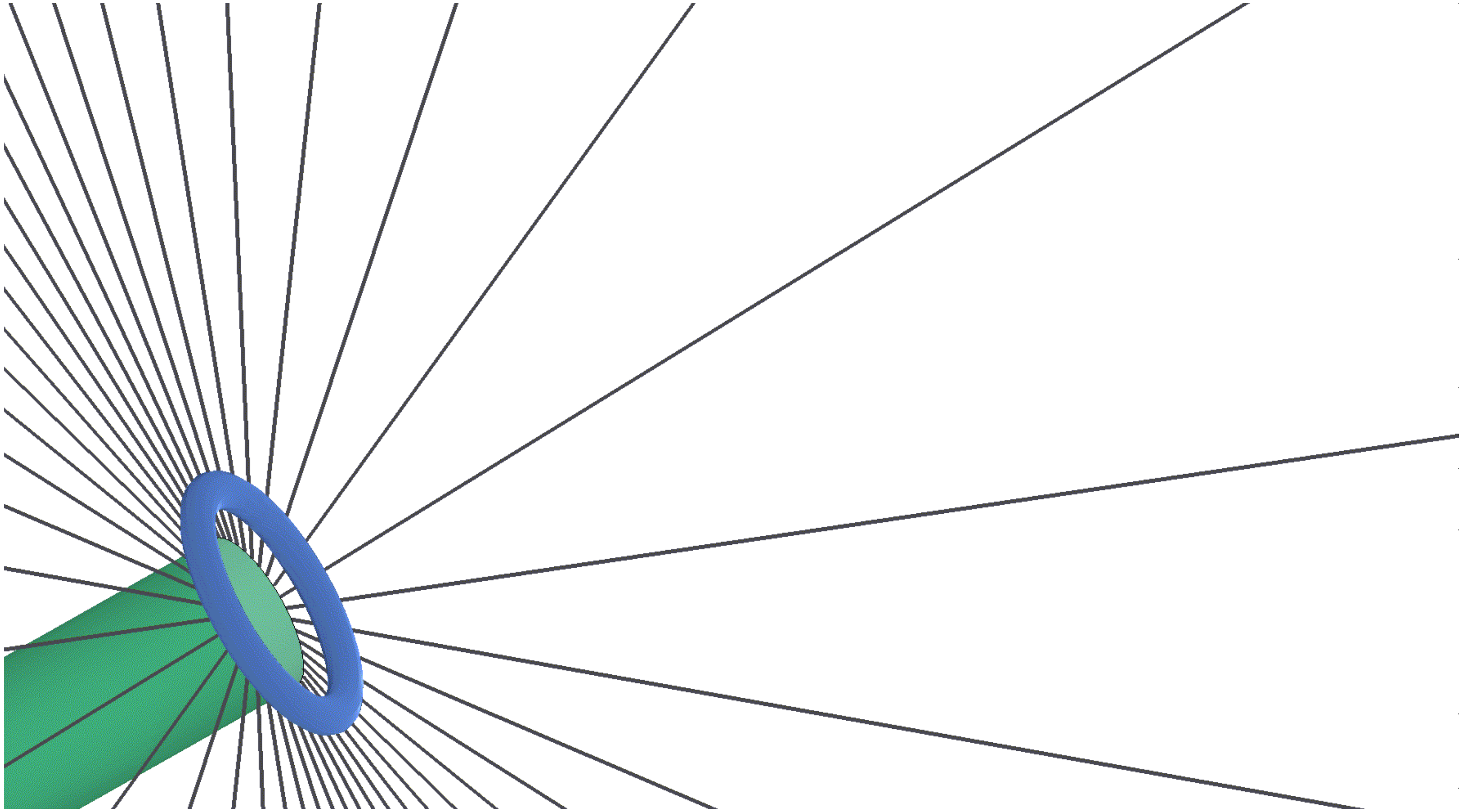
- 42 yarns
- 86172 Beam elements, 2 parts
- Fibers are rotated and then moved up- and down to create the braiding-pattern
- Braiding core is pushed through the braiding ring

Braiding simulation with UD reinforcement:

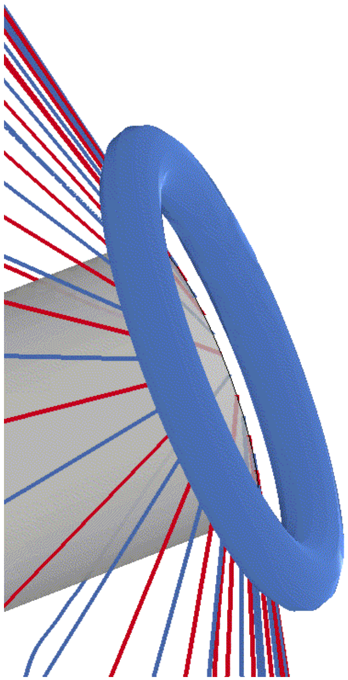


- 84 yarns
- 174348 Beam elements, 3 parts
- Half the elements used as UD – reinforcement parts
- Fibers are rotated and then moved up- and down to create the braiding-pattern
- Braiding core is pushed through the braiding ring

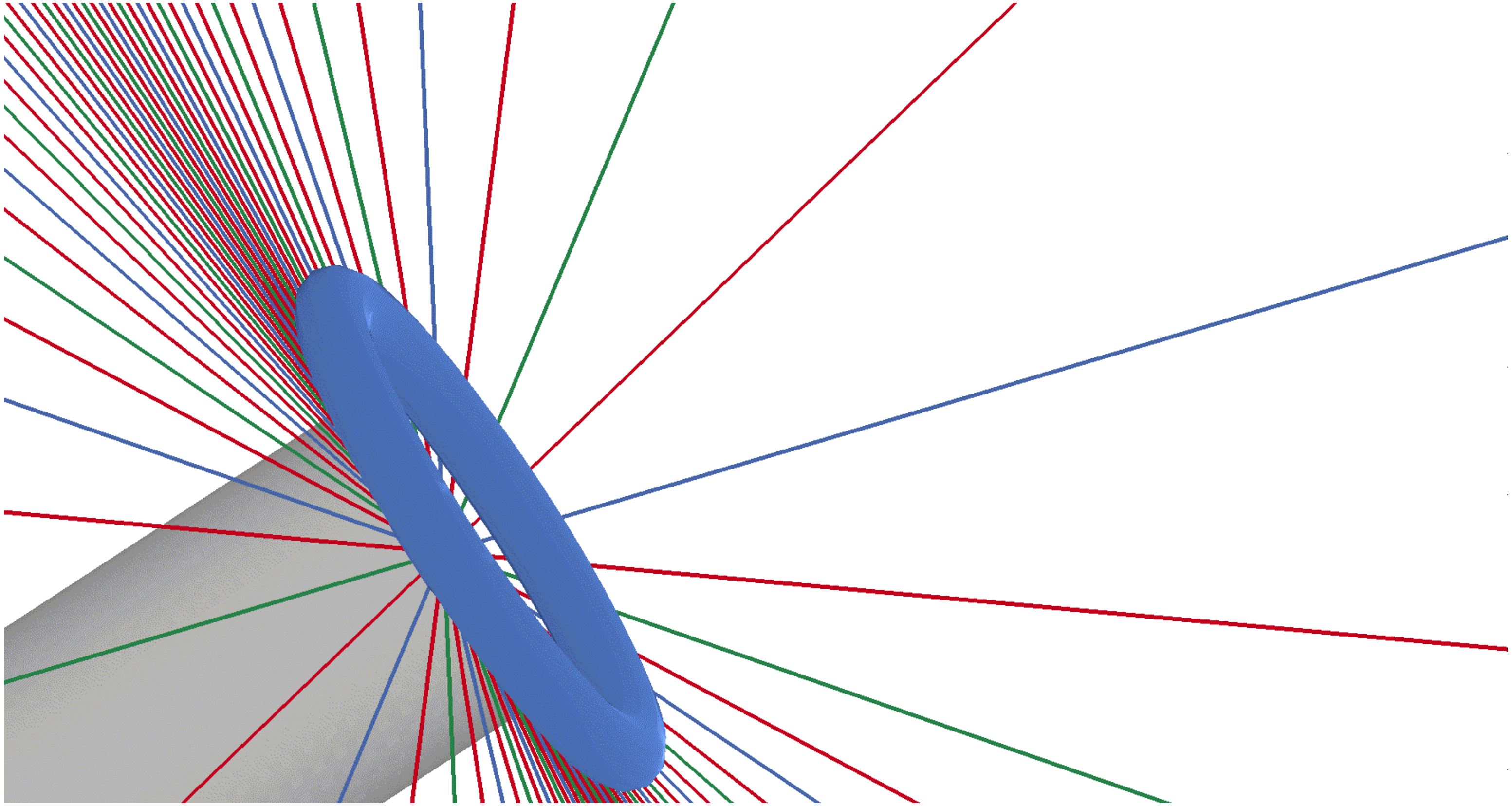
Process simulation: Filament winding

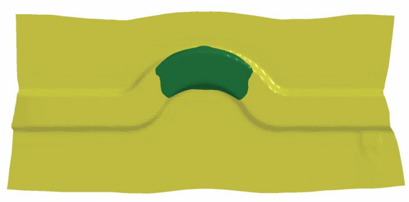


Process simulation: Simple braiding



Process simulation: Braiding with UD reinforcement





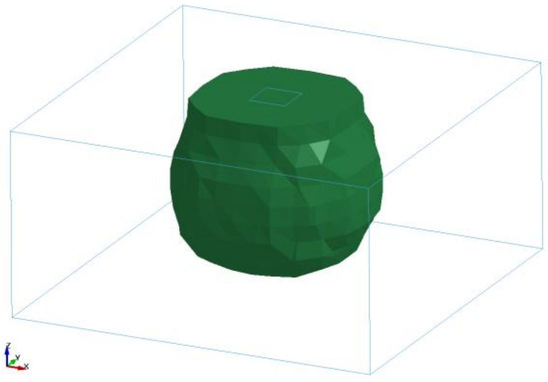
Producibility

RTM

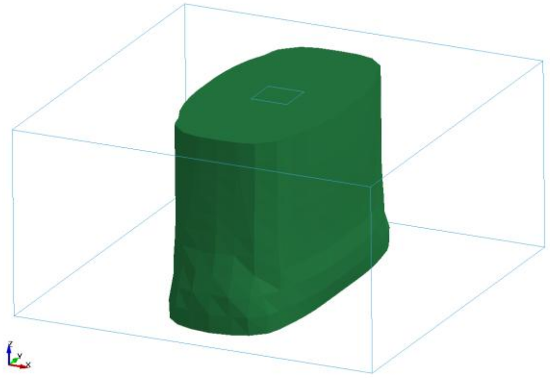
Proof of concept 1: Injection of Resin with ALE-feature

- Infiltration is a 3D flow problem through a porous media
- Porosity depends on the packing density of the fibers
- Fiber orientation results in an anisotropic porosity distribution in the domain

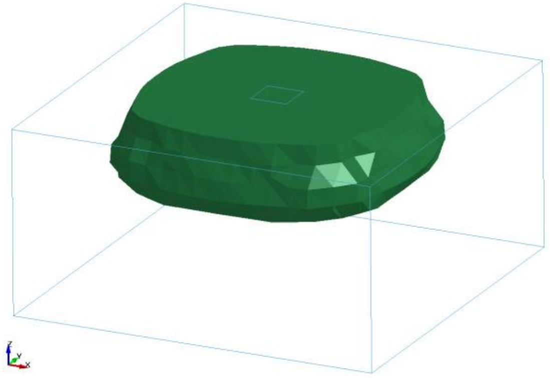
- Flow through porous media can be modeled in LS-DYNA using the CONSTRAINED_LAGRANGE_IN_SOLID keyword



same porosity in all directions

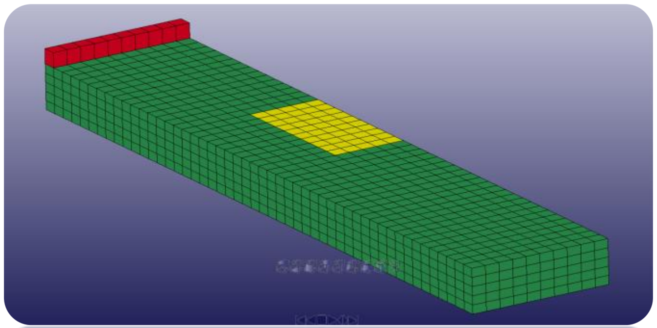


low porosity in x-direction

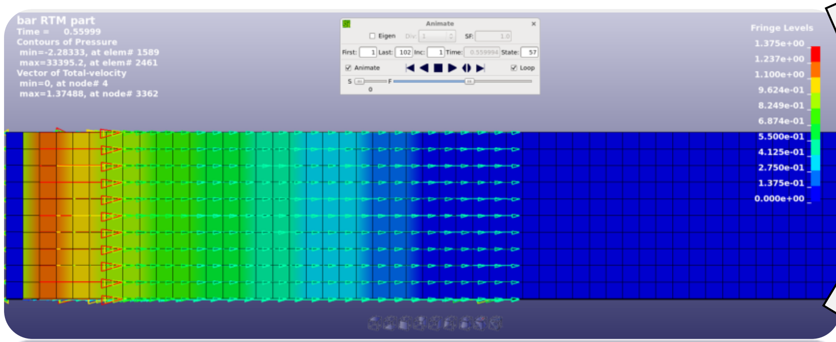


low porosity in z-direction

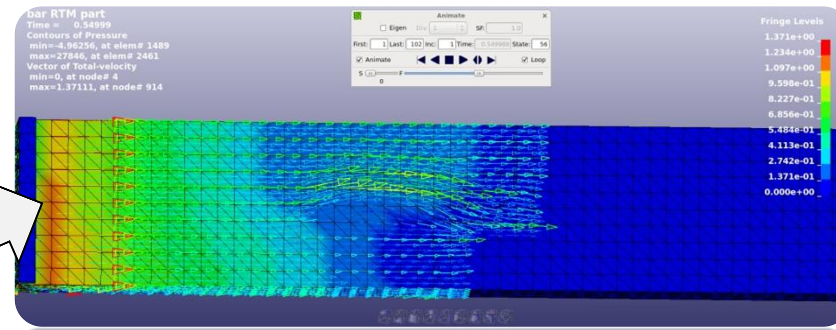
Proof of concept 2: Injection of Resin with ALE-feature



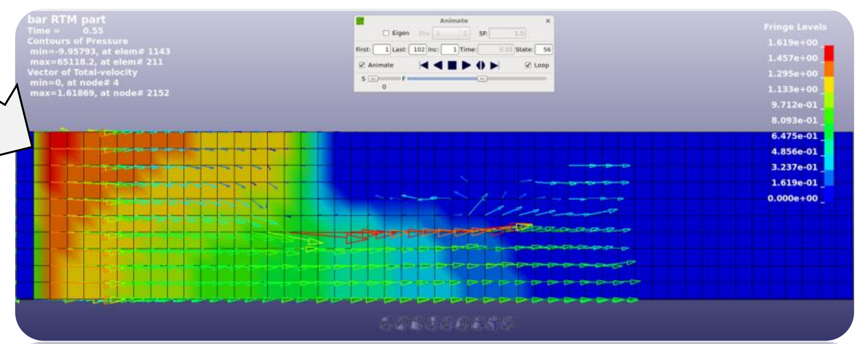
- Box with an inclusion
- Inflow defined at red elements
- Main material (green) and inclusion (yellow) have same/different viscous coefficients.



Same porosity coefficients



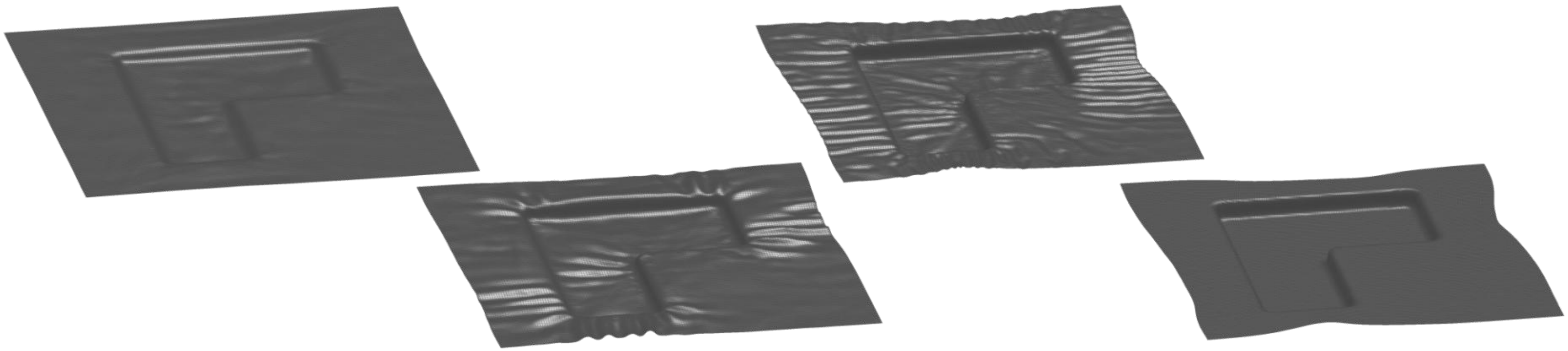
Inclusion has higher porosity



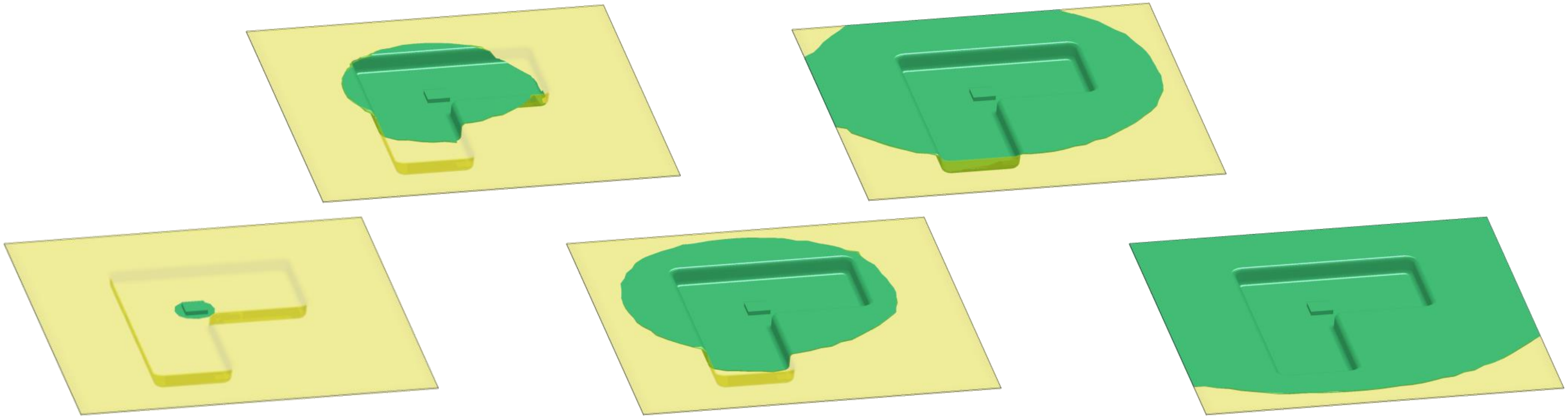
Main material has higher porosity

Example: L-Shape

Draping

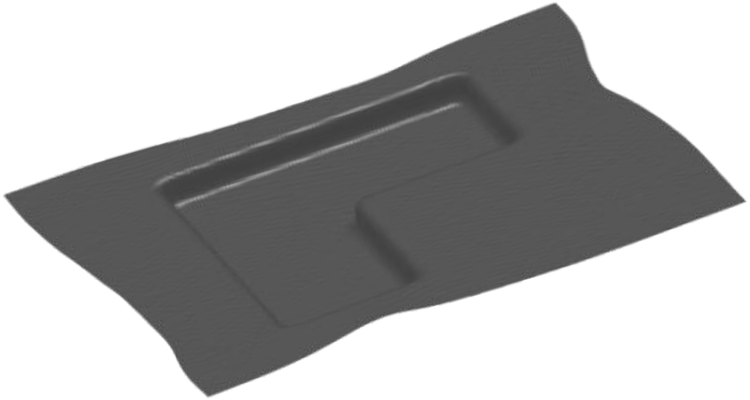


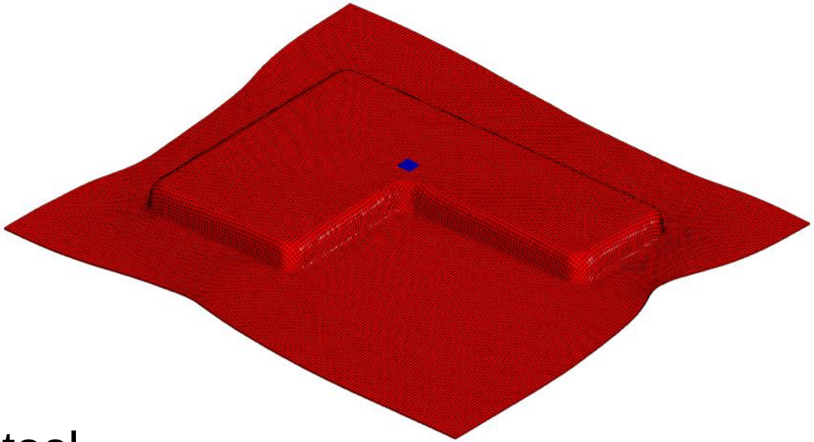
Infiltration – visualized on cavity defined by tool



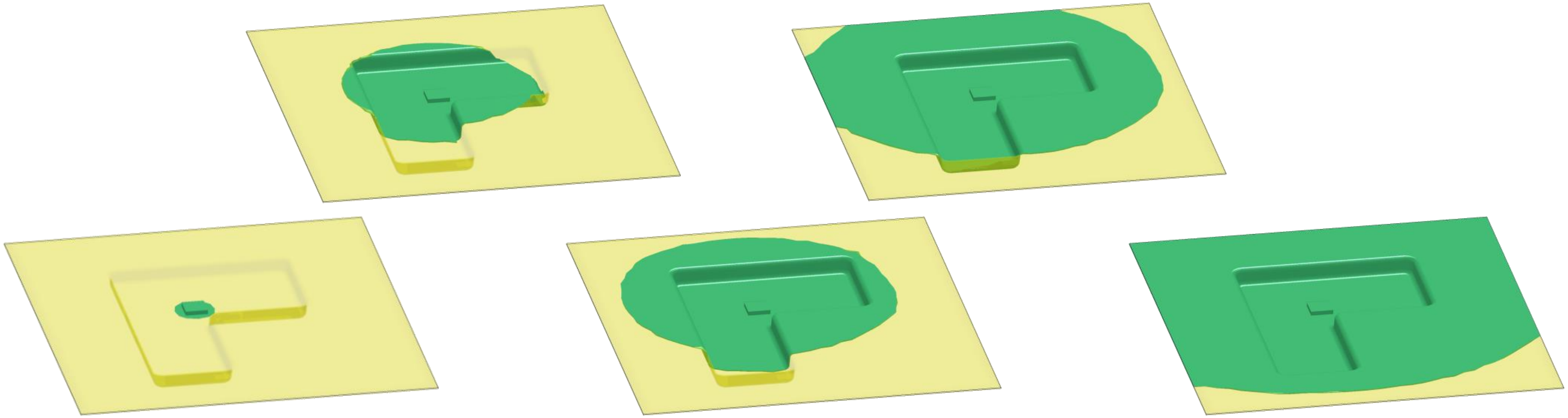
Example: L-Shape

Infiltration – visualized on cavity defined by fabric



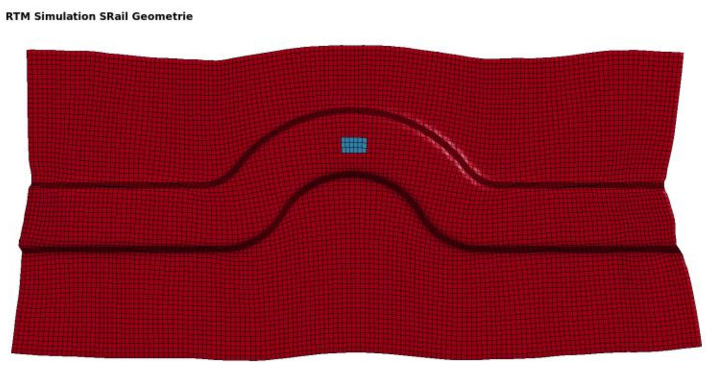


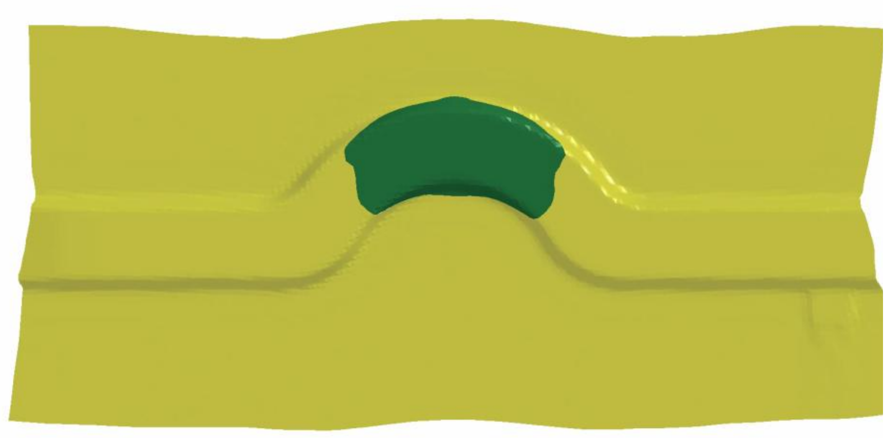
Infiltration – visualized on cavity defined by tool

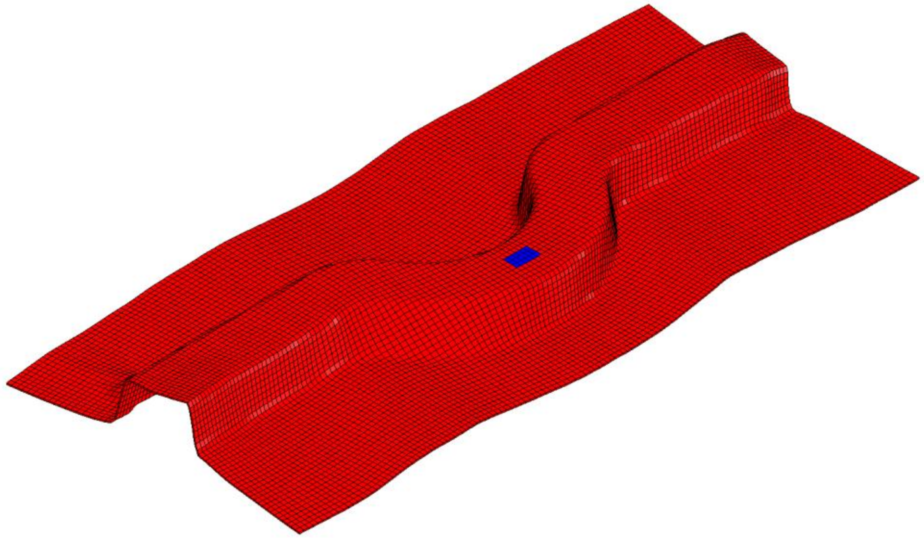


Injection of resin in draped rail-geometry

- Mesh obtained from draping simulation
- Flow induced by pressure inlet
- Isotropic porosity
- One injection point for resin
  is considered (blue)



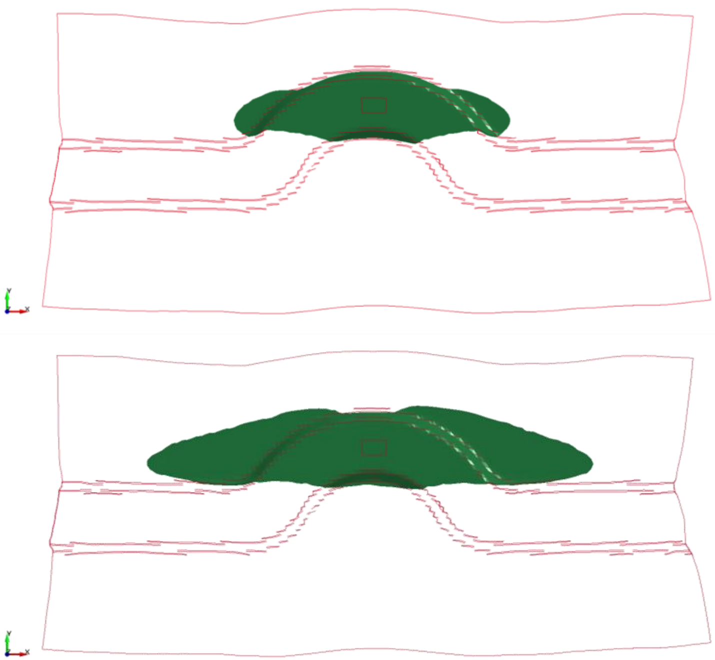




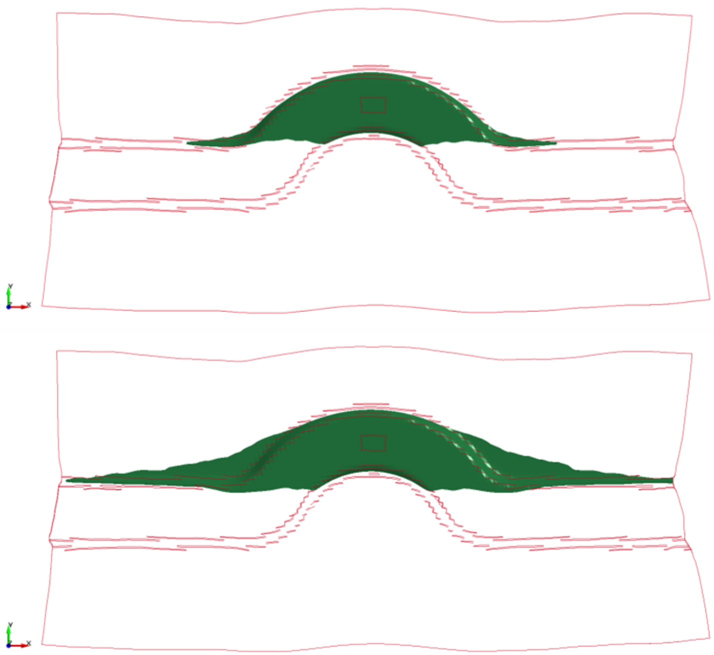
Injection of resin in draped rail-geometry

- LS-DYNA allows to define the porosity with respect to the element coordinate system:
  - Easy to specify a porosity in thickness direction even for curved geometries
  - Important if the geometry results from a previous draping simulation

High porosity in global x-direction



High porosity in element x-direction

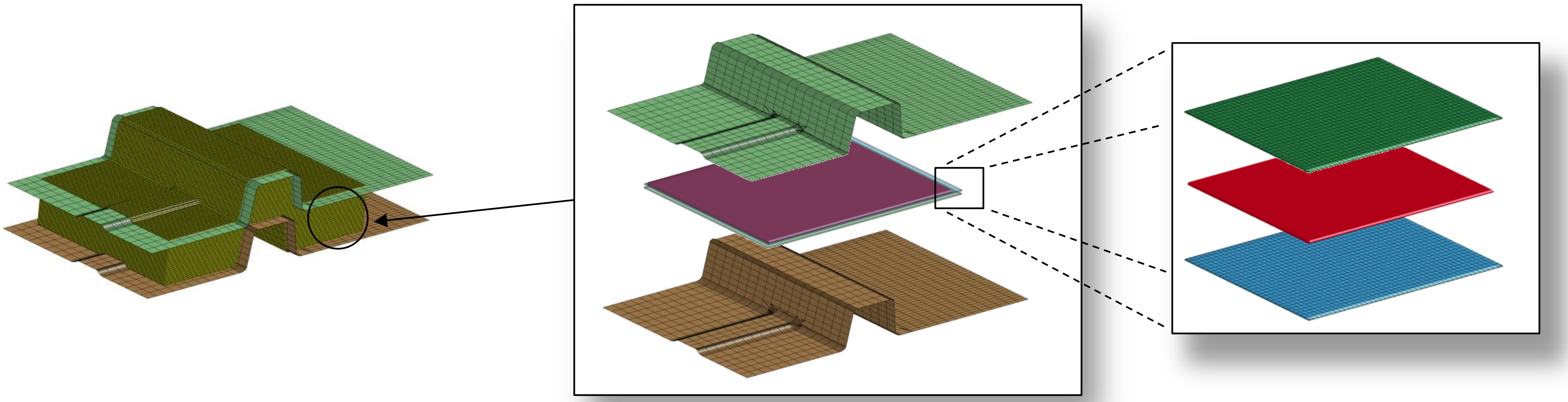


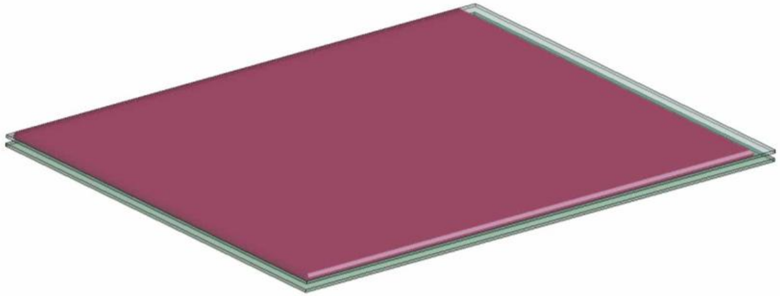
Producibility

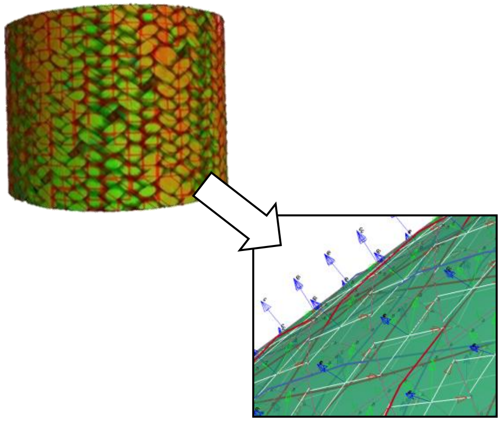
Wet moulding

A first proof of concept for wet moulding

Cut-out from rail geometry

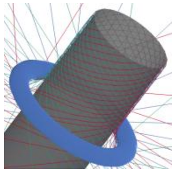




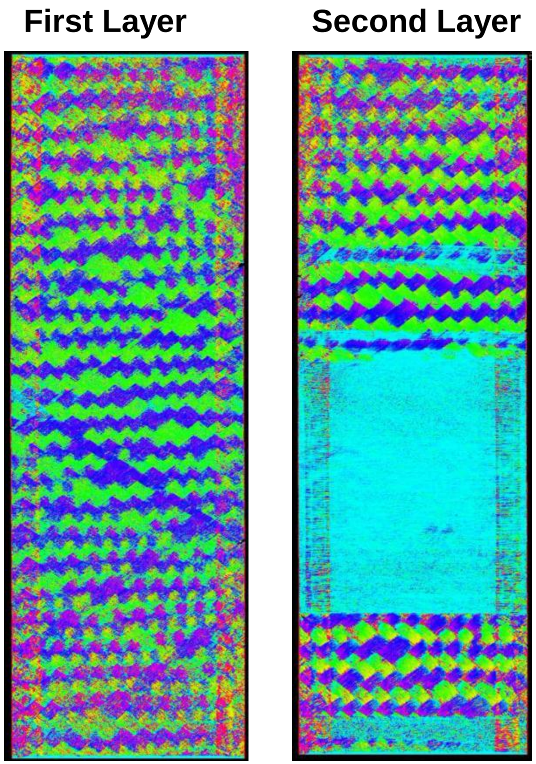


Orientations from measurement

Alternative: CT-data of braided tube for model setup



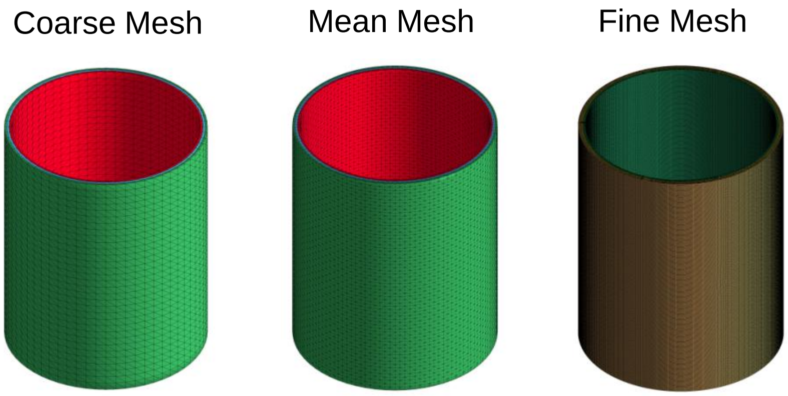
- transfer of fiber orientation-tensors onto a LS-DYNA gained by mesh by CT measurement
- Three different mesh sizes considered so far: Coarse, Mean, Fine
- Example-part: 3-layered braided tupe with 0-deg reinforcement fibers



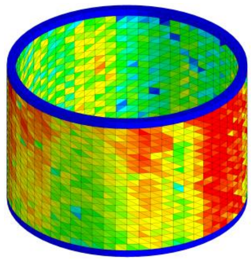
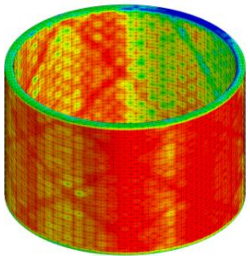
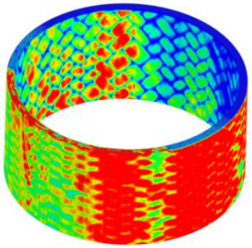
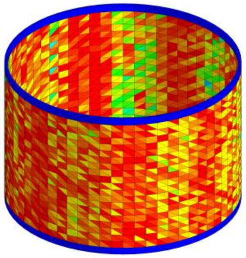
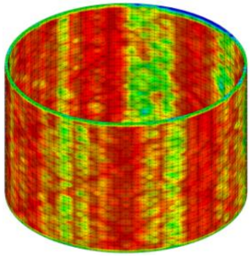
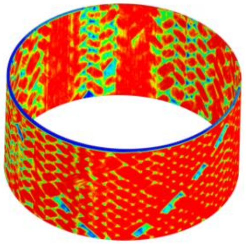
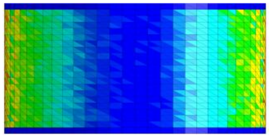
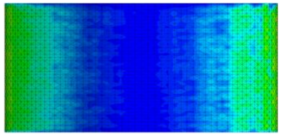
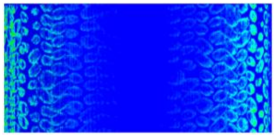
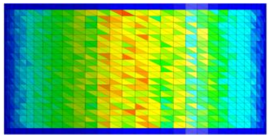
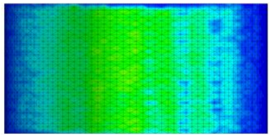
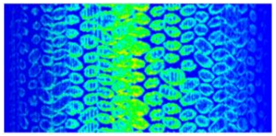
[H. Finckh, ITV Denkendorf // Th. Günter, Volume Graphics]

Transfer of orientation data

	Num. of Elements	Layers	Element-Size
Coarse Mesh	38420	1	0,3 - 1,25 mm
Mean Mesh	150039	2	0,15 - 0,62 mm
Fine Mesh	15078400	4	0,075 - 0,1 mm



Alternative: CT-data of braided tube for model setup

Mapped data	Coarse Mesh	Mean Mesh	Fine Mesh
Fiber-Volume Fraction:			
z-Orientation – Layer 2:			
x-Orientation:			
y-Orientation:			

Alternative: CT-data of braided tube for model setup

Next steps: Homogenization

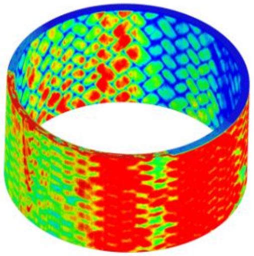
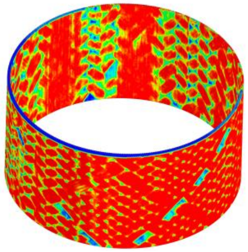
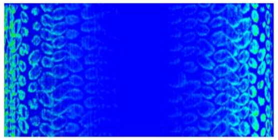
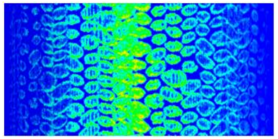
Fiber Orientation Tensor:

[1] $$a_{ij} = \frac{1}{n}\sum_{k=1}^{n} a_{ij}^{k} = \frac{1}{n}\left(\sum_{k=1}^{n} p_i^k p_j^k\right) = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

Number of fibers/Volume

Orientation of a single fiber: $p = \begin{pmatrix} \sin\theta\cos\phi \\ \sin\theta\sin\phi \\ \cos\theta \end{pmatrix}$

Polar coordinates: $$\begin{cases} r = \sqrt{x^2+y^2+z^2} \\ \theta = \arccos\left(\dfrac{z}{\sqrt{x^2+y^2+z^2}}\right) \\ \varphi = \arctan\left(\dfrac{y}{x}\right) \end{cases}$$

Mapped data	Fine Mesh
Fiber-Volume Fraction:	
z-Orientation – Layer 2:	
x-Orientation:	
y-Orientation:	

[Kastner et.al.: *Pipeline zur dreidimensionalen Auswertung und Visualisierung der Faserverteilung in glasfaserverstärkten Kunststoffbauteilen aus µ-Röntgen-Computertomographiedaten*, DACH-Jahrestagung St. Gallen, 2008]

Transfer CT-data to LS-DYNA model

Next steps: Homogenization

Get Eigenvalues: $\det(\mathbf{A} - \lambda\, \mathbf{E}) = 0$

→ Eigenvectors (Fiber main directions)

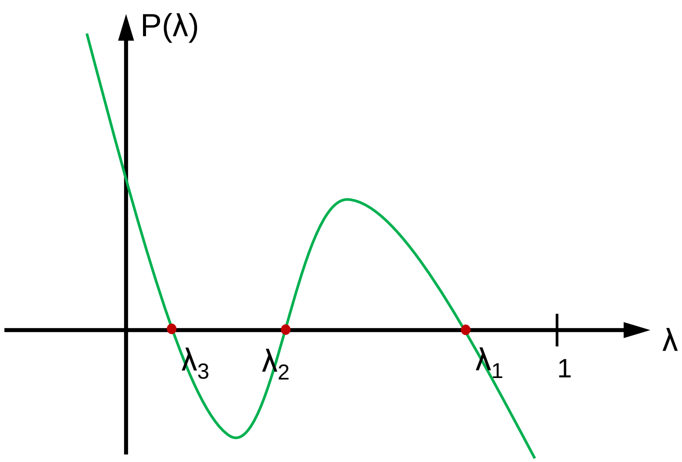
$$A = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{12} & a_{22} & a_{23} \\ a_{13} & a_{23} & a_{33} \end{pmatrix}$$

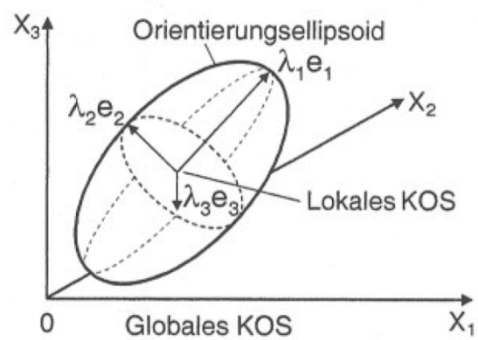
where k = 1, trace (A) = 1 $\qquad P(\lambda) = -\lambda^3 + k{*}\lambda^2 + l{*}\lambda + m$

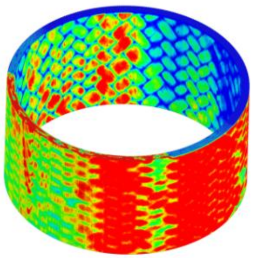
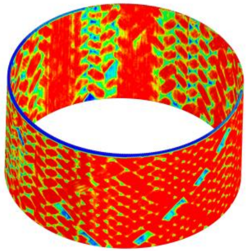
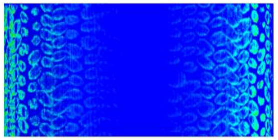
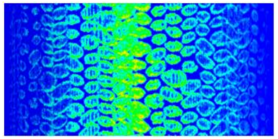
$\mathbf{A} - \lambda_i\, \mathbf{E} \Rightarrow \mathbf{e_i}$

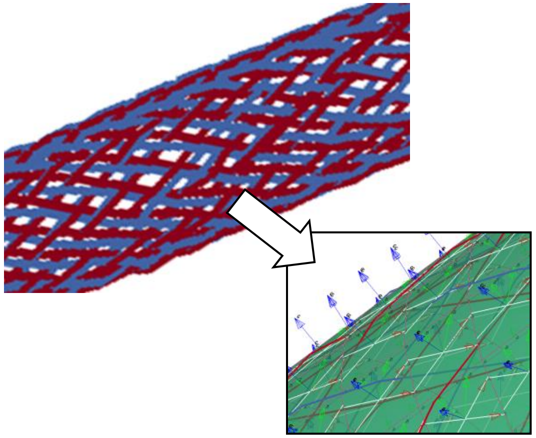
$\mathbf{e_i}$ -> Eigenvectors ≙ Fiber Main directions

λ_i – probability for fibers being aligned along this axis





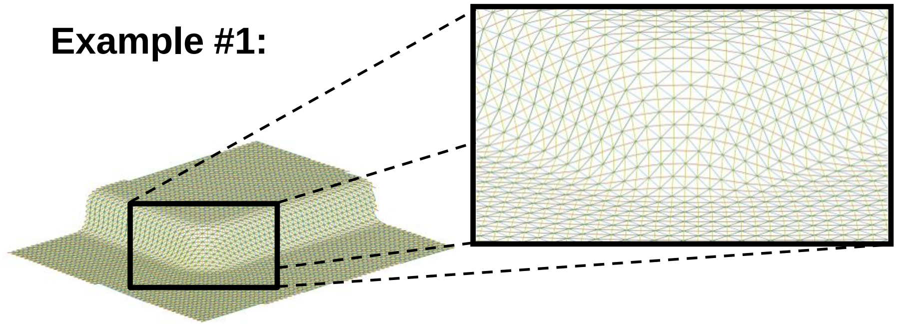
Mapped data	Fine Mesh
Fiber-Volume Fraction:	
z-Orientation – Layer 2:	
x-Orientation:	
y-Orientation:	



Mapping of orientations

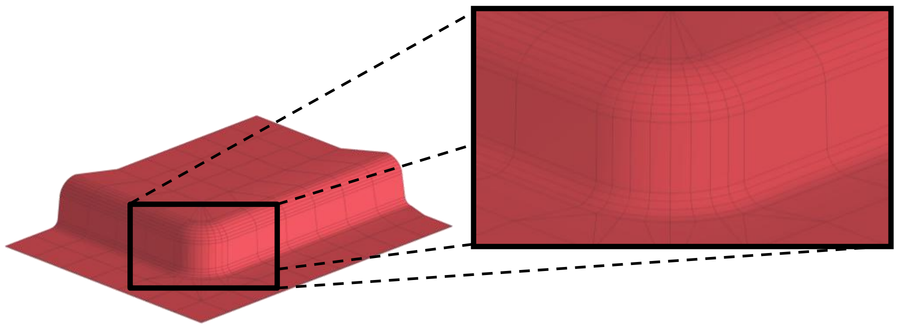
Mapping of material directions on different target meshes

Example #1:



Source Mesh:

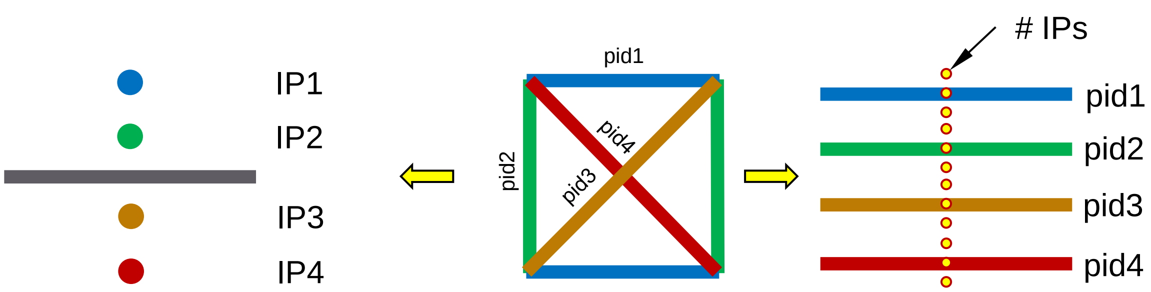
- four Parts
- 10461 Beam Elements
- avg. length: 1.65 – 3.30 mm



Target Mesh:

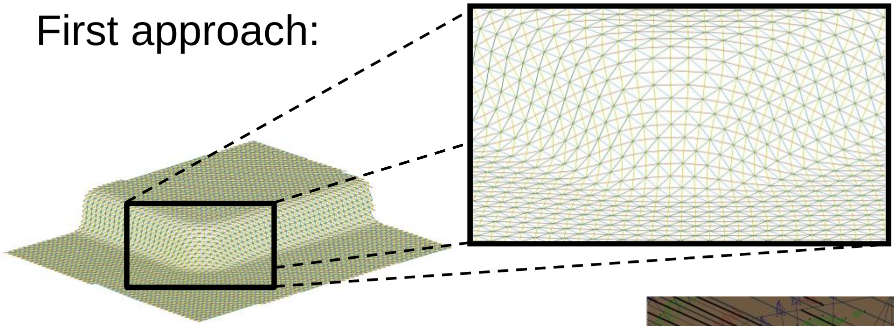
- one or four Parts
- 4x 300 Shell Elements
- avg. length: 1.80 – 18.40 mm

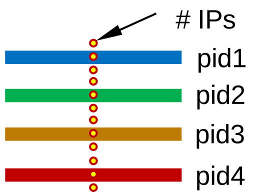
Homogenization strategy:



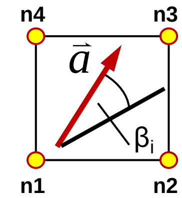
Mapping of material directions on different target meshes

First approach:

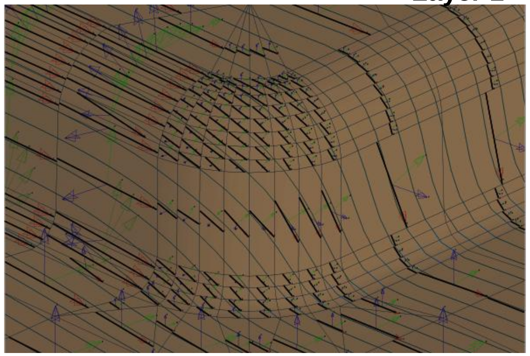




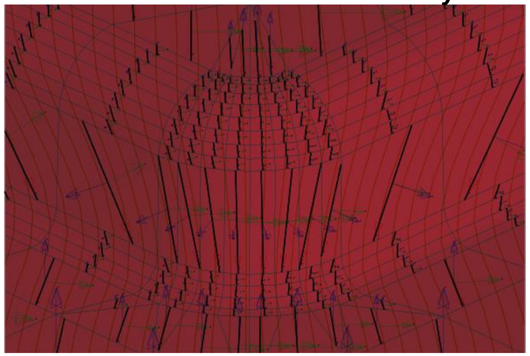
AOPT = 2



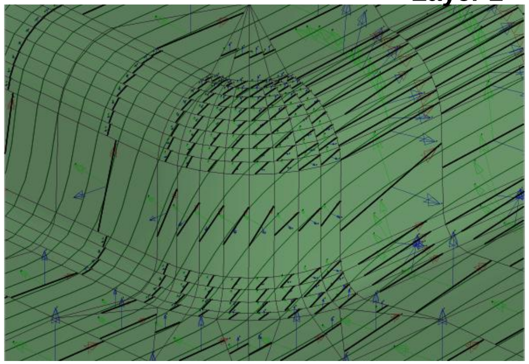
Layer 1



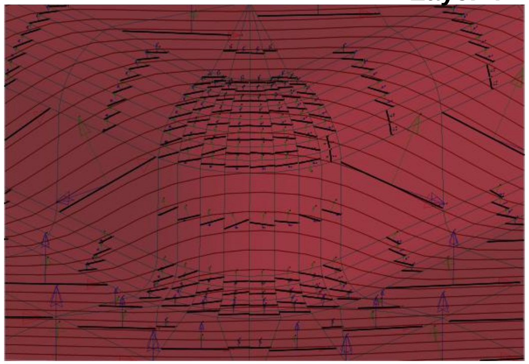
Layer 3



Layer 2



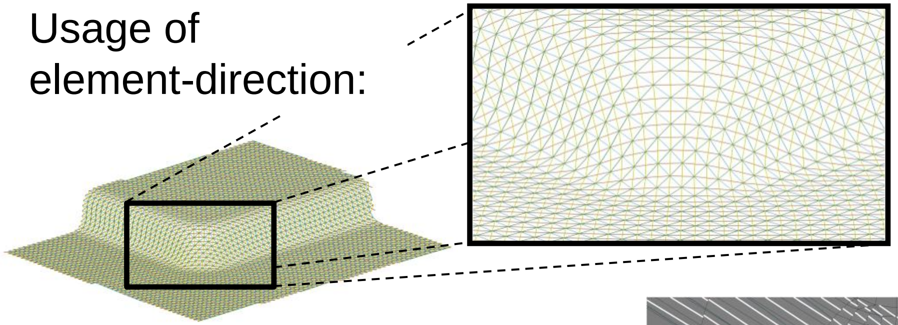
Layer 4



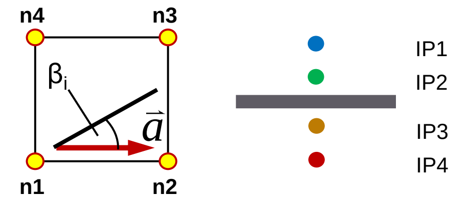
- Vector $\vec{a}$ is given directly by the orientations of the beam elements
- *ELEMENT_SHELL_-COMPOSITE or *PART_COMPOSITE
- Main disadvantage:
  - Each element get‘s an assigned material card -> 300 elements eq. 300 diff. material cards
  - good as a first tryout, but not relevant for any kind of simulation

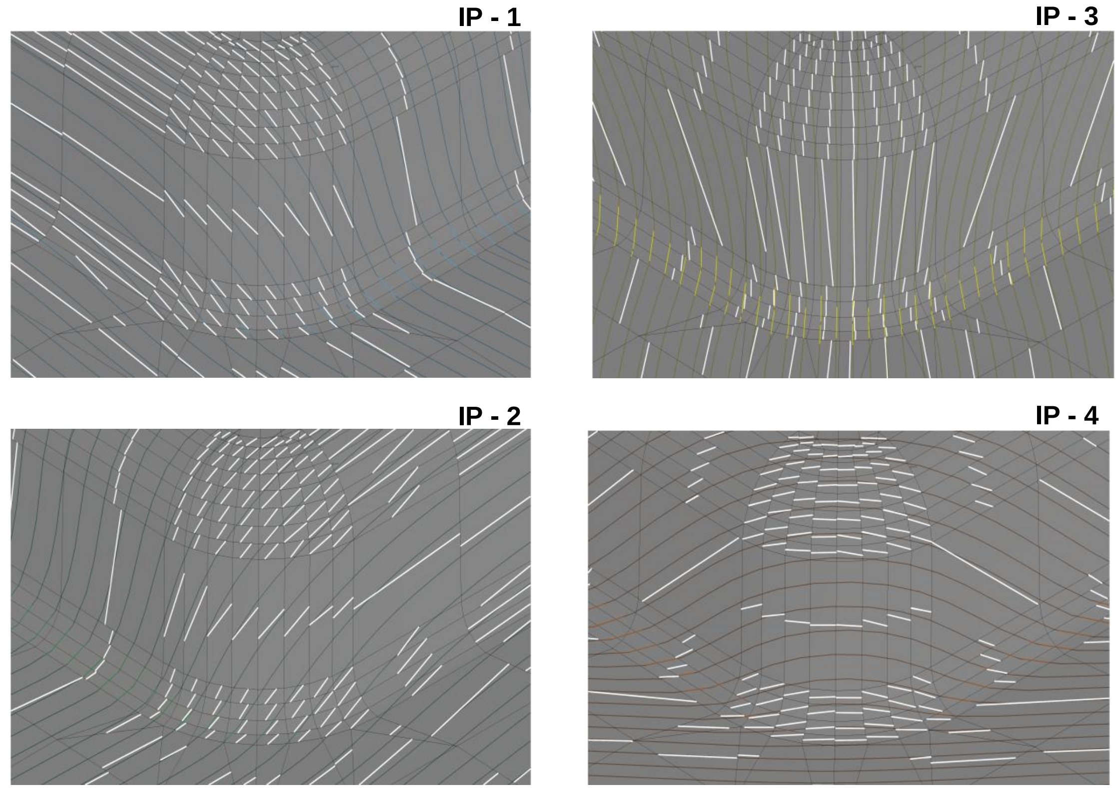
Mapping of material directions on different target meshes

Usage of
element-direction:



AOPT = 0



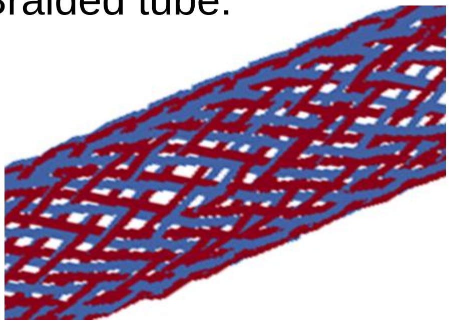


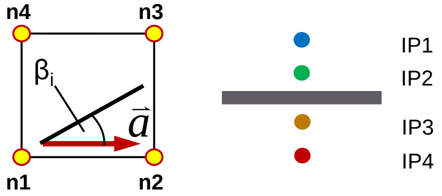
- Vector $\vec{a}$ is given directly by the element orientation
- *ELEMENT_SHELL_-COMPOSITE or *PART_COMPOSITE
- Identifiaction of β_i is a little bit more complicated than writing fiber orientation directly into the material card
- Only one material card per part! Relevant for crash simulations…

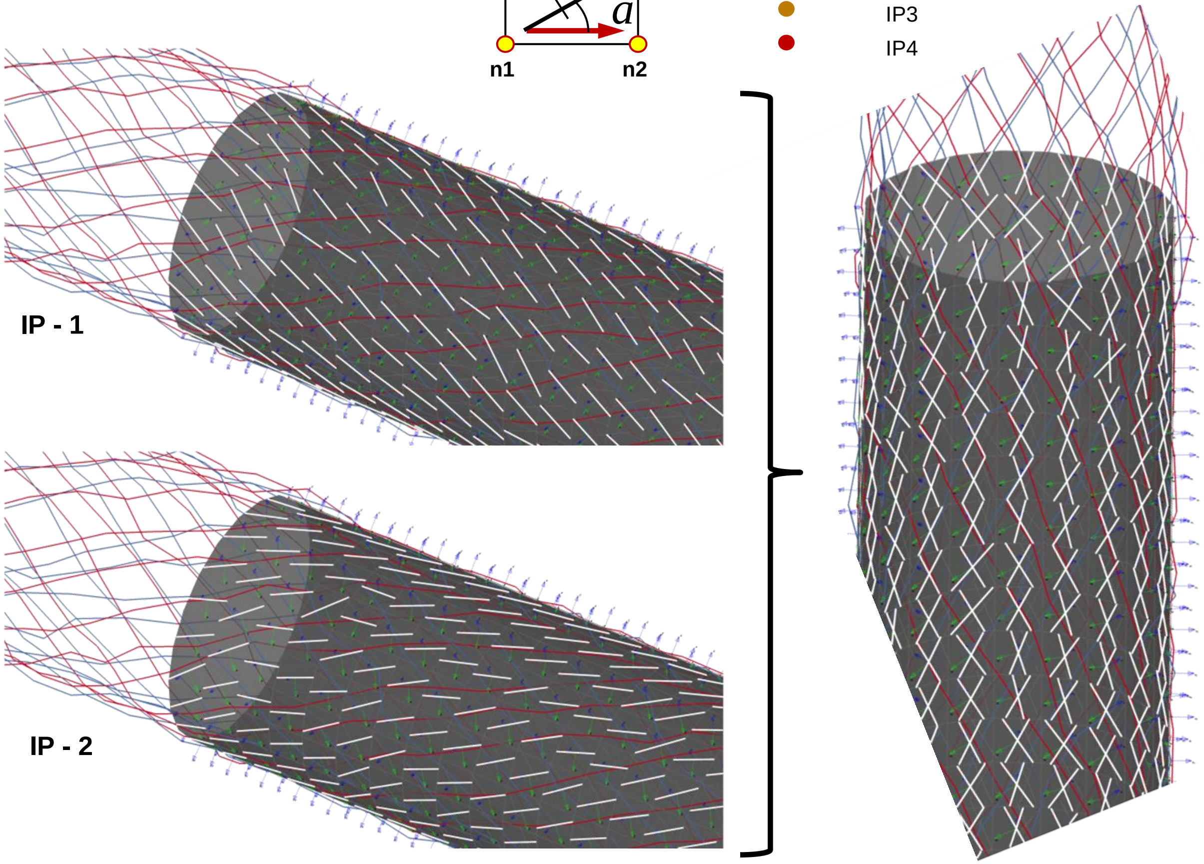
Mapping of material directions on different target meshes

AOPT = 0

Braided tube:







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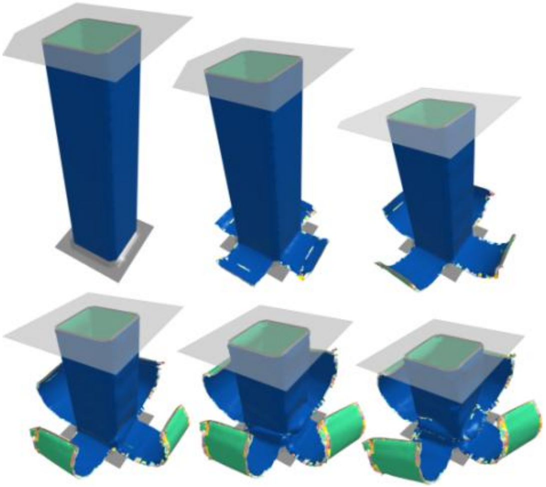

Serviceability

Crashworthiness

Skipped!!

Summary

- Solutions to simulate various different production techniques have been presented.
- Main target is the prediction of constitutive properties (matrix/fiber) during the process and in the final product
- Mapping towards coarser meshes for subsequent servicability simulations (i.e. crashworthiness) has been addressed

Open issues/not discussed:

- Modeling techniques and calibration in crashworthiness
- Assessment of predictiveness of such models
- This will be the target of future work: ARENA2036, T-PULT, Swim-RTM, ….

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FIN