

Composite Simulation

Möglichkeiten zur Abbildung der Prozesskette von FVK in LS-DYNA

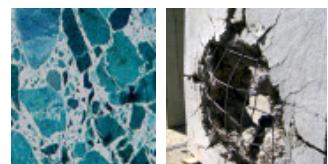
Dr. André Haufe, Dr. Thomas Klöppel, Dr. Stefan Hartmann, Christian Liebold

DYNAmore GmbH
Stuttgart

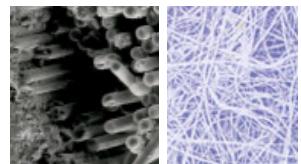
Composites: A rather broad term!

Definition

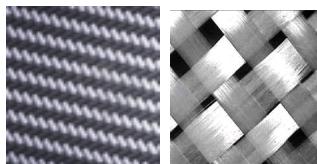
A **combination** of two or more **materials** (reinforcing elements, fillers, and composite matrix binder), differing in form or composition on a **macroscale**. The constituents retain their identities, i.e. they do not dissolve or merge completely into one another although they act in concert. The components can be physically identified and exhibit an interface between one another.



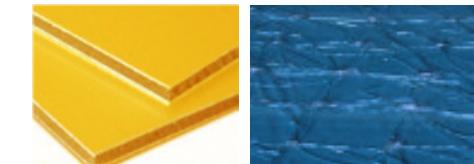
Concrete
(cement/stone/steel)



Short/long fiber
reinforced polymers
(glass/PP)



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



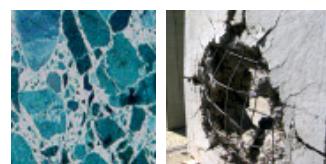
Sandwich/Laminates
(alloy/polymer/..glass/PVB/...)



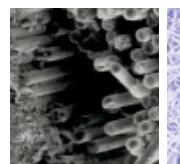
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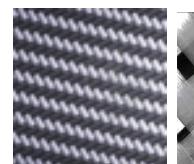
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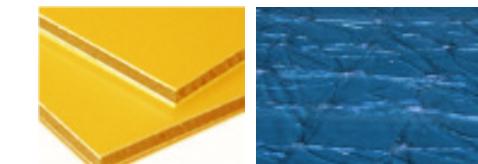
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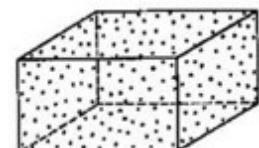
Short fiber
reinforced polymers
(glass/PP)



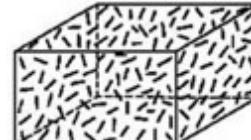
Long fiber
reinforced polymers
(glass/carbon/PA/PP/EP)



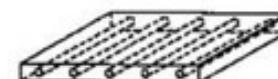
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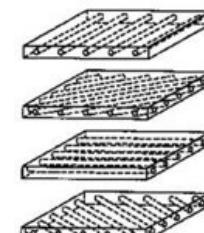
particulate composite materials
(particles in a matrix)



short fibers



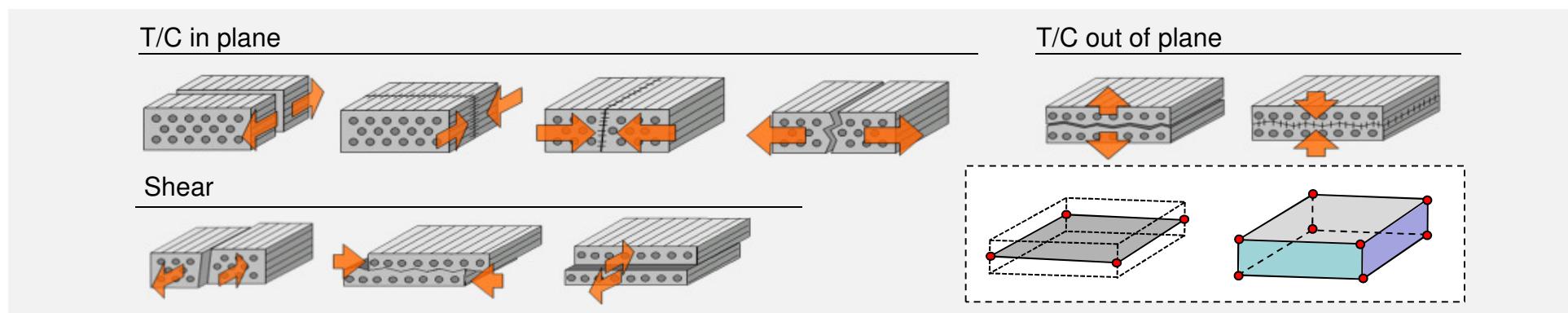
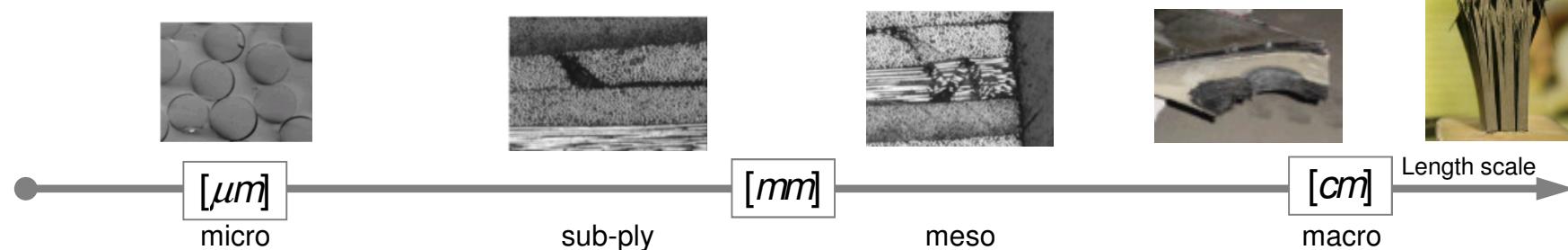
long fibers



laminated composite materials
(layers of various materials)

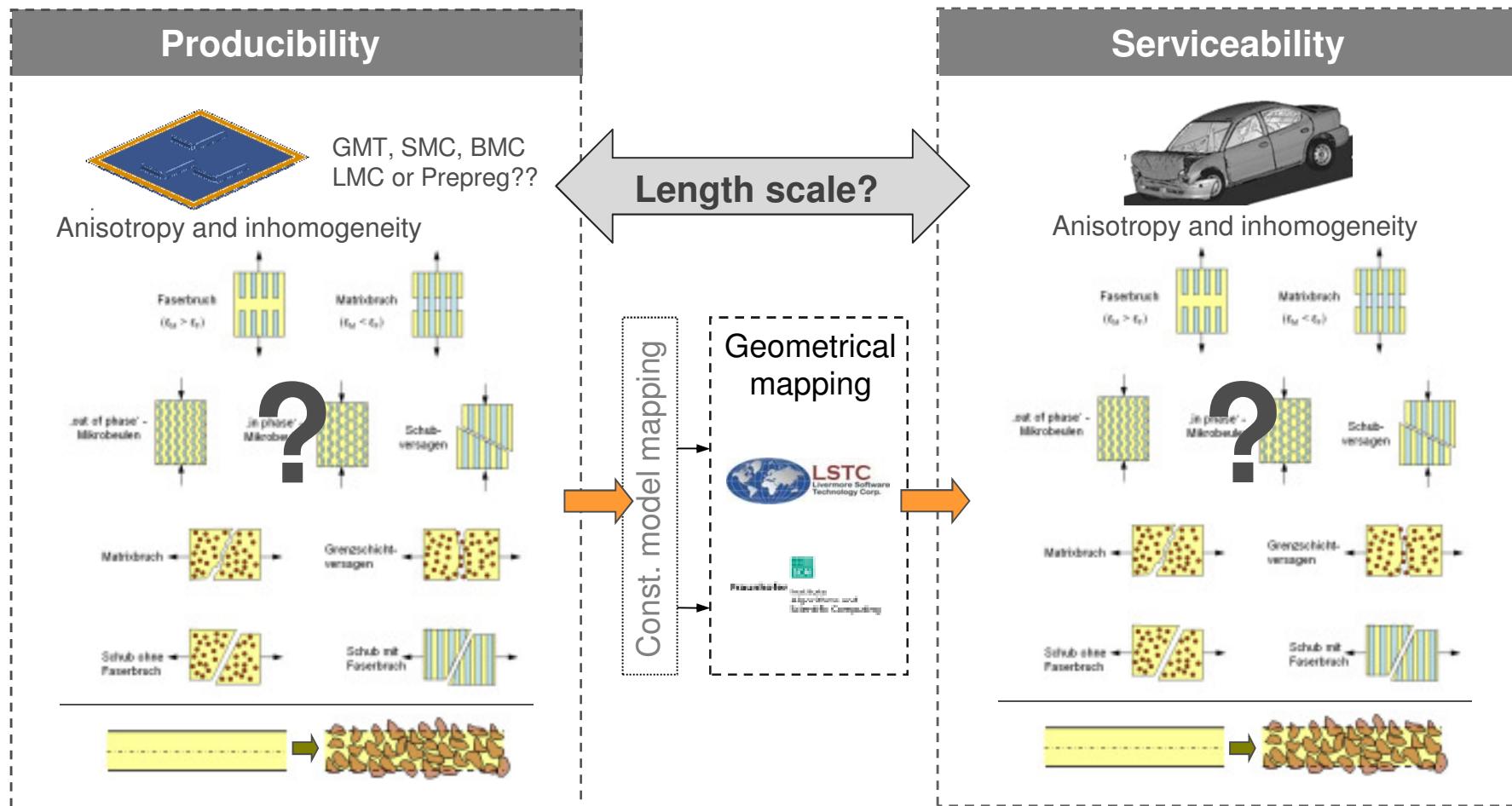
Application: Predict serviceability in crashworthiness

→ Crushing/cracking/delamination/buckling on different length scales...



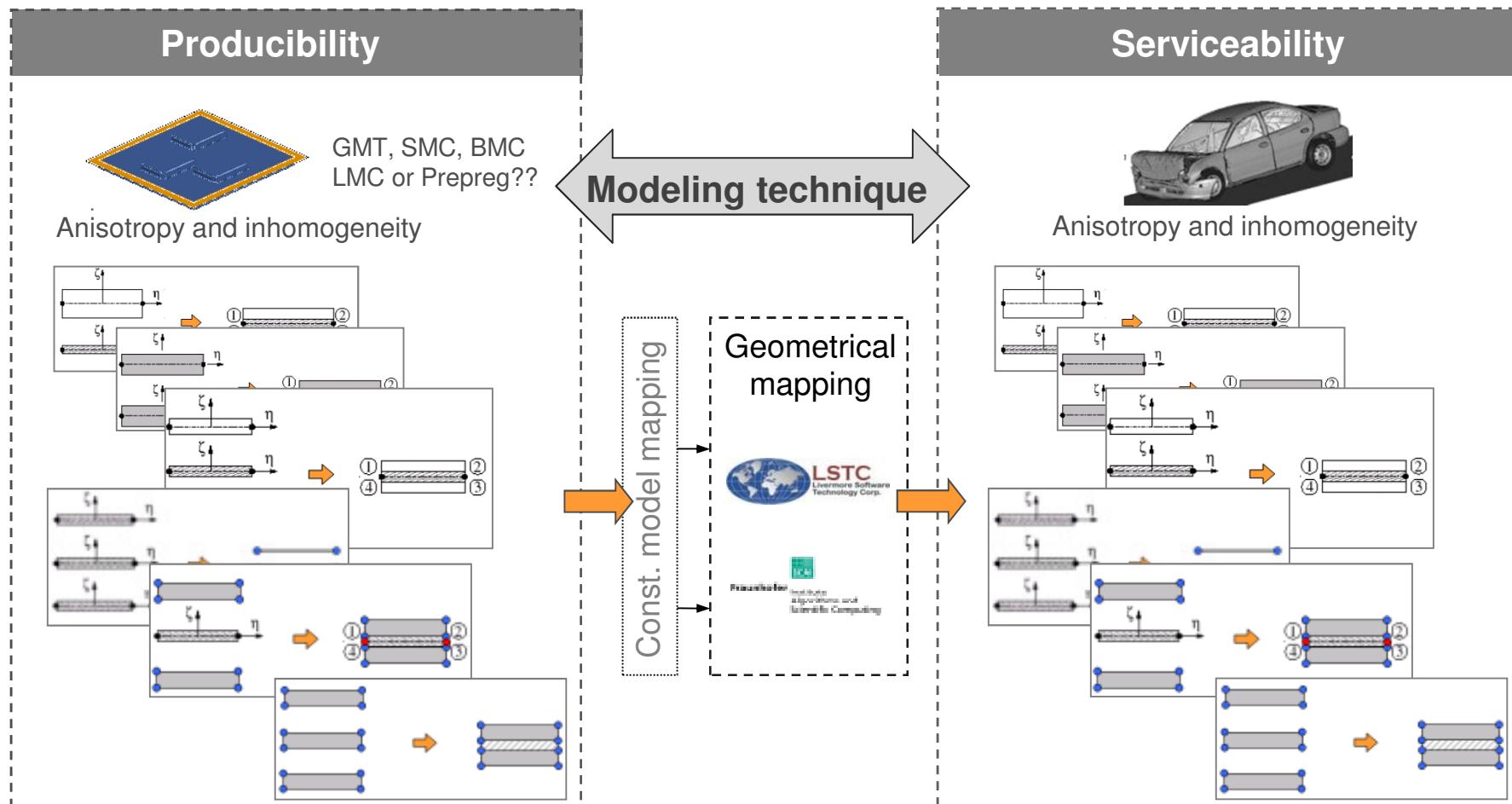
Composite process chain: Producibility2Servicability

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



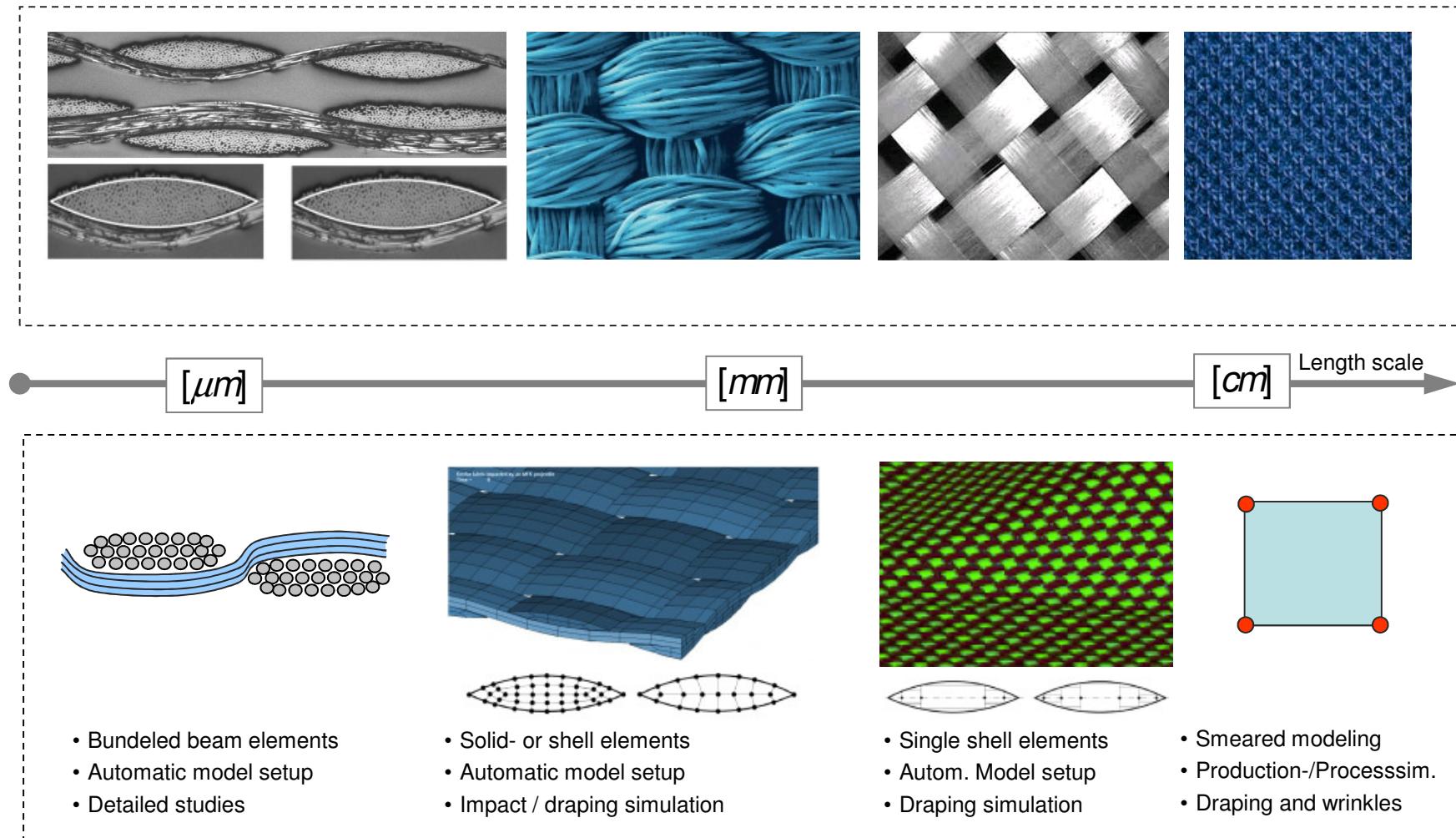
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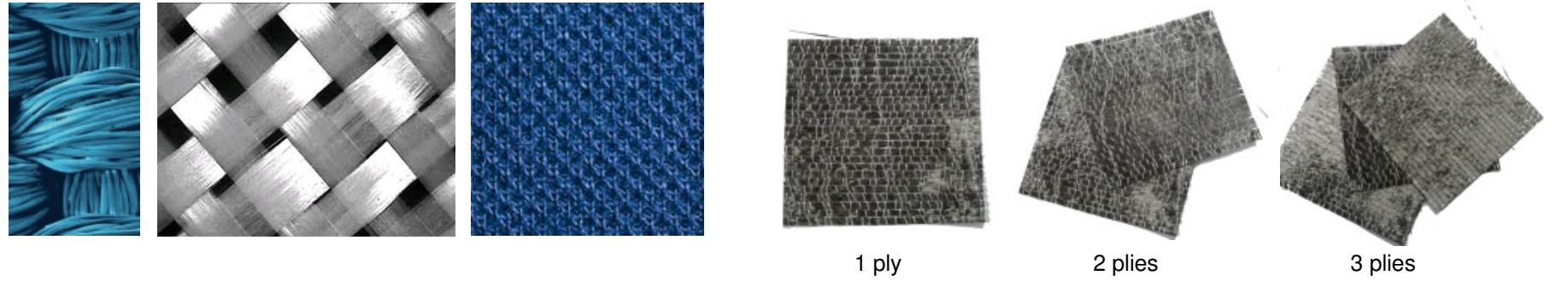


Producibility Overview

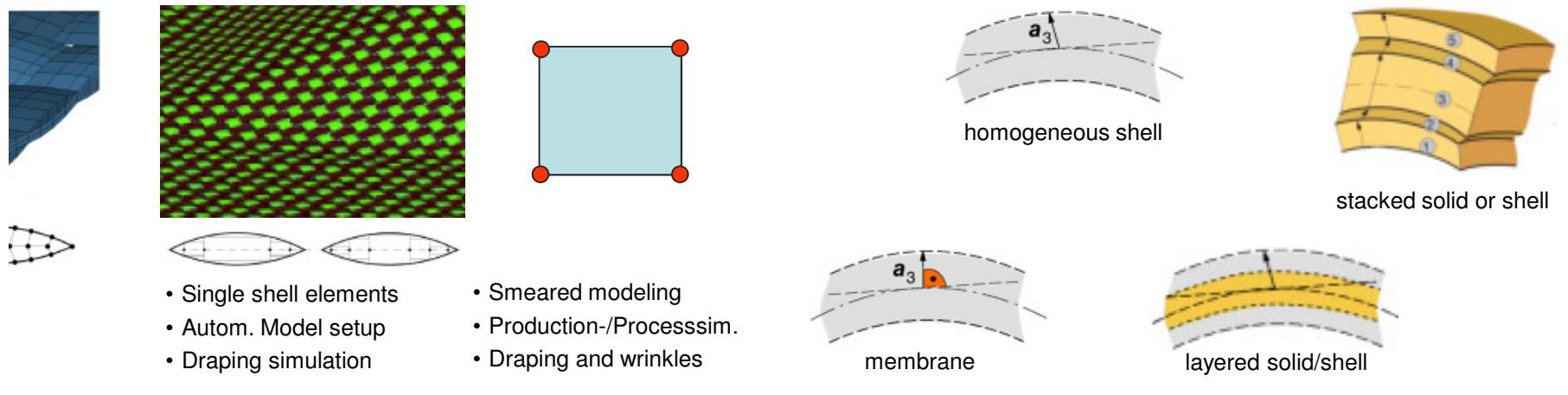
Process simulation: Motivation



Process simulation: Motivation

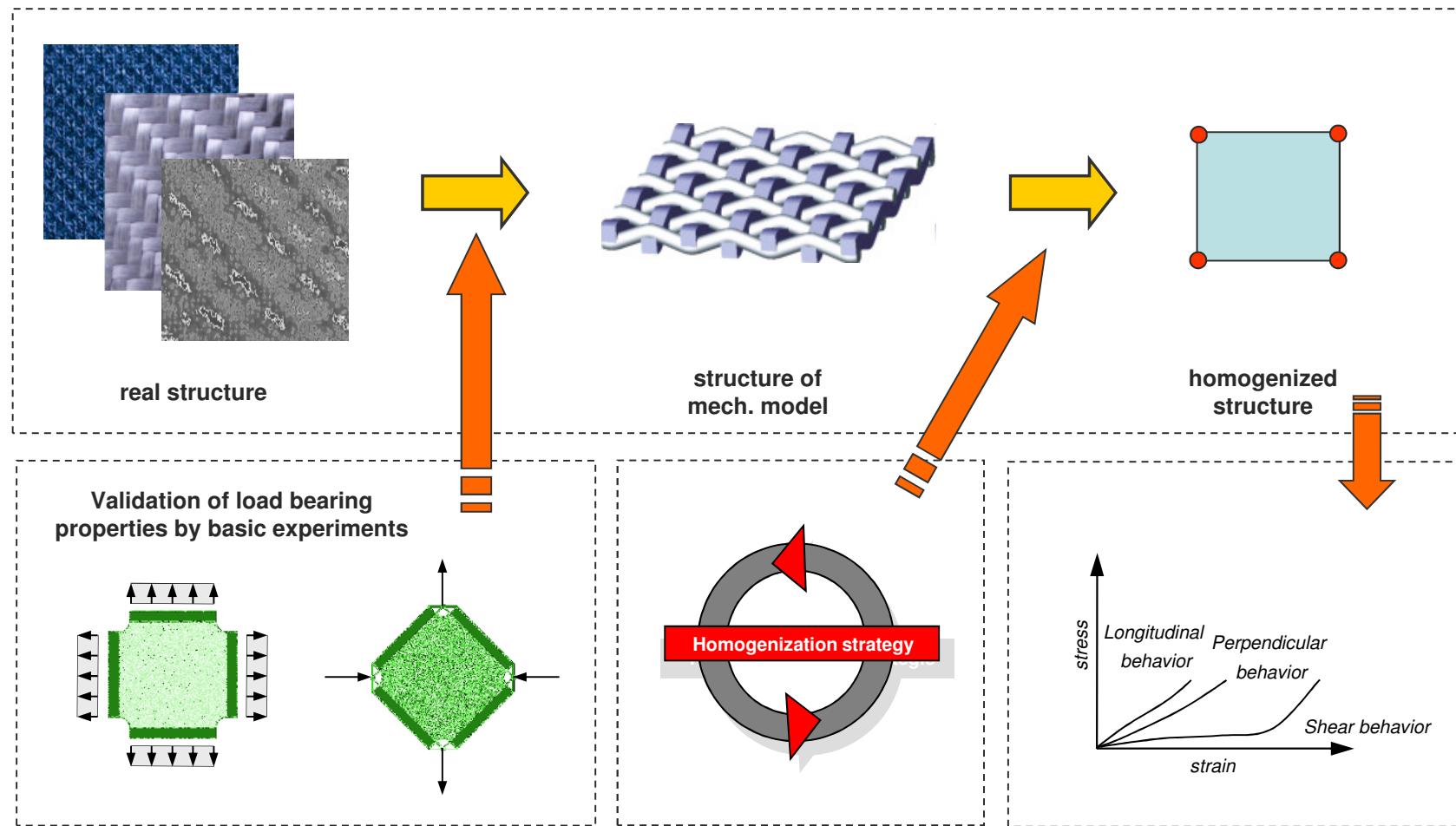


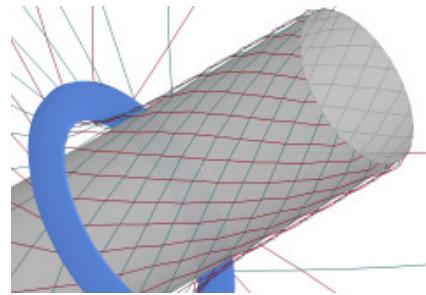
mm [cm] Length scale →



Simulation on cm-scale

Smeared approach: Homogenization of local structure and constitutive properties

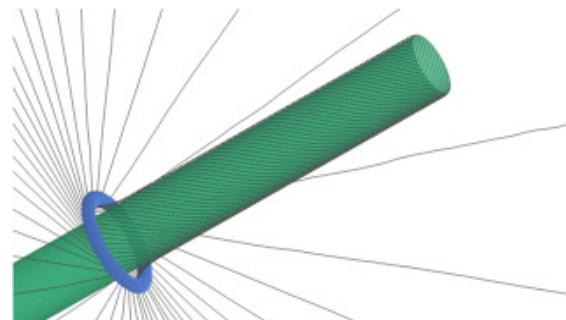




Producibility Braiding

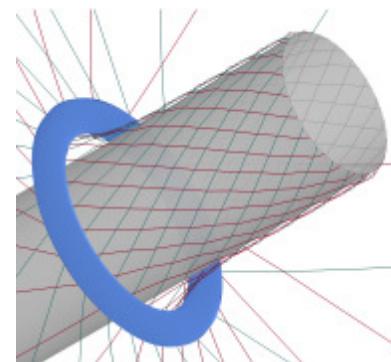
First steps for processing simulation

Filament winding simulation:



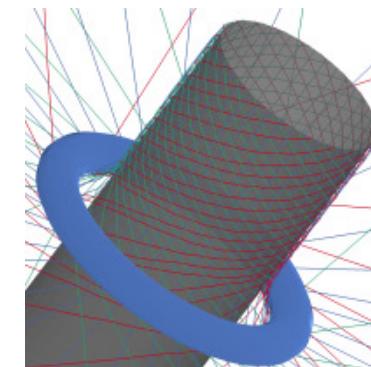
- 21 yarns
- 21543 Beam elements, 1 part
- Simple rotation of the fibers and pushing of the braiding core through the braiding ring
- Simple filament winding

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:



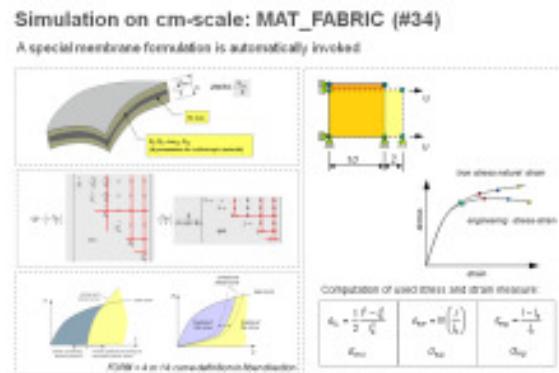
- 84 yarns
- 174348 Beam elements, 3 parts
- Half the elements used as UD – reinforcement parts
- Fibers are rotated and then moved up- and down to create the braiding-pattern
- Braiding core is pushed through the braiding ring



Producibility Draping

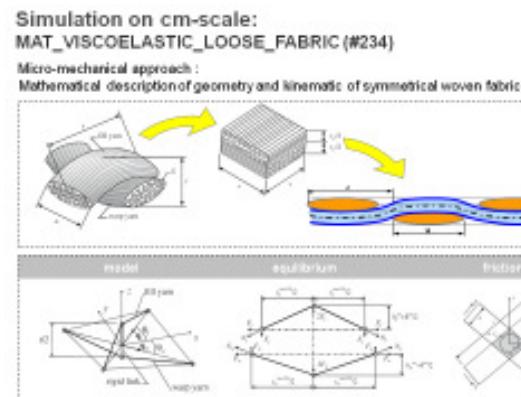
Modeling techniques on cm-scale: Fabric materials available for draping simulation

MAT_34

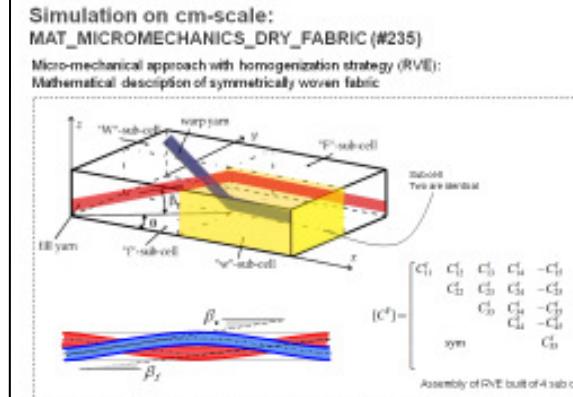


New in R7.0: bending stiffness

MAT_234



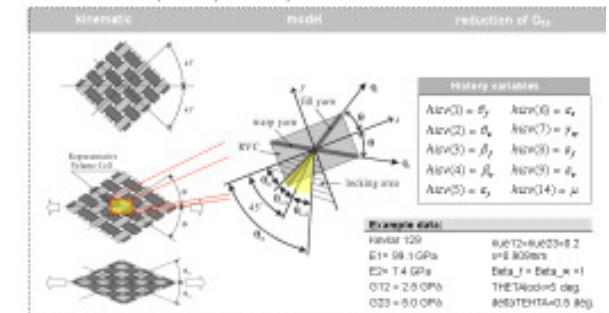
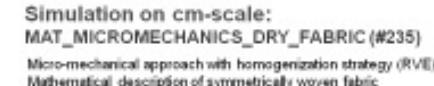
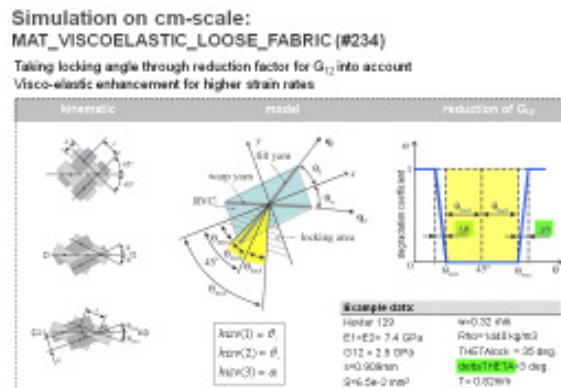
MAT_235



New: ACMD



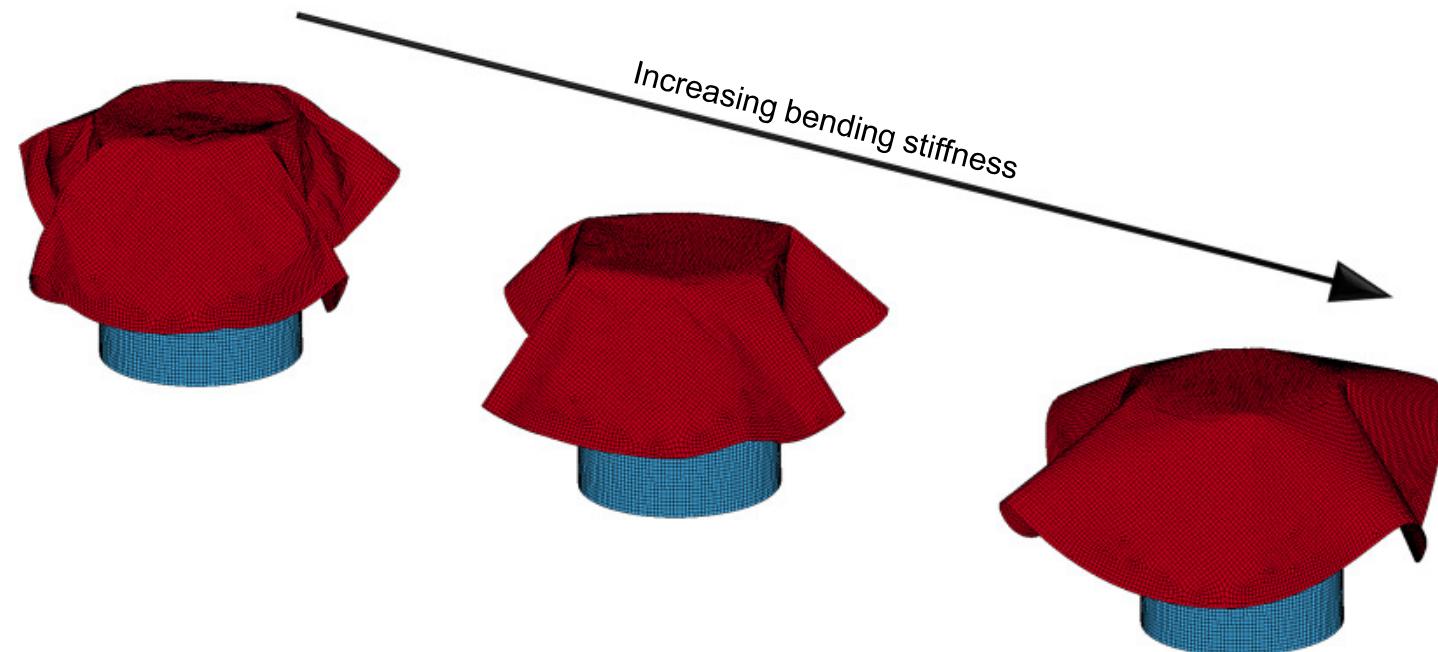
Anisotropic unidirectional layered
constitutive model for draping
NEW in future release.



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

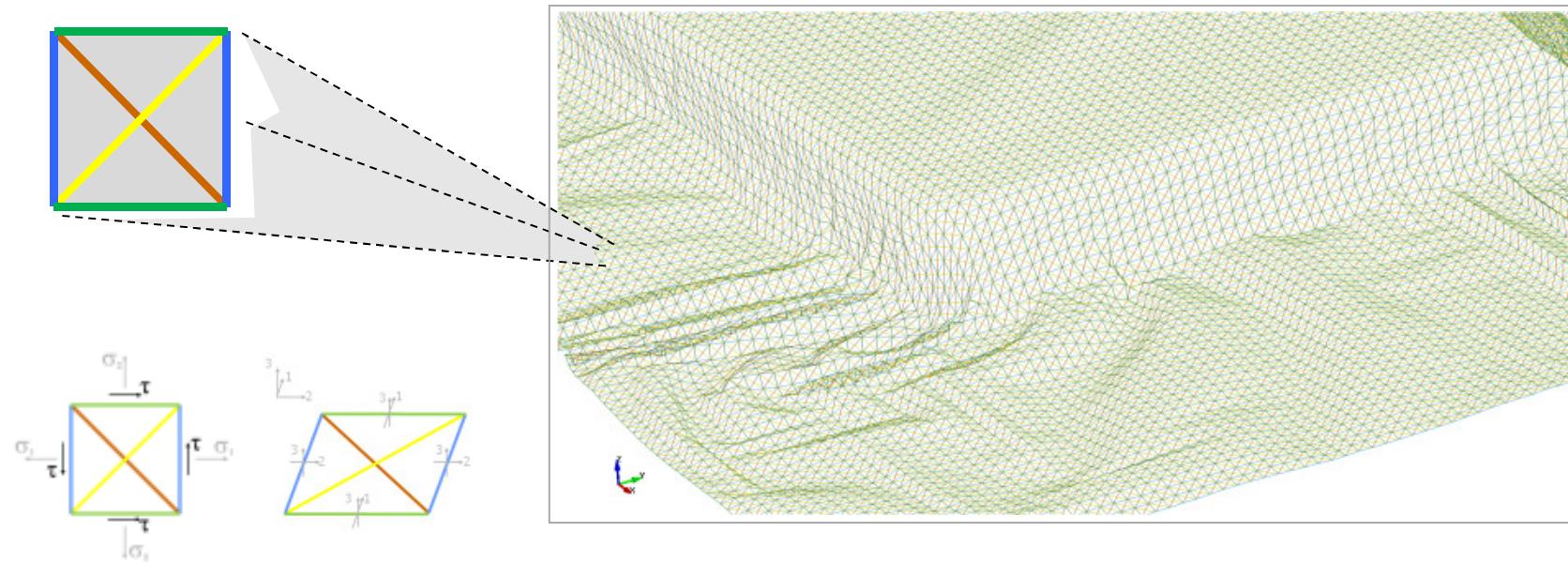


Draping: Using discrete elements for strong anisotropy

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)

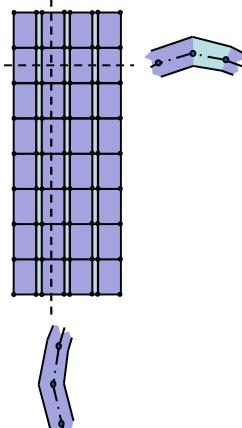
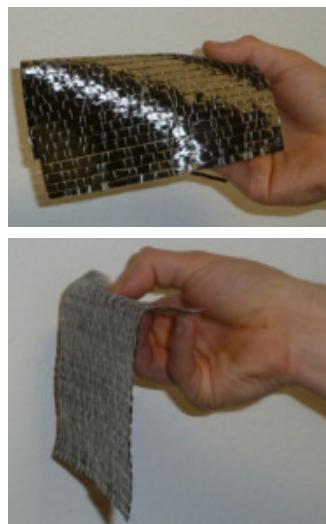
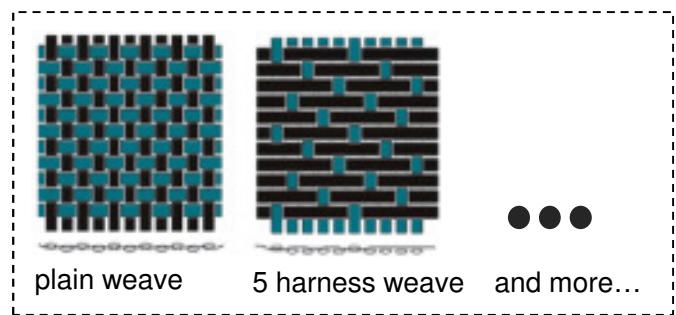


This approach allows also to model positive and negative shear loading.

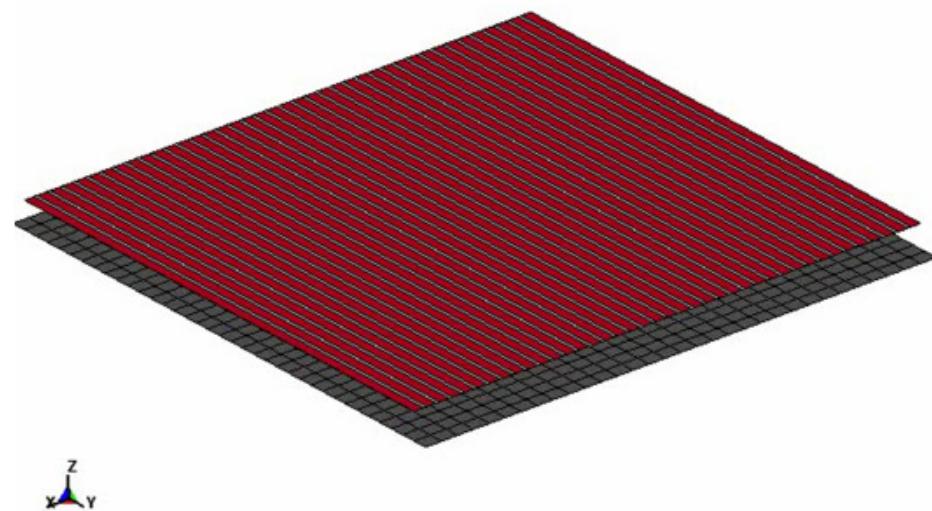
Optional matrix may be represented with shell elements and elastic/plastic material.

Process simulation: Draping with strong anisotropy

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



modeling technique
single layer



New model for draping (beta status)

(Could be expanded for thermoforming of organo sheet)

New anisotropic constitutive model for draping (ACMD)

- Implementation as UMAT in LS-DYNA
- 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 $f(\lambda_i)$ defined by a load curve
- Stresses due to elongation of the individual fibers families are then computed as

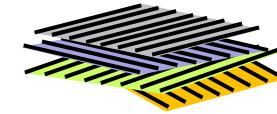
$$\underline{\sigma} = \sum_{i=1}^n \frac{1}{J} f(\lambda_i) \underline{F} (\vec{m}_i^0 \otimes \vec{m}_i^0) \underline{F}^T$$

- Interaction between neighboring fiber families can be accounted for by

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

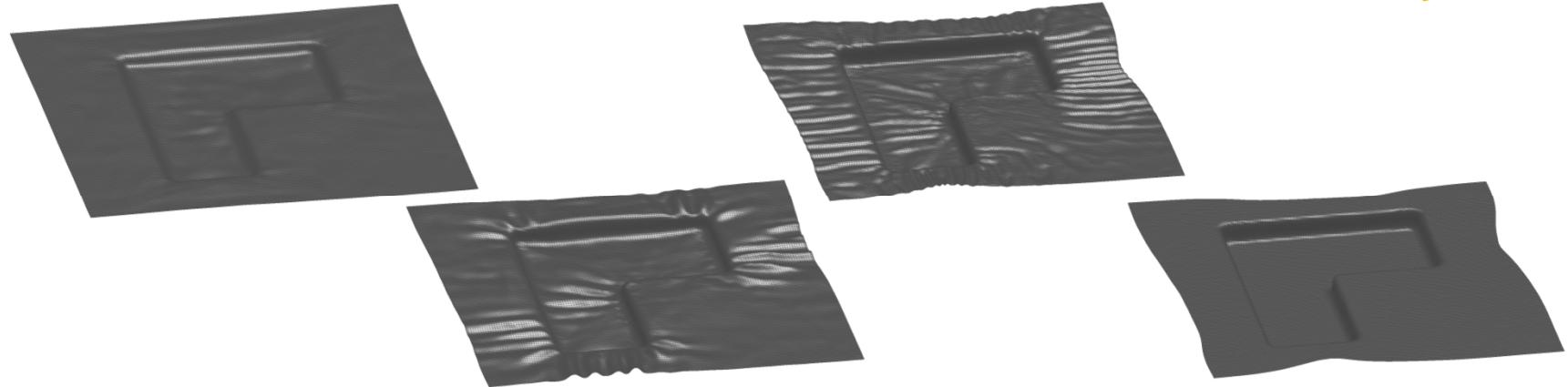
where function g can again be provided as a load curve

- 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

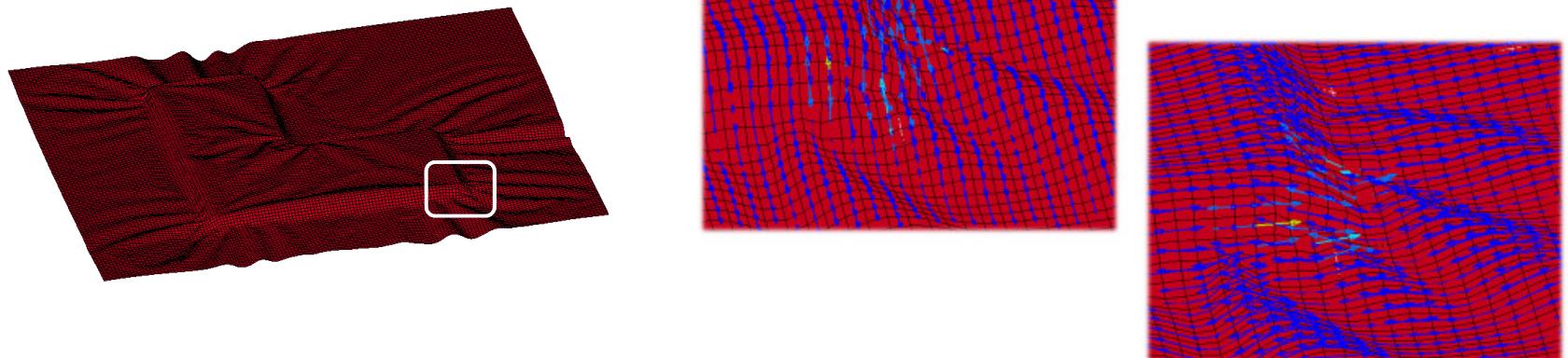


Example: L-Shape (ACMD)

- Process simulation



- Detailed view of fiber directions



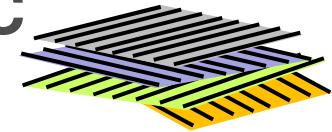
Example: Comparison ACMD vs. MAT_FABRIC

- Draping (0 /90)

*New anisotropic
constitutive model*



MAT_FABRIC



- Draping (-45 /+45)



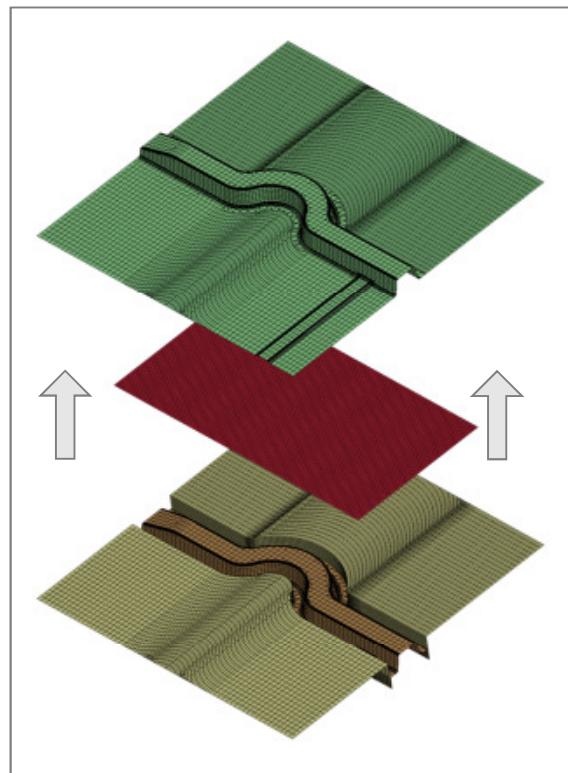
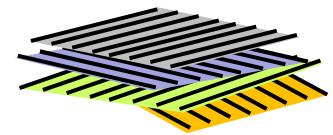
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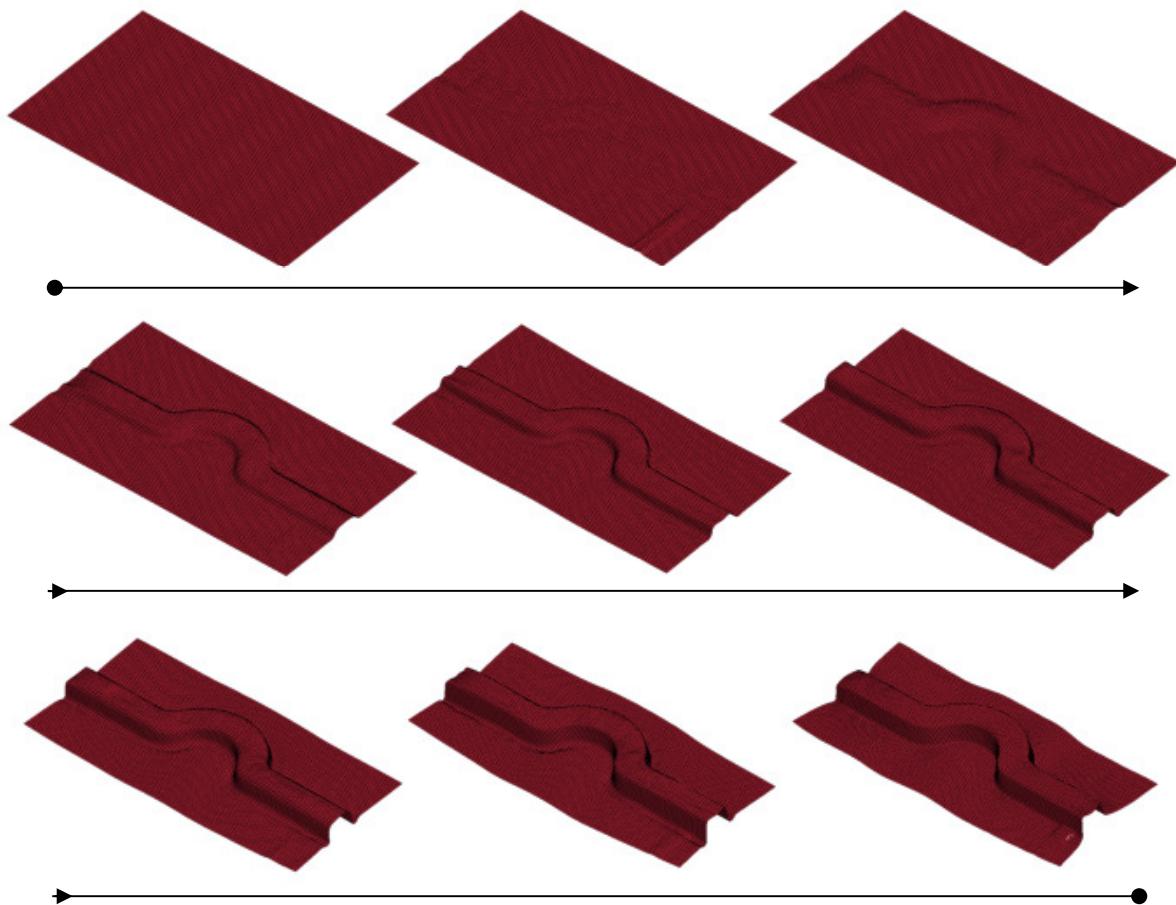
MAT_FABRIC

Draping example: S-Rail

Process simulation



[geometry provided by Benteler-SGL]

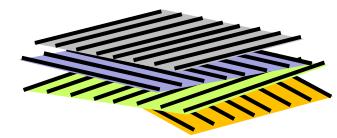


Draping example: S-Rail

- Fiber angle $\pm 45^\circ$, final state



- Fiber angle $\pm 60^\circ$, final state

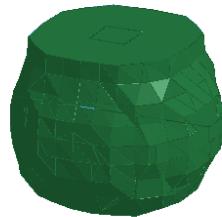




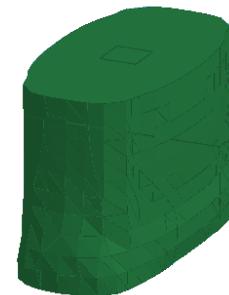
Producibility RTM

Injection of Resin

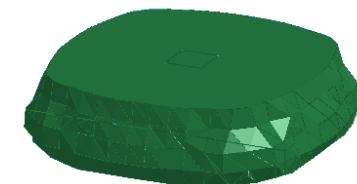
- Infiltration is a 3D flow problem through a porous media
- Porosity depends on the packing density of the fibers
- Fiber orientation results in an anisotropic porosity
- Flow through porous media can be modeled in LS-DYNA using the CONSTRINED_LAGRANGE_IN_SOLID keyword



same porosity in all directions



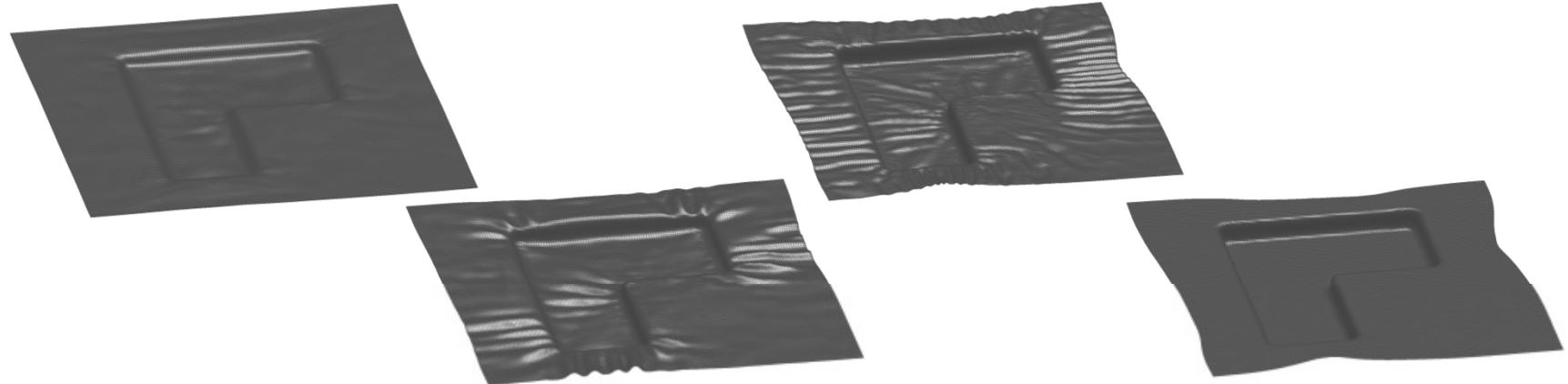
Low porosity in x-direction



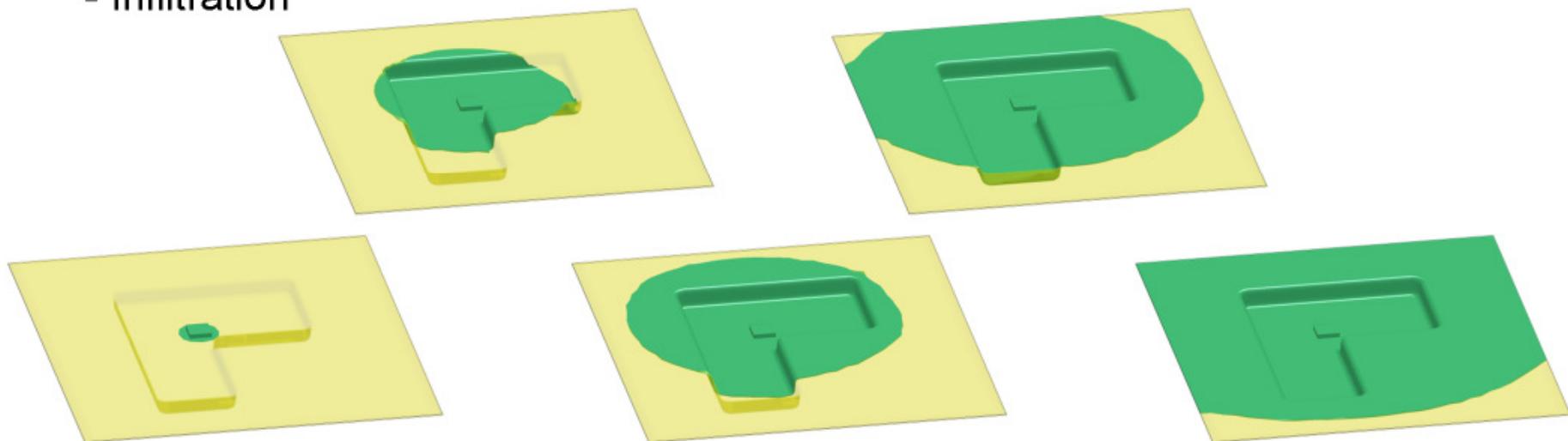
Low porosity in z-direction

Example: L-Shape

- Draping

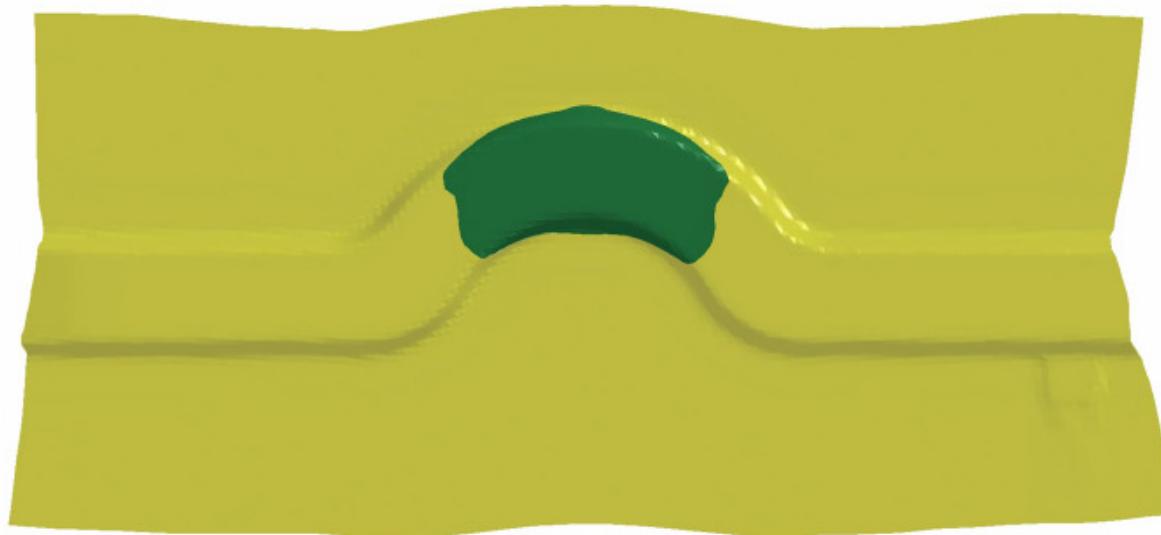


- Infiltration



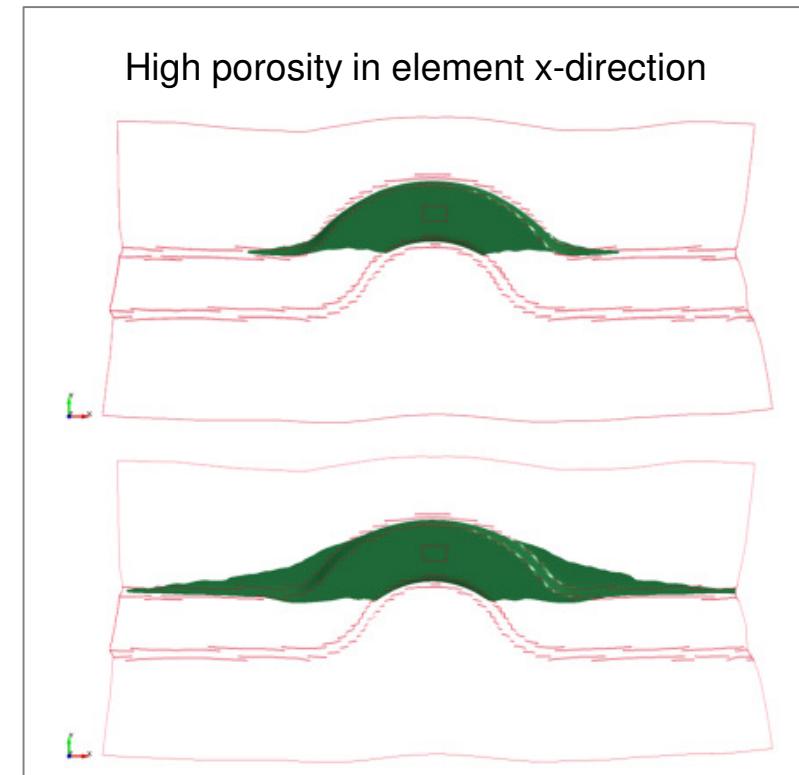
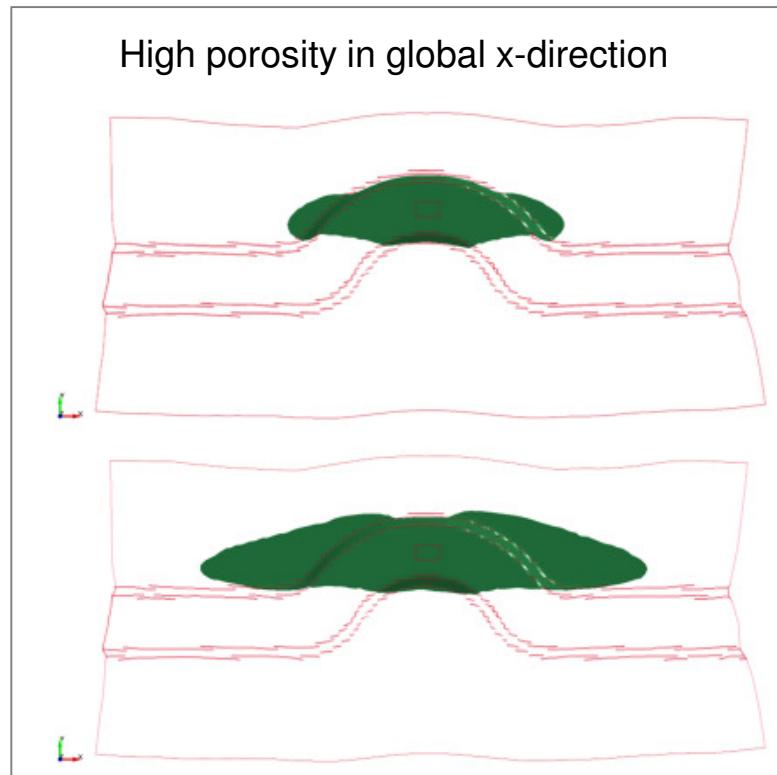
S-Rail example: Isotropic porosity

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



S-Rail example: Anisotropic porosity

- 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

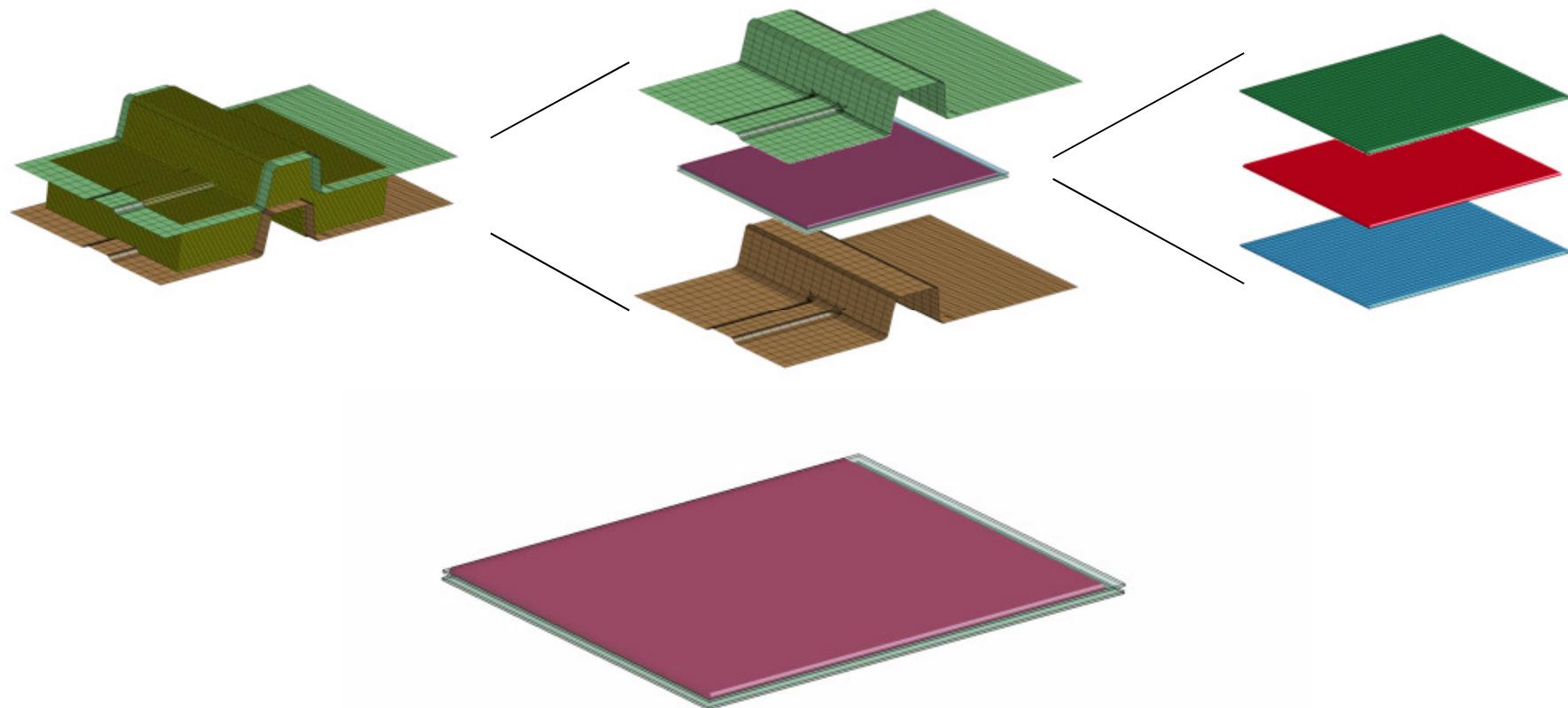


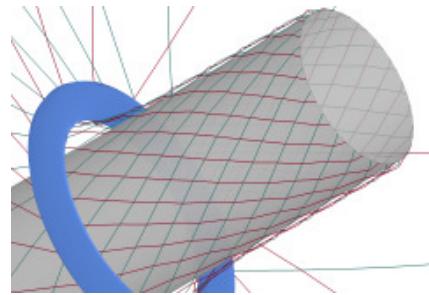


Producibility Wet Moulding

First example for wet-moulding

Cut-out from S-Rail geometry

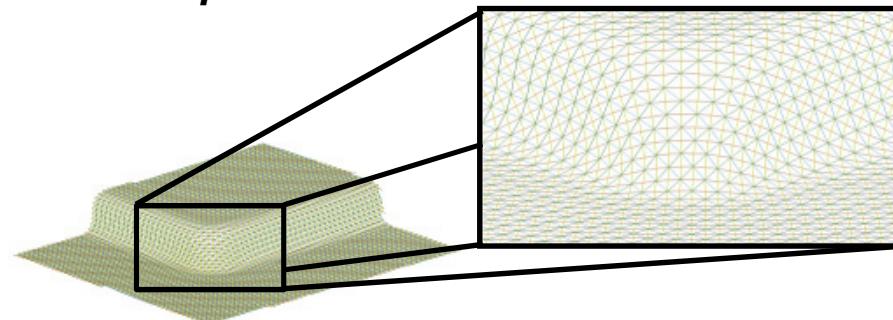




Mapping

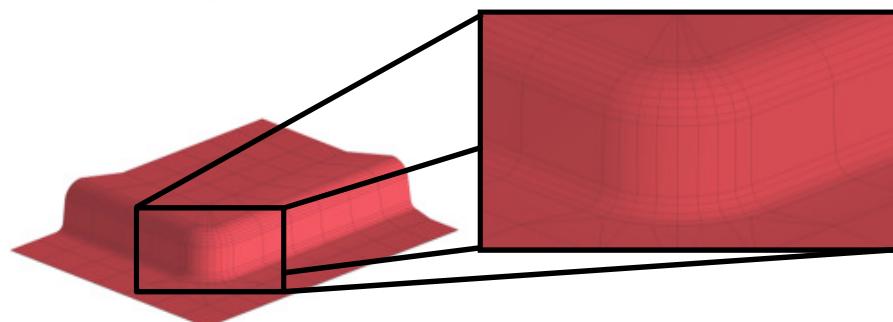
Mapping of material directions on different target meshes

Example #1:



Source Mesh:

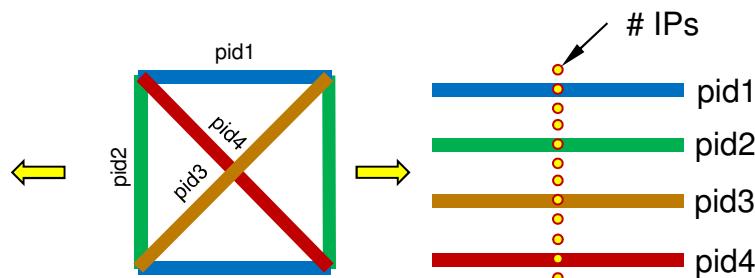
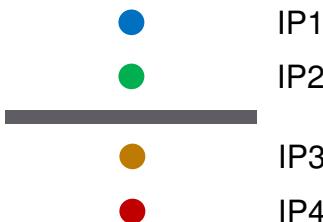
- four Parts
- 10461 Beam Elements
- avg. length: 1.65 – 3.30 mm



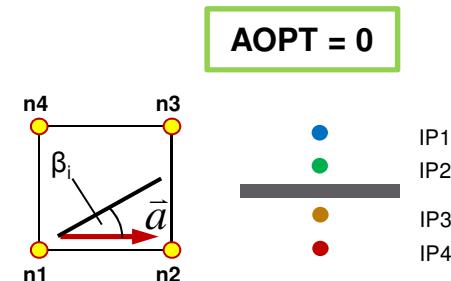
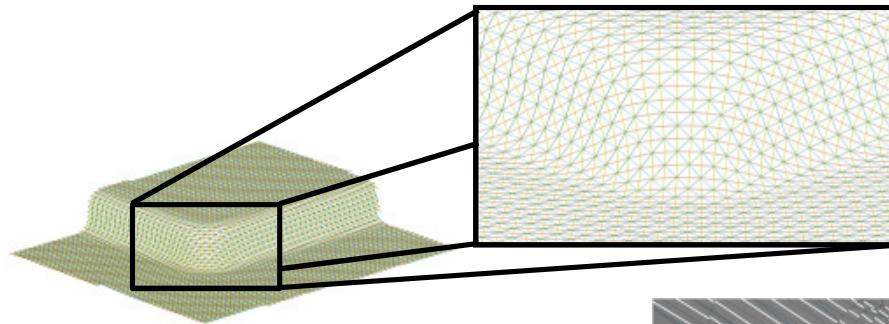
Target Mesh:

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

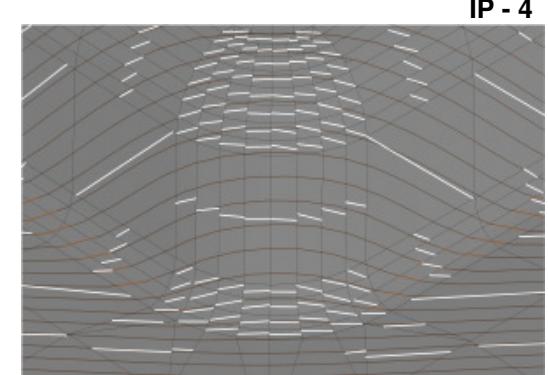
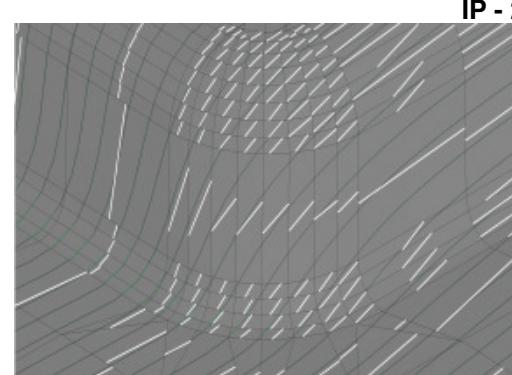
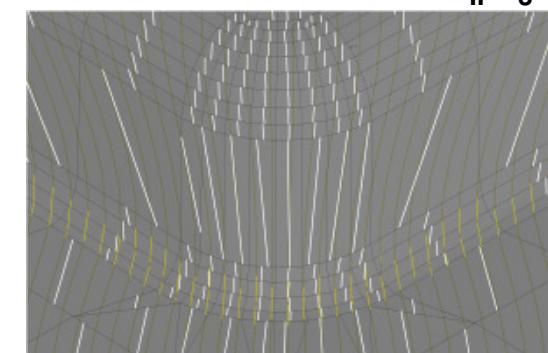
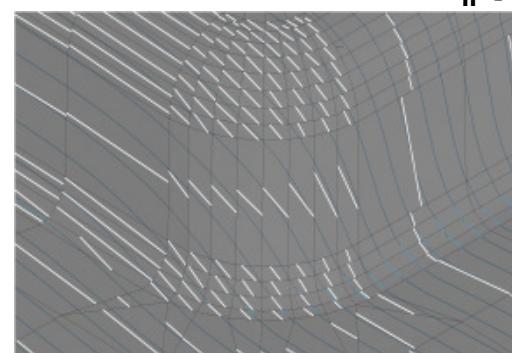
Homogenization strategies:



Mapping of material directions on different target meshes

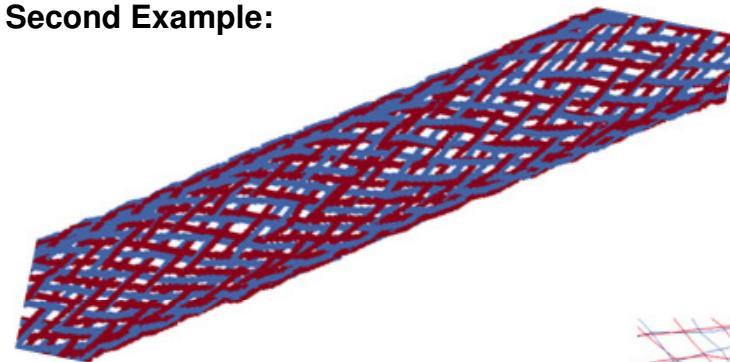


- Vector \vec{a} is given directly by the element orientation
- *ELEMENT_SHELL_COMPOSITE or *PART_COMPOSITE
- Identification of β_i is a little bit more complicated than writing fiber orientation directly into the material card
- Only one material card per part!
Relevant for crash simulations...

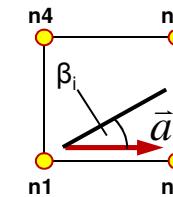


Mapping of material directions on different target meshes

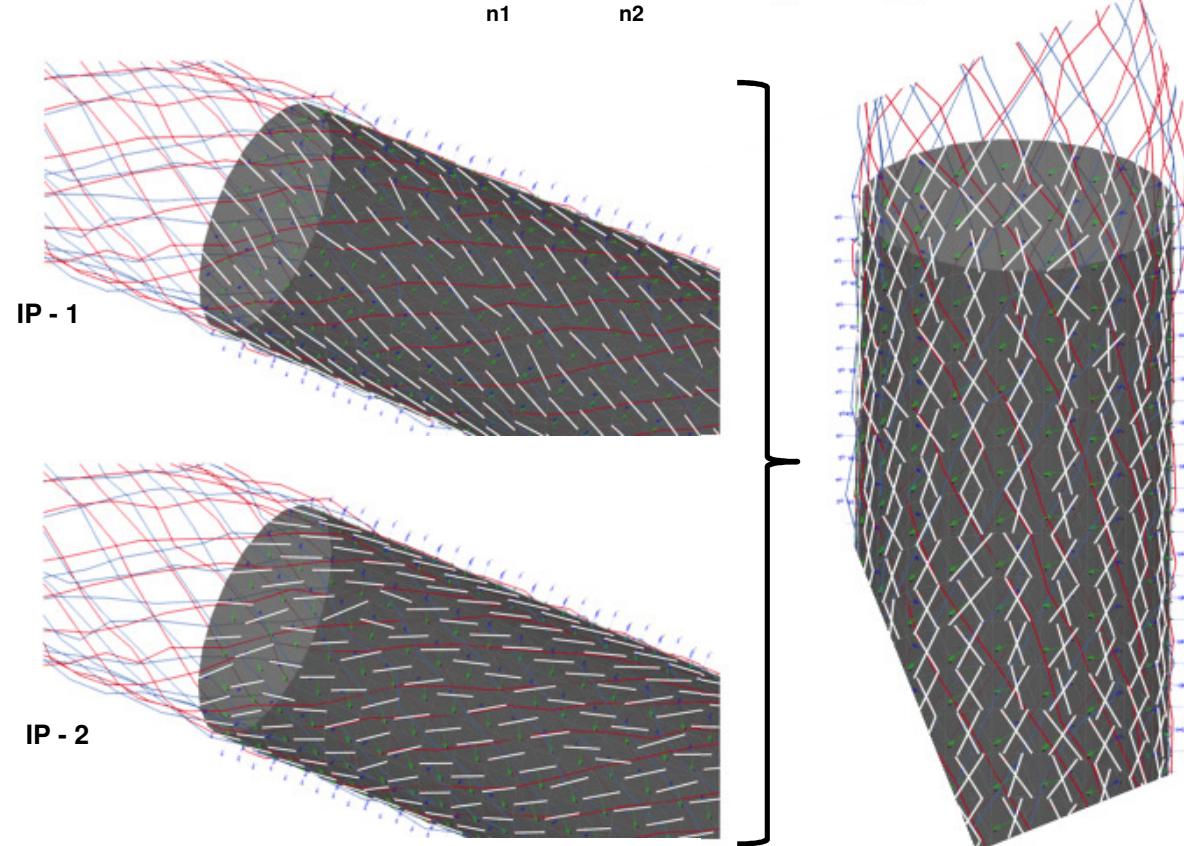
Second Example:



AOPT = 0



●	IP1
●	IP2
●	IP3
●	IP4

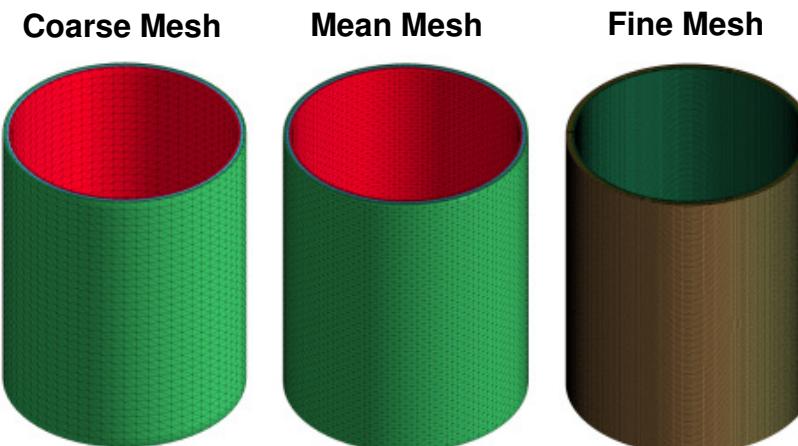


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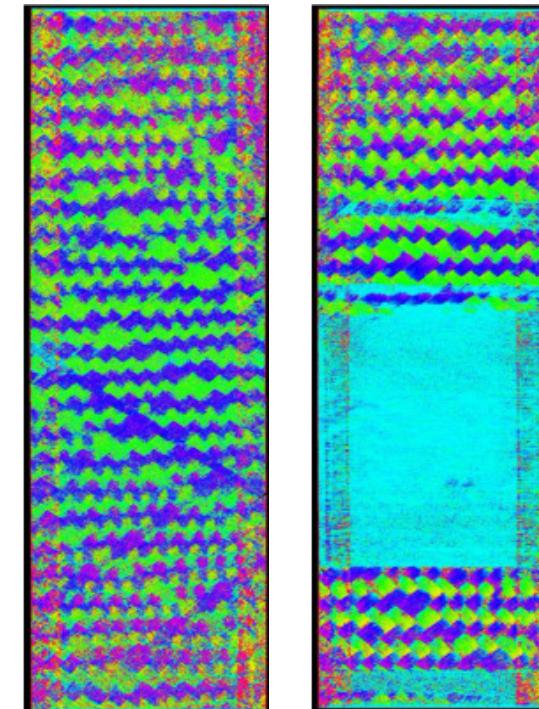
Mapping CT-scan data to LS-DYNA model

- so far: transfer of fiber orientation-tensors onto a LS-DYNA mesh
- Input: patran-format mesh, output: csv-file containing orientation tensor & fiber-volume ration per element, transfer as *INITIAL_STRESS_SOLID data for visualization purposes only
- Three different mesh sizes considered so far: Coarse, Mean, Fine
- Example-part: 3-layered braided tube with 0-deg reinforcement fibers
- Further enhancements supposed to work with Hexa-elements, may be with (T)shell elements

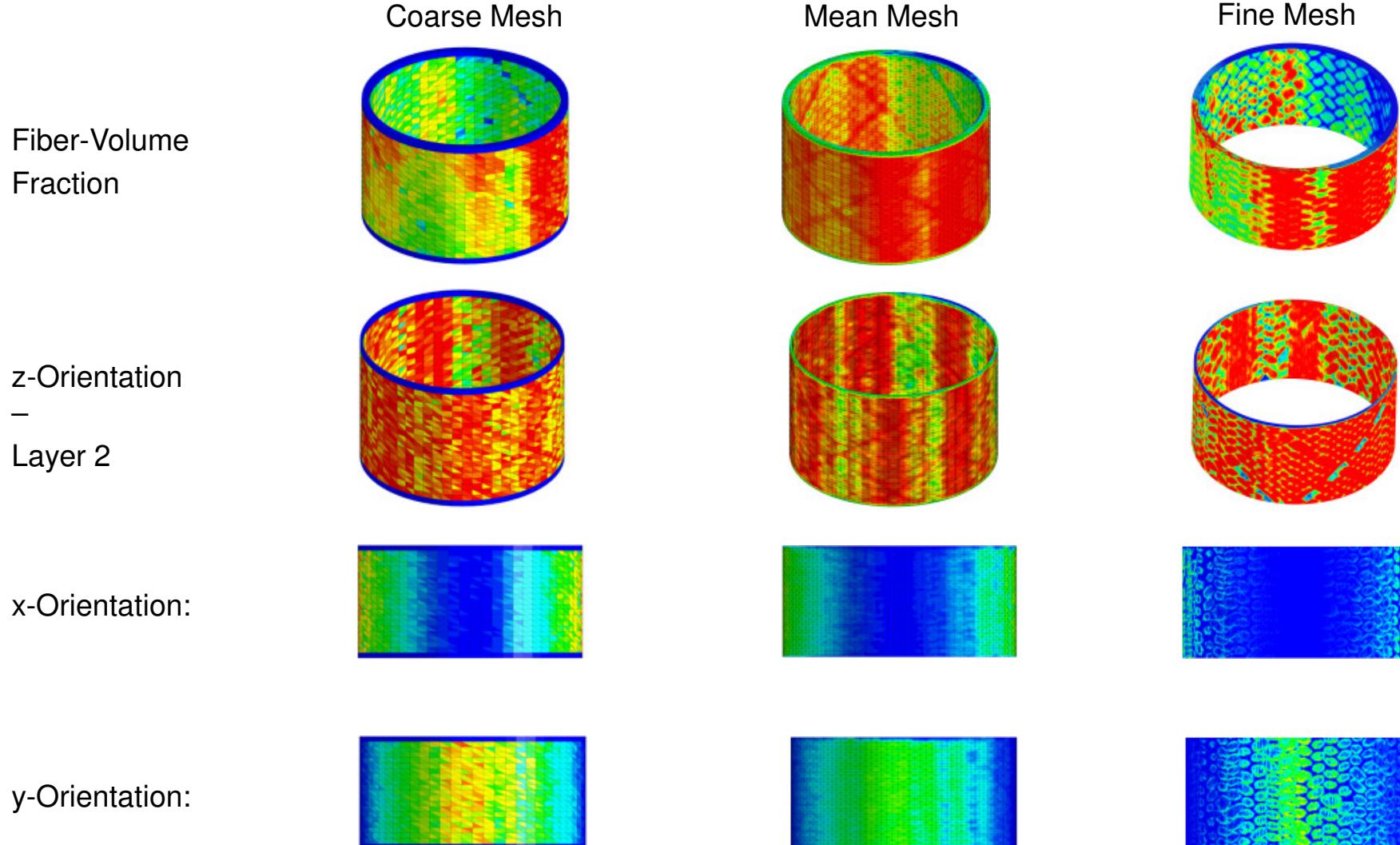
	Num. of Elements	Layers	Element-Size
Coarse Mesh	38420	1	0,3 - 1,25 mm
Mean Mesh	150039	2	0,15 - 0,62 mm
Fine Mesh	15078400	4	0,075 - 0,1 mm



First Layer Second Layer



Mapping CT-scan data to LS-DYNA model





FIN