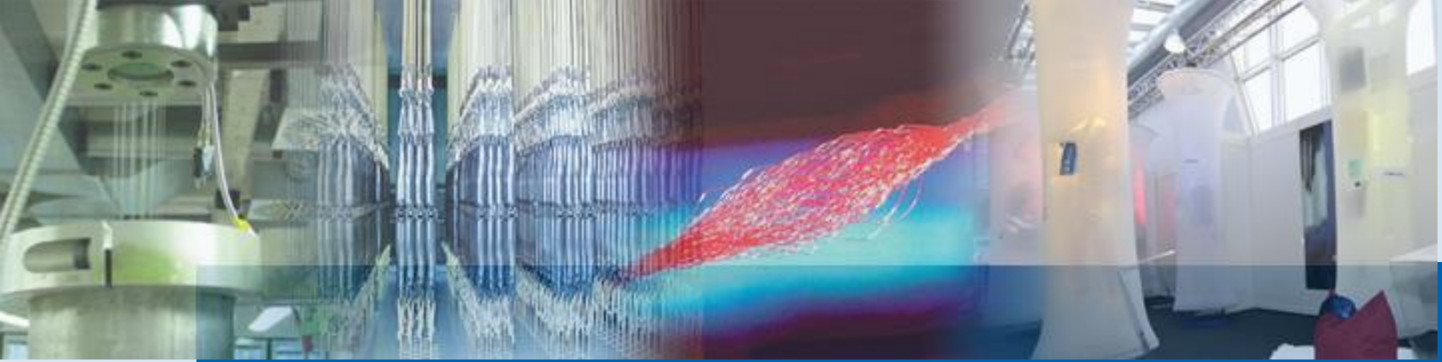
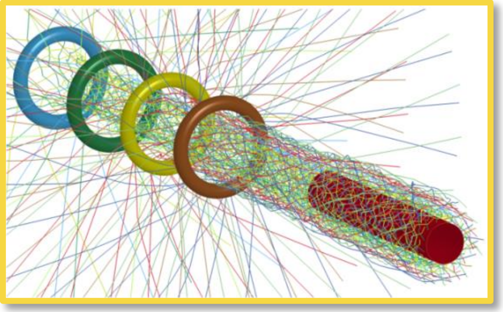


13th LS-DYNA Forum, Bamberg, 8 October 2014



About the usage of LS-DYNA and modern CT technology for braided structures for textile lightweight design

Hermann Finckh[1], Christian Liebold[2], Florian Fritz[1]

[1]Institute of Textile Technology and Process Engineering Denkendorf

[2]DYNAmore GmbH

Europe‘s largest Textile Research Center

German Institutes for Textile and Fiber Research Denkendorf (DITF)

1 Institute for Textile Chemistry and Chemical Fibers

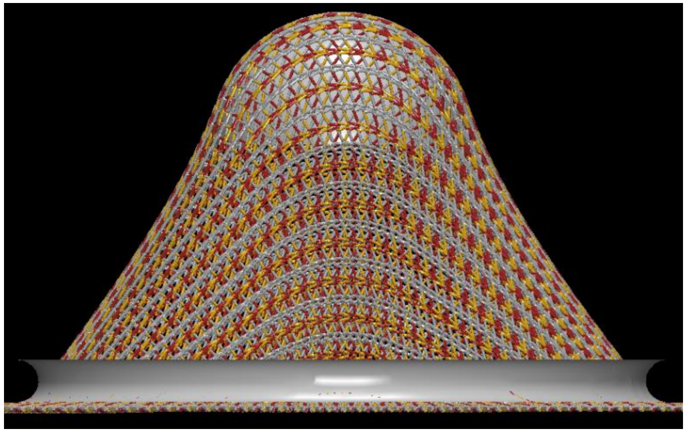
2 Institute of Textile Technology and Process Engineering

3 Center for Management Research

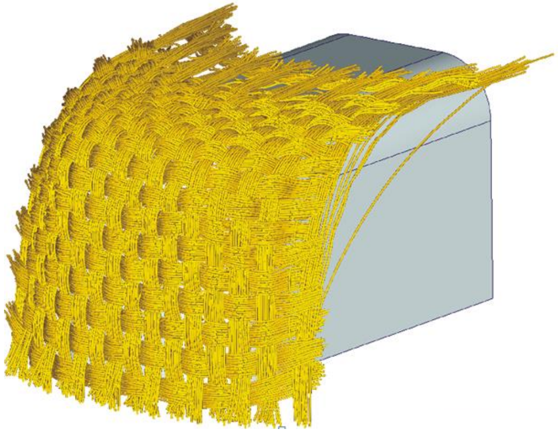
4 Denkendorf Product Service Ltd.

Finite-Element-Simulation at ITV:
micro/meso-models considering real stucture

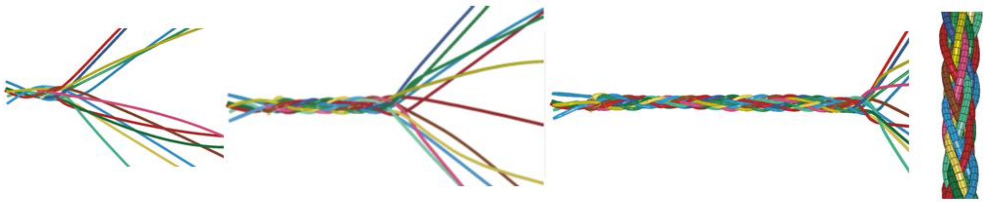
- **spinning**
- **weaving**
- **knitting**
- **braiding**
- **composite**



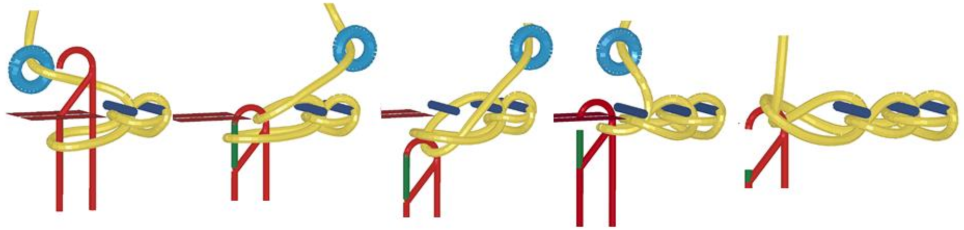
FEM-draping a clamped knitwear by a shere



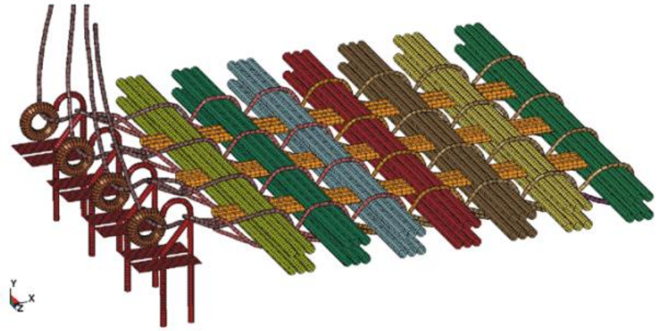
FEM: draping a aramid fabric over a part



FE-Simulation of a braiding process



FE-Simulation of a knitting process



FEM: warp knitting of multiaxial fabrics

Draping carbon 4 UD-layers

Draping knitwear

Content

1. Introduction
2. Generating detailed fabric models as base to compute fibre reinforced plastics (FRP).
3. CT - important tool for FE-simulation
4. Conclusion & Outlook

1. Introduction

Mechanical properties of fibre reinforced plastics depend on:

- Fibre and matrix material
- structure of the reinforcement fabric
- Fibre/matrix-adhesion
- Manufacturing Quality (z.B. imperfections, air pockets) and particulary
- Fibre orientation and fibre density.

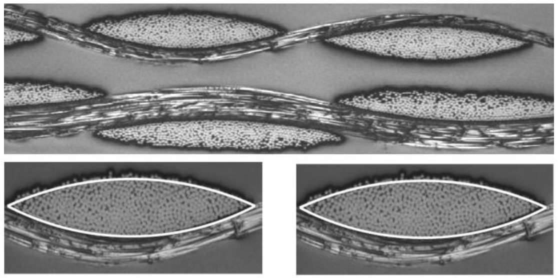
- Producing composite parts require draping of the reinforcement fabric
- Leads to large fibre displacements and changes of fibre orientations and fibre denistiy.

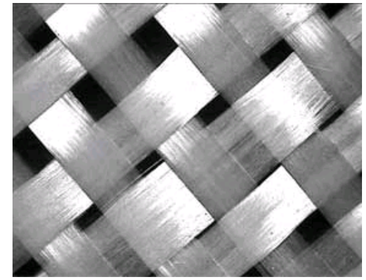
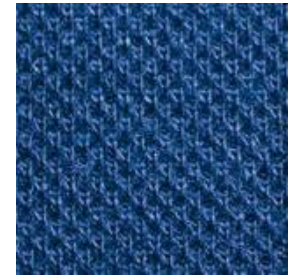
- Numerical Simulation using micro/meso-models to optimize production process and mechanical properties of composite parts.

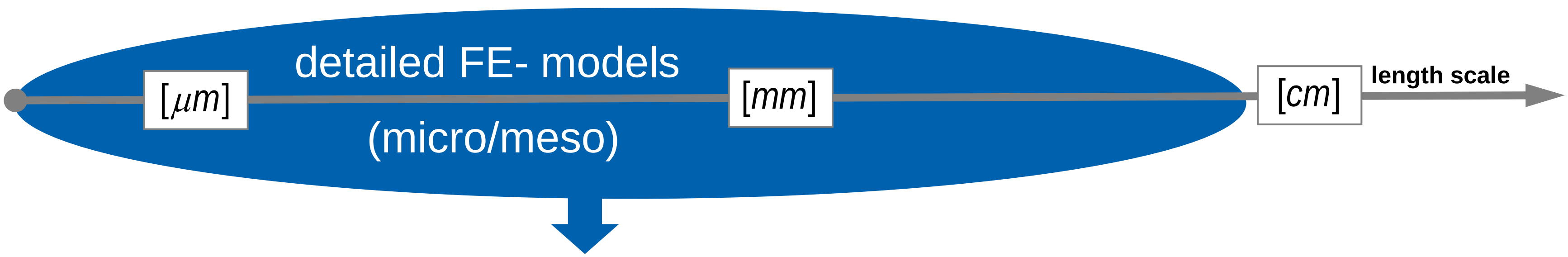
Main question:

- How to get simulation models with correct fibre informations as orientation and density, so that mechanical properties of composite parts can be computed more realistic?

2. Generating detailed fabric models

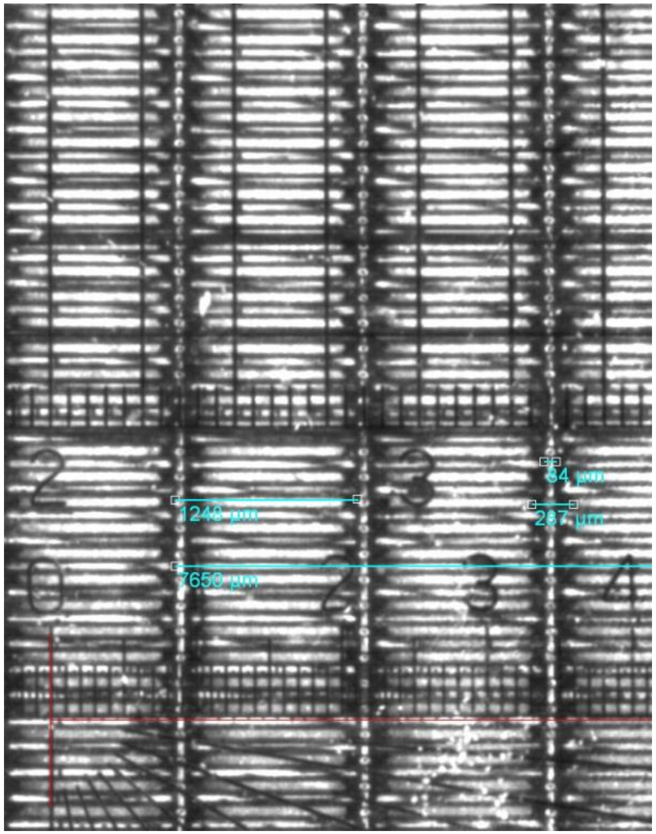




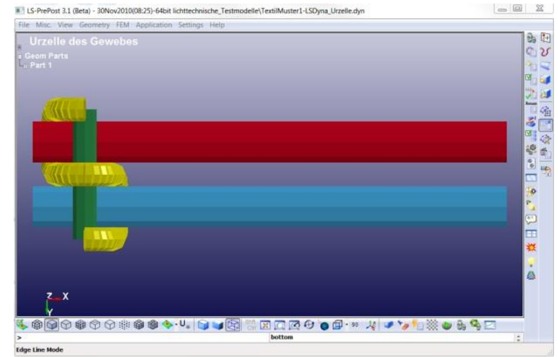
- using analytical and geometrical relations (e.g. TexGen, WiseTex)
- the simulation of the manufacturing process itself
- high resolution CT-Scans

2. Generating detailed fabric models – analytical and geometrical relations

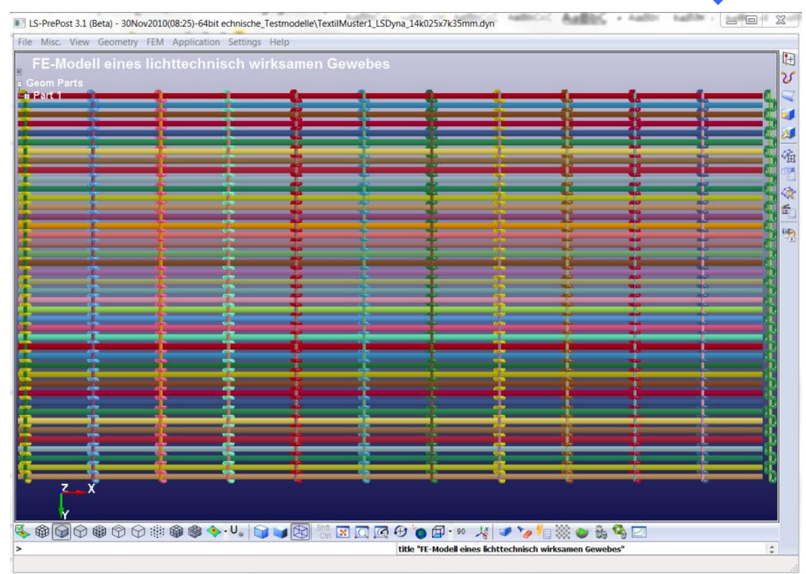


measurement of fabric by microscope / REM

extracting a „unit cell“ by geometrical relations



generating a FE-model of fabric required required dimensions



2. Generating detailed fabric models process simulation

Process simulation requires knowlege about the real manufacturing process in detail.

Success depends on choosing suitable:

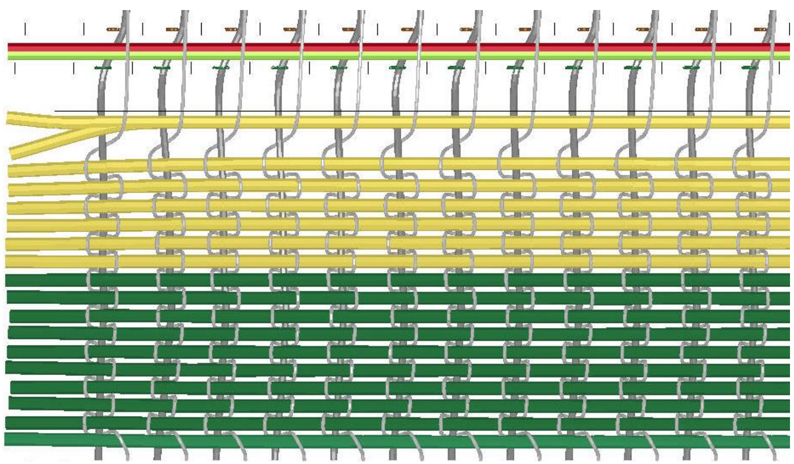
- yarn models
- discretization (especially yarn model)
- idealization of machine parts
- boundary conditions
- several different contact definitions:
  - contact check is main part of the simulation (about 60-90% computation time).
- computation parameters (time step, damping, etc.).

2. Generating detailed fabric models process simulation weaving

FE-Simulation of the production of a special kind of woven fabric: „Drehergewebe“

weft:
PES-Monofil, yarn count 355 dtex: Ø 0,18 mm

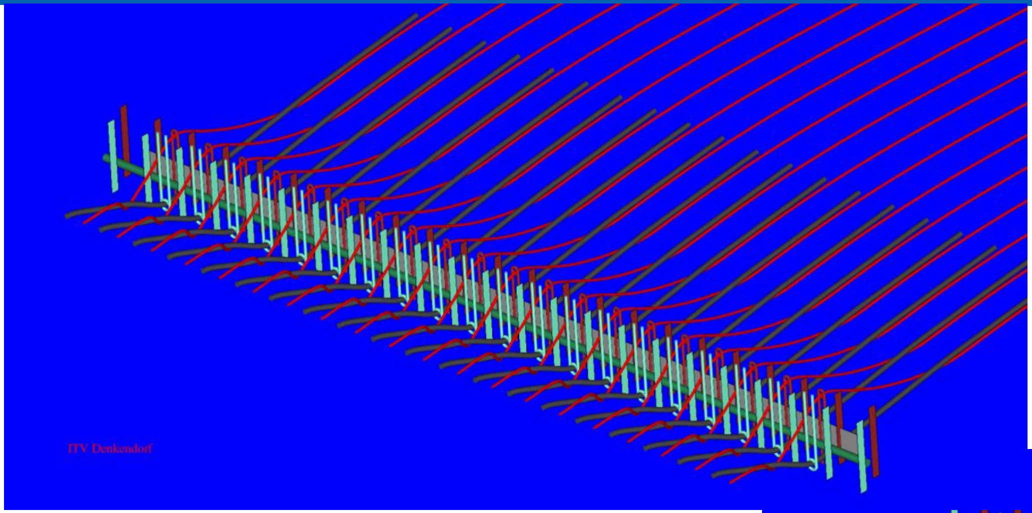
warp:
PES-Monofil, yarn count 88 dtex: Ø 0,09 mm

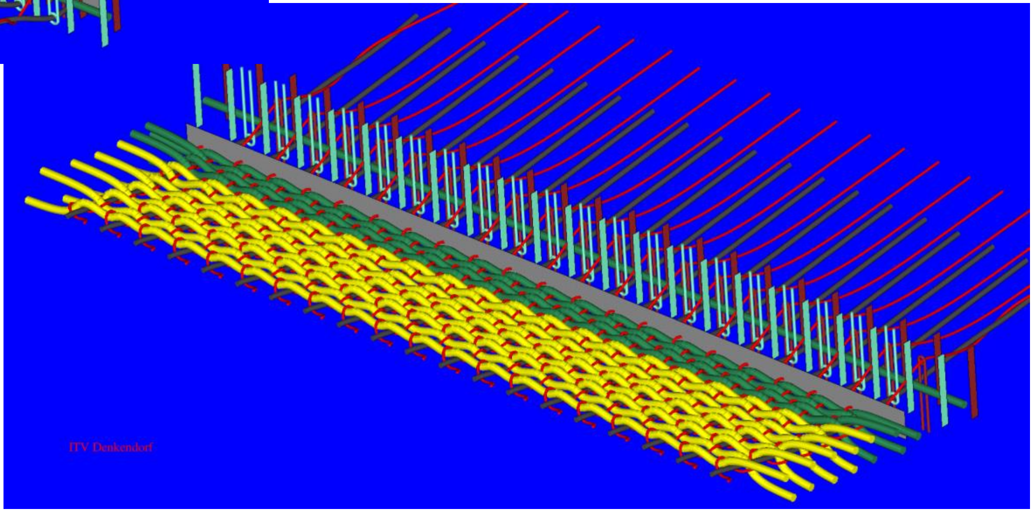


result of the simulation
density weft yarns: 27,3 yarns/cm

real produced woven fabric

2. Generating detailed fabric models process simulation weaving



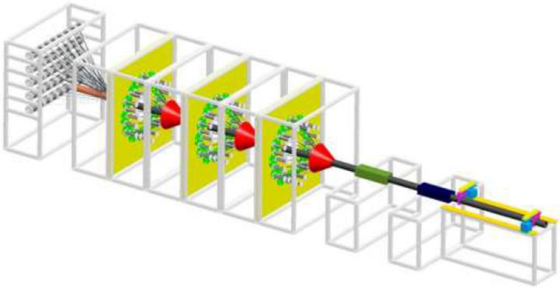


FE-Simulation of the production of a special kind of woven fabric:
„Drehergewebe“

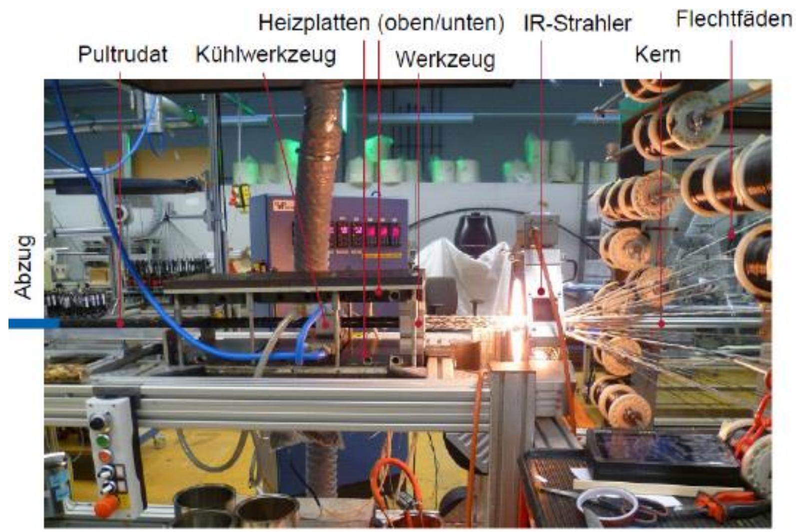
Braiding process chain (Tpult)

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

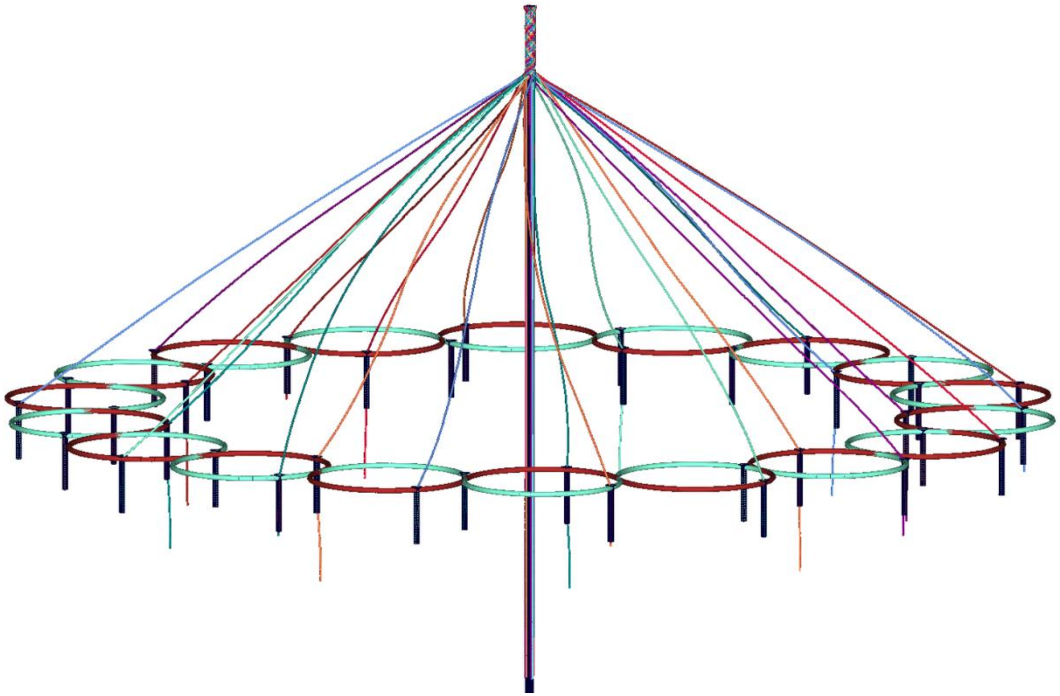
- Why run braiding simulations?
  - Predict the roving layup prior the actual braiding process
  - Get information about the influence of roving pre-tensioning and friction btw. the rovings and the core/braiding rings
- Use simulation data for machine coupling (CAM)



- Government funded research-project Tpult:
  - Braiding on one core with four braiding machines in a row with rovings using a thermoplastic resin
  - Re-heating of the resin for further forming steps



2. Generating detailed fabric models - process simulation braiding

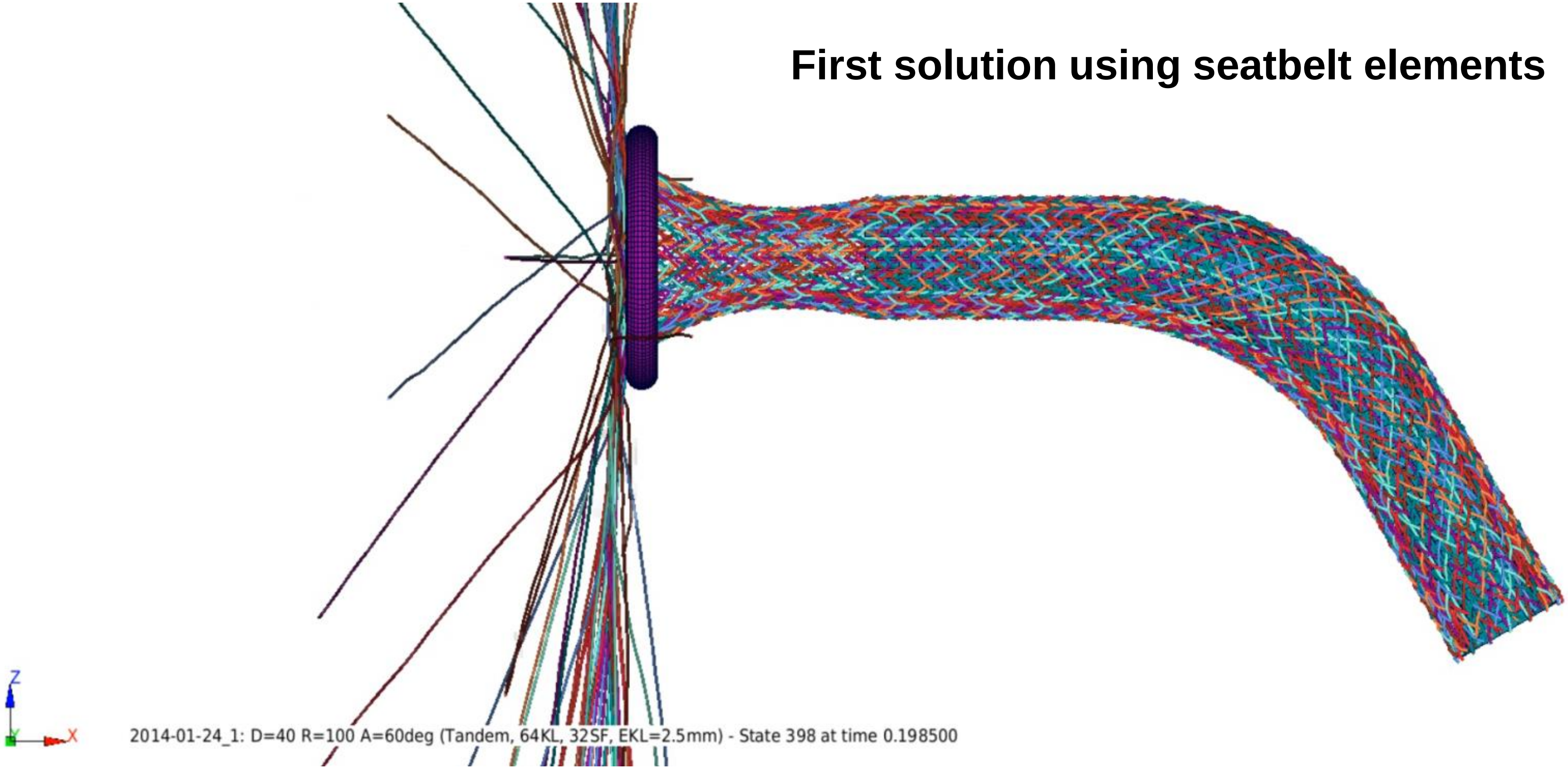


Simulation of brading :

- Using of contacts: yarn guides modeled as tubes lead the threads.
- All thread length must be provided at start of simulation
- Leads to huge models, long computation times, ocillation-, damping- contact-problems)
- Reduction of computation time by switching deformable to rigid and vice versa

2. Generating detailed fabric models - process simulation braiding

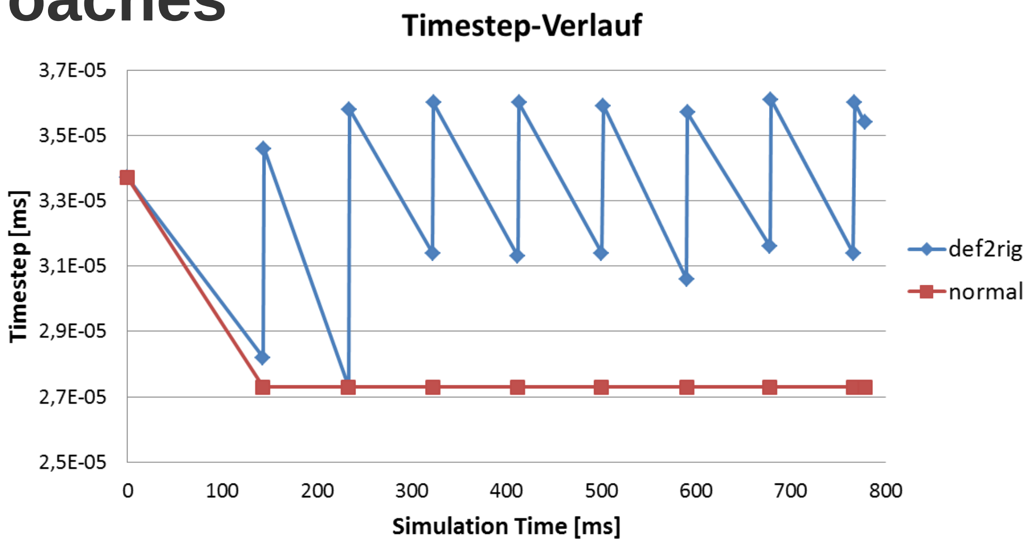
First solution using seatbelt elements



Simulation of braiding using seatbelt elements:

- beam is pulled out of the „retractor“
- when a defined length is reached beam is divided
- „new“ truss beam appears in the simulation

Braiding simulation approaches



- *ELEMENT_BEAM
- *DEFORMABLE_TO_RIGID
- 12120 beam elements,
  24 discrete elements
- 24 rovings
- mppR7.1 – s – beta - Rev. 86381

- 19 h, 31 min, 33 sec
- 33h, 32min, 23 sec
- ~20.420.000 cycles
- ~27.660.000 cycles

- Intel(R) Xeon(R) CPU E5-2670 0 @ 2.60GHz

- 2.51% element processing
- 2.04% element processing
- 72.91% contact processing
  - 34,14% Beam-Beam contact
  - 29,28% Beam-Core contact
  - 7,76% Beam-Ring contact
- 80.70% contact processing
  - 40,86% Beam-Beam-Contact.
  - 33,25% Beam-Flechtkern-Contact.
  - 5,44% Beam-Flechring-Contact.

2. Generating detailed fabric models new feature for process simulation

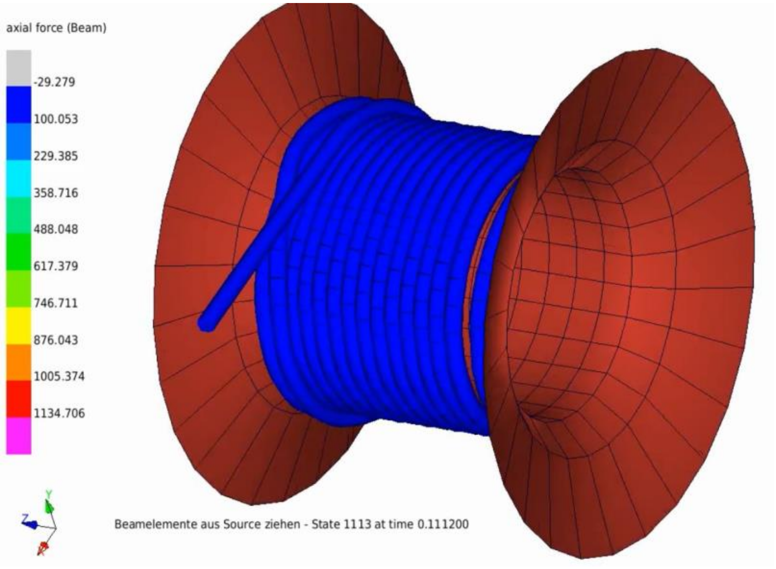
Development work required for automatic extension of yarn models during process simulation:

- as the yarn models consist of beams, this leads to the function of **generating new beams** (including correct boundary conditions and taking them into contact check).

New LS-DYNA feature:

*ELEMENT_BEAM_SOURCE

Automatic generation of beam elements at
- defined nodes with defined element length,
- when pull out force is reached.



- correct considering of contact diameter
- more material models will be available
- more type of beam elements will available
- further investigations are going on now.

*ELEMENT_BEAM_SOURCE

```
*ELEMENT_BEAM_SOURCE
$#------1|--------2|--------3|--------4|--------5|--------6|--------7|--------8|
$      BSID      BSNID      BSEID     BSNELE       LFED      FPULL       LMIN
```

BSID: Beam source ID

BSNID: Beam source node ID – different from the node to which the new element will be connected to

BSEID: Beam source element ID – all new generated beam elements will be connected to this element

BSNELE: number of elements that can be generated

LFED: max. length of elements after pull-out.

FPULL: initialforce

LMIN: min. length at pull out

- Main advantage: simple pre-processing
- no discrete elements needed → higher accuracy for full component simulation
- a little less calculation time

- So far, this works for: ETYP 3 (truss) & *MAT_ELASTIC
- ETYP 6 (discrete beam/cable) & *MAT_CABLE_DISCRETE_BEAM

3. CT – important tool for FE-simulation
µ-Computertomograph GE nanotom m at ITV

nanotom m for analyzing composites, textile fabrics and coatings perfect because of:

- extremely high image quality due to unique temperature stabilized digital GE DXR detector (3072 x 2400 pixels) for a high-dynamic range > 10,000 : 1
- new open 180 kV / 15 W high-power nanofocus X-ray tube with up to 200 nm detail detectability and internal cooling – optimized for long-term stability

BMBF-research project:

„Energy-efficient pultrusion-process for manufacturing of composites with thermoplastic matrix in series applications“ - TPult

Production

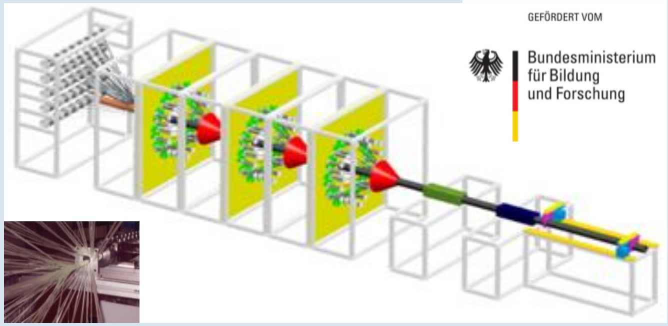
braiding machines

tool manufacturing

systems engineering pultrusion

composite process engineering & production

infrared technology



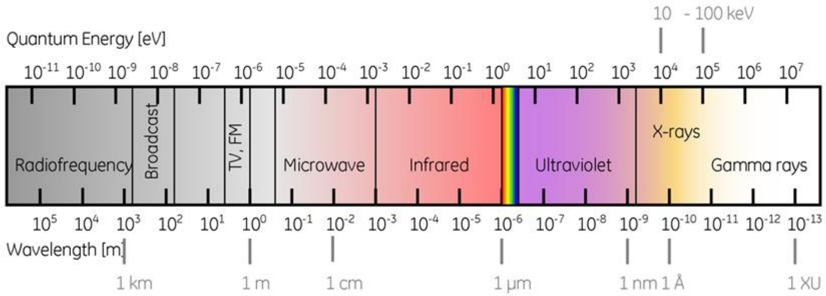
Simulation (FEM) & CT

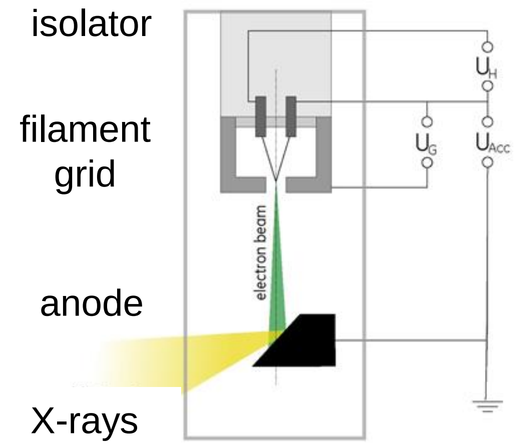
software development for CT

CT-Scans, process simulation

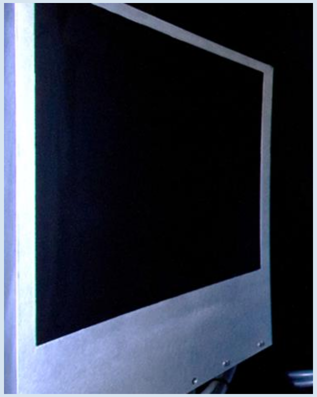
composite simulation

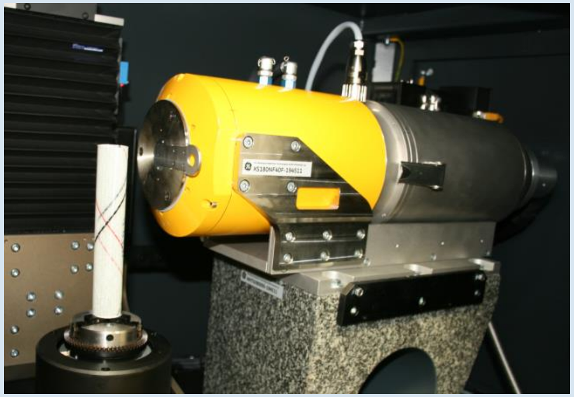
3. CT – important tool for FE-simulation
Computer tomography (CT)

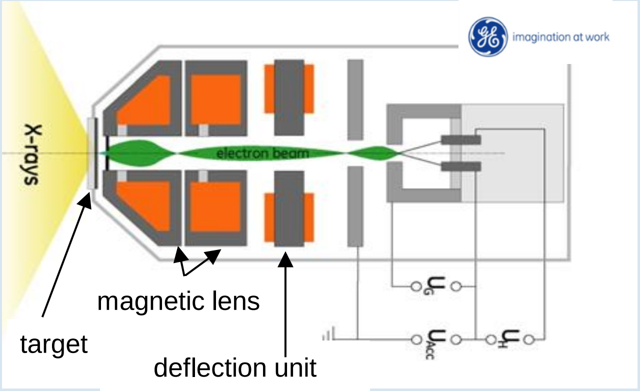




- X-rays are electromagnetic waves (as light)
- Wavelength 0,001 to 1 nm



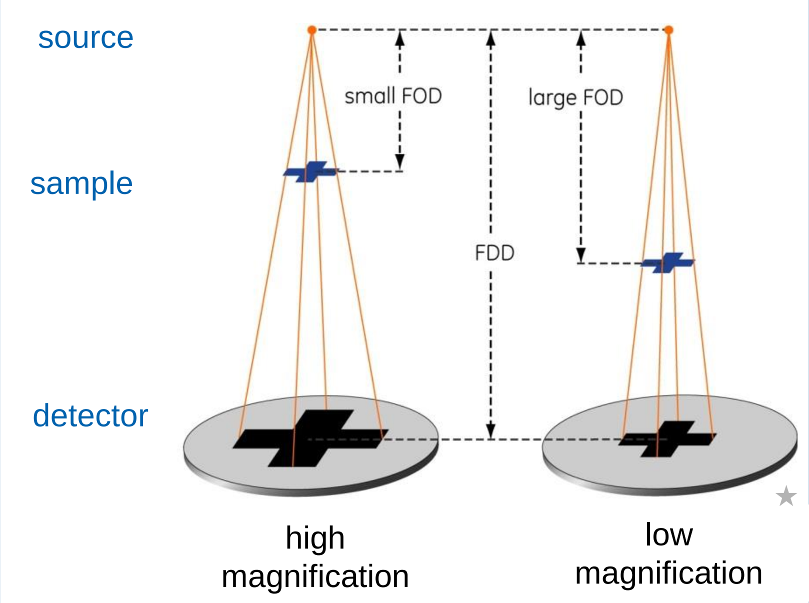




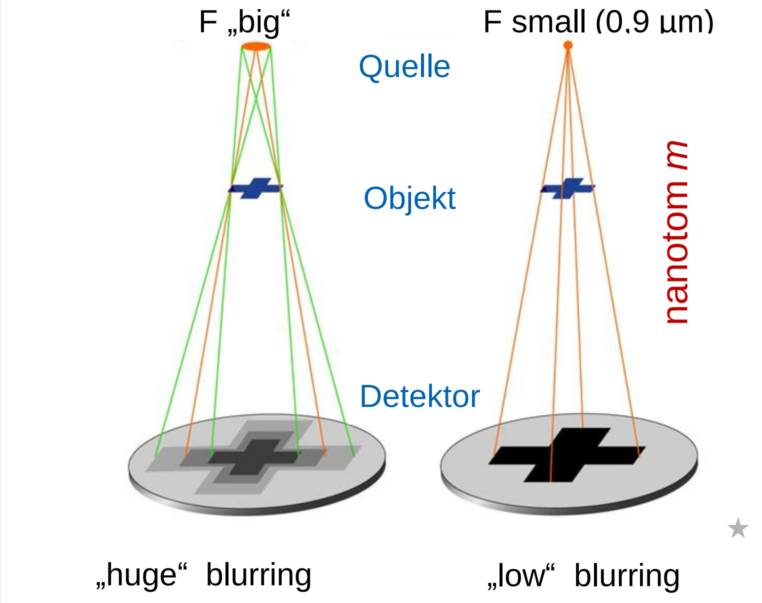
high dynamic range detector „nanofocus“ tube with sample tube „nanofocus“

Fundamentals of X-ray Inspection / Dr. H. Roth 2009-04-15

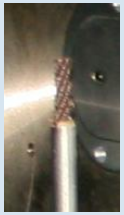
3. CT - important tool for FE-simulation
Computer tomography (CT)



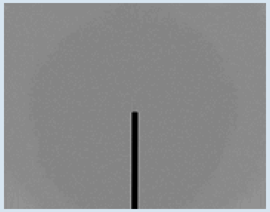
geometrical magnification M =FDD/FOD



geometrical unsharpness by focus dimension F

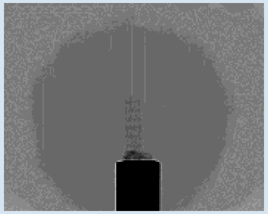


Fabric sample
4mm width



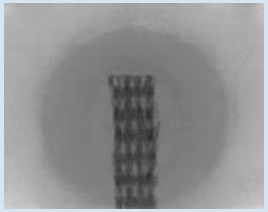
FOD = 400mm

Voxel:66³µm³



FOD = 50mm

Voxel:8,3³µm³

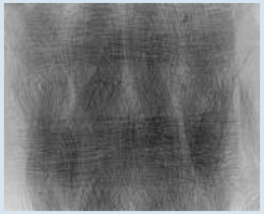


FOD = 20mm

Voxel:3,3³µm³

FOD = 8mm

Voxel:1,3³µm³



FOD = 4mm

Voxel: 0,66³µm³

3. CT - important tool for FE-simulation scan experience

Analysis of fibre orientation requires best CT scan quality

Using max. performance of nanotom m:

perfect result by CT-scan:
multi-layer tube of glass fibre and thermoplastic matrix

(tube produced by braiding and pultrusion technology)

- whole detector area (14,5 MB/image, up to 5000 frames)
- highest magnification possible
- low voltage (as fibres and matrix do have low density)
- high filament current and long exposure time to get high grey values and best contrast.

These leads to scan times from 3 up to 8 h

- image data amount to handle are immense:
  70 GB (4800 images x 14,5 MB) images
  plus ~60-70 GB for reconstructed voxel model

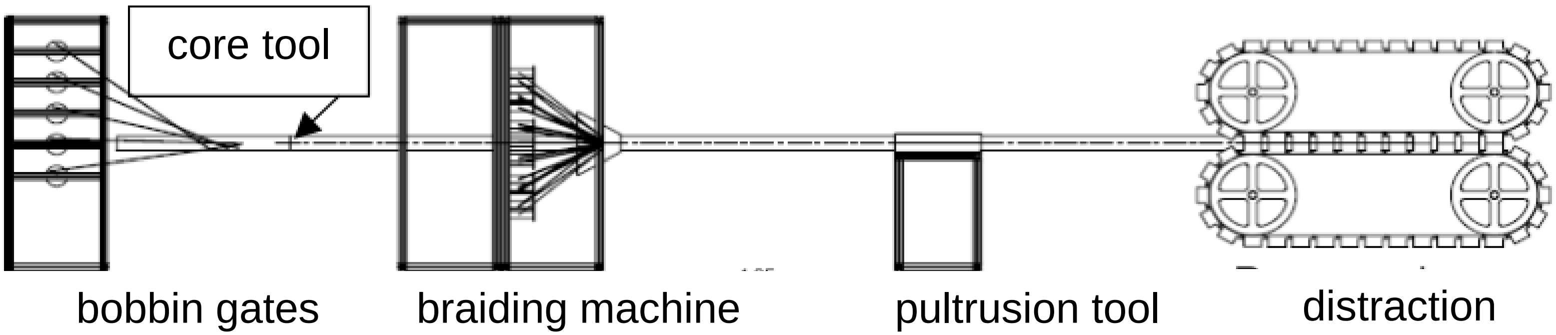
Optimal scan parameters depend on composite part (materials, dimensions)

After long optimization works we do have a perfect running CT, which give us the high resolution, high contrast at very low noise/signal ratio.

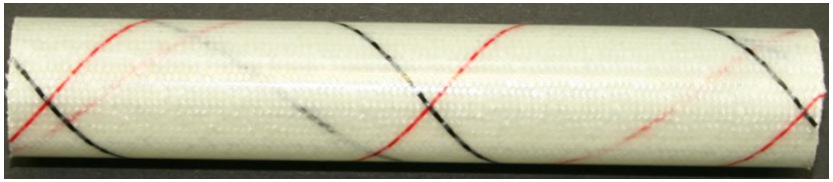
tensile sample   CFK   UD non crimp   crack   permeability

3. CT - important tool for FE-simulation
Fibre orientation analysis of high resolution CT-

pultrusion process



Optimal sample for CT/FEM development work in BMBF-project T-Pult:



density matrix material: EP 1,2 g/cm³,
density glass fibre: 2,6 g/cm³, 16 µm fibre diameter

production of tubes consisting of

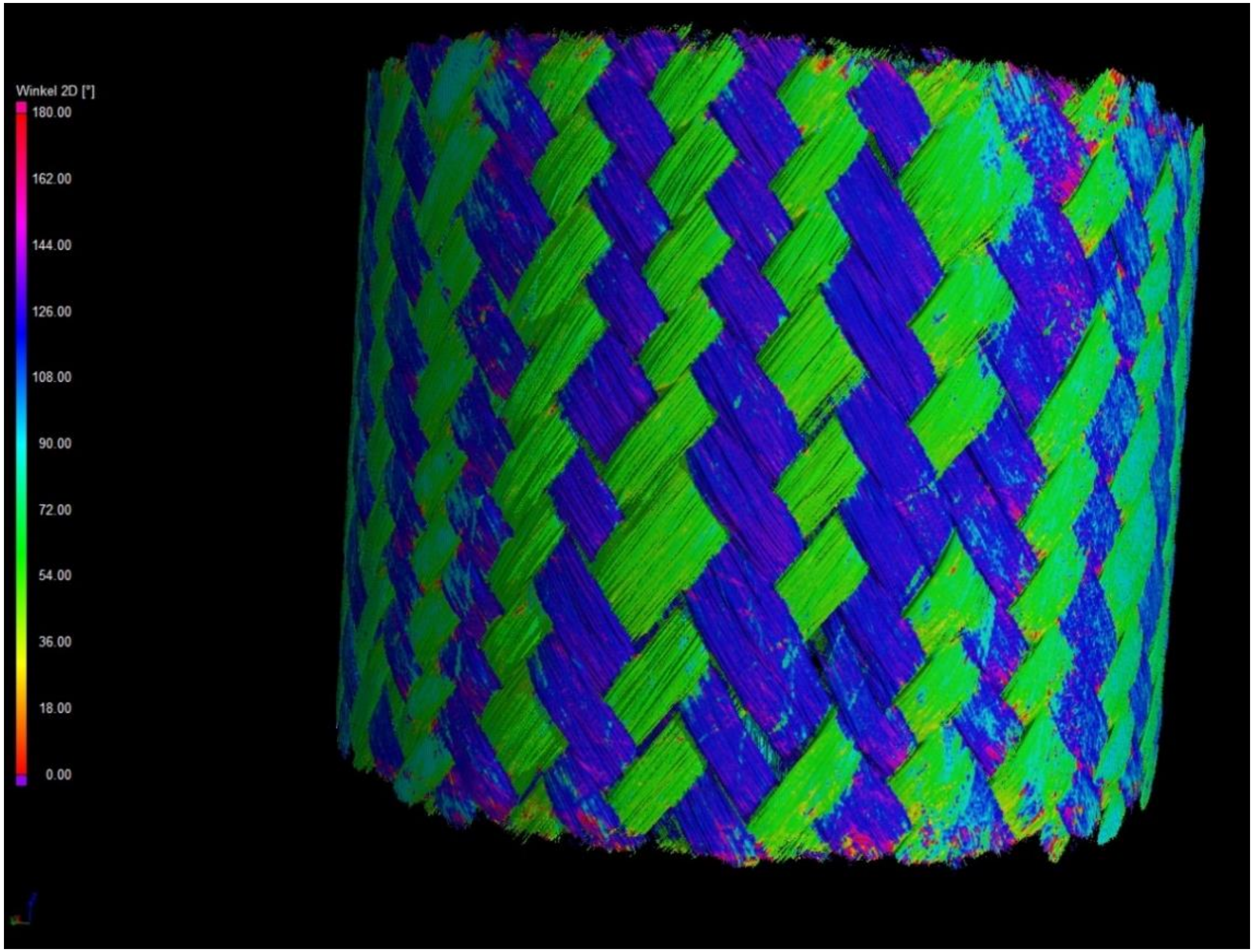
3 layers glass fibre :

1. layer: braid with braiding angle 1

2. layer: unidirection reinforcement threads

3. layer: braid with braiding angle 2

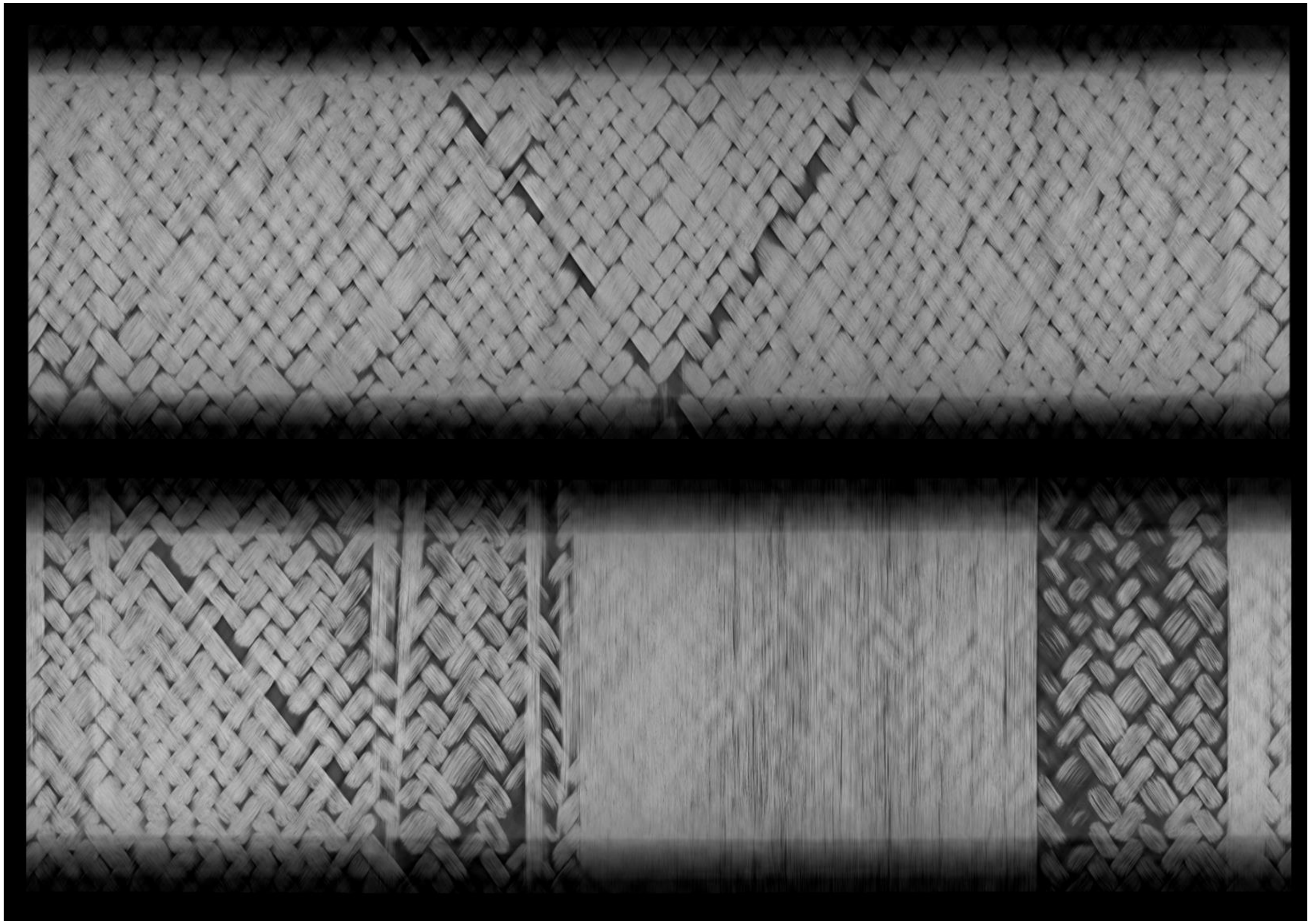
3. CT – important tool for FE-simulation
Fibre orientation analysis of high resolution CT-



CT scan of the 3 layer FRP-tube:
extracted fibre orientation (angle relative to image plane)

fibre orientation analyses are done with CT-Software VGStudio MAX of Volume Grpahics GmbH

3. CT – important tool for FE-simulation
Fibre orientation analysis of high resolution CT-



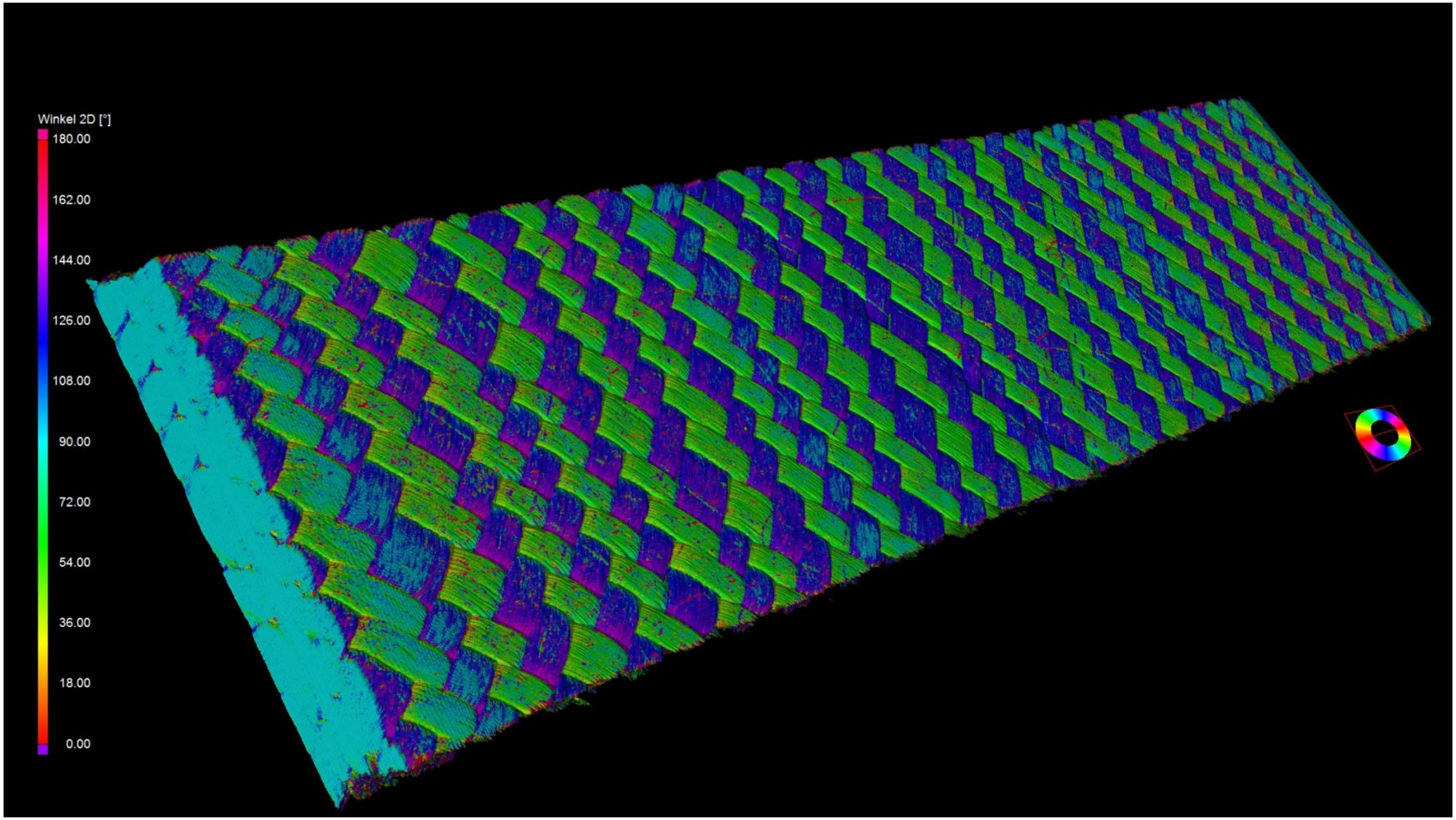
first
layer

second
layer

containing
irregular,
uniaxial
arranged
reinforcem
ent fibres

flat projection of fibre reinforced tube

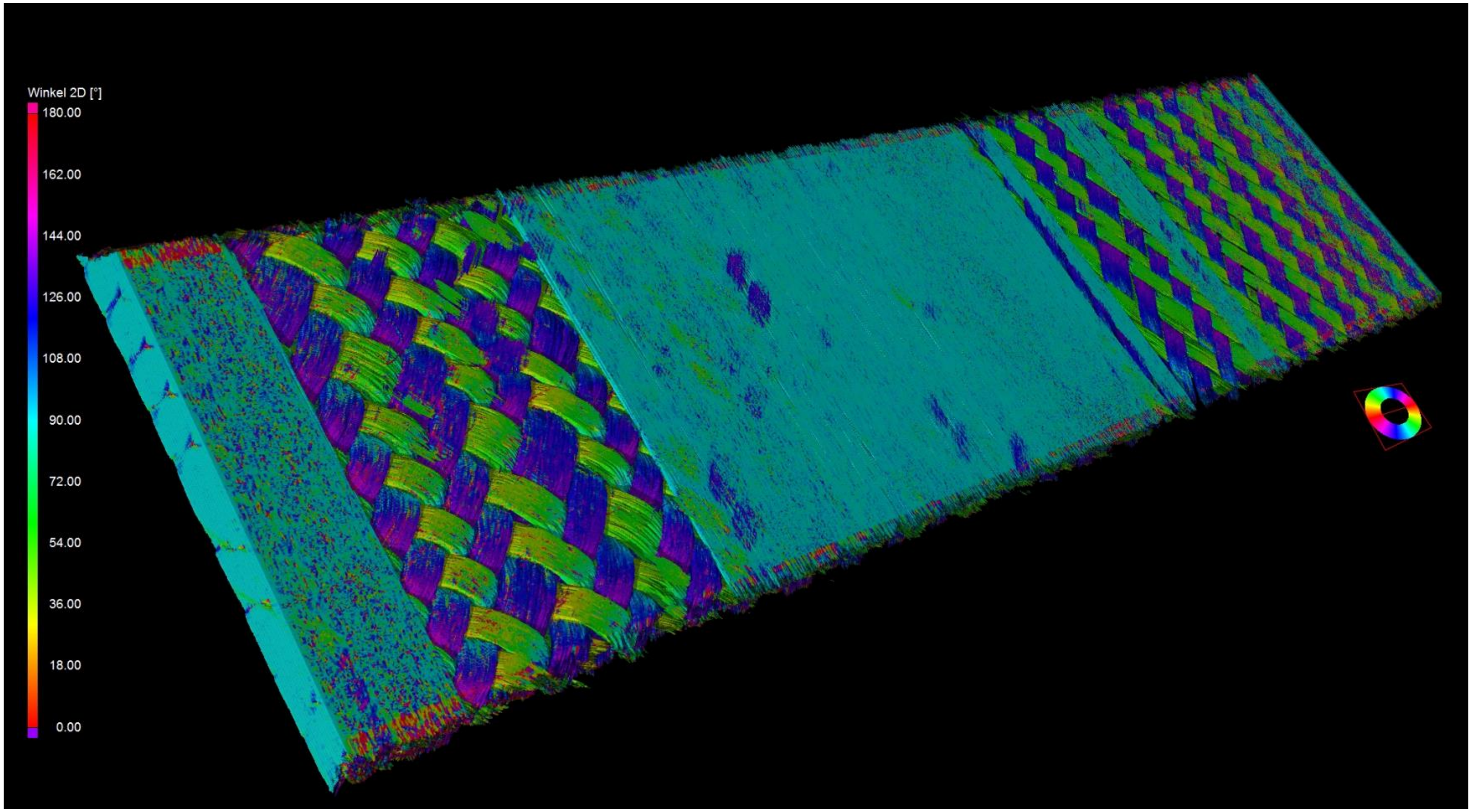
3. CT - important tool for FE-simulation
Fibre orientation analysis of high resolution CT-



analysis of fibre orientation by new „Fibre Composite Material Analysis Module“

first layer: flat projection of fibre reinforced tube

3. CT - important tool for FE-simulation
Fibre orientation analysis of high resolution CT-

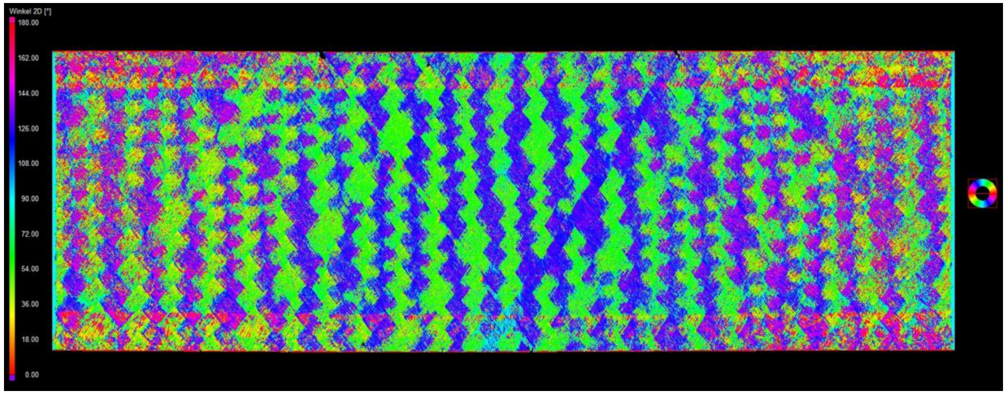


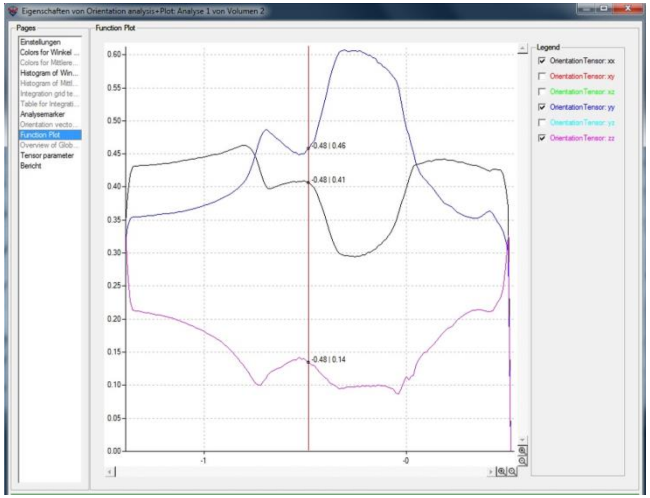
analyses of fibre orientation by new „Fibre Composite Material Analysis Module“

second layer: flat projection of fibre reinforced tube

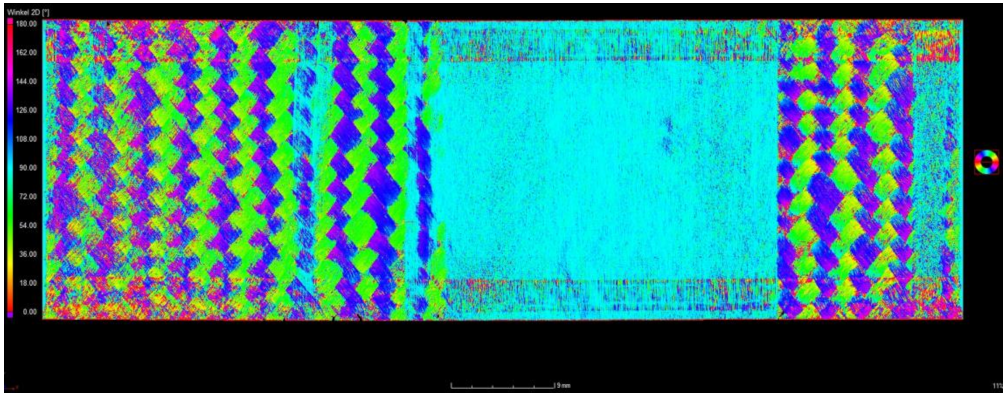
3. CT - important tool for FE-simulation
Fibre orientation analysis of high resolution CT-

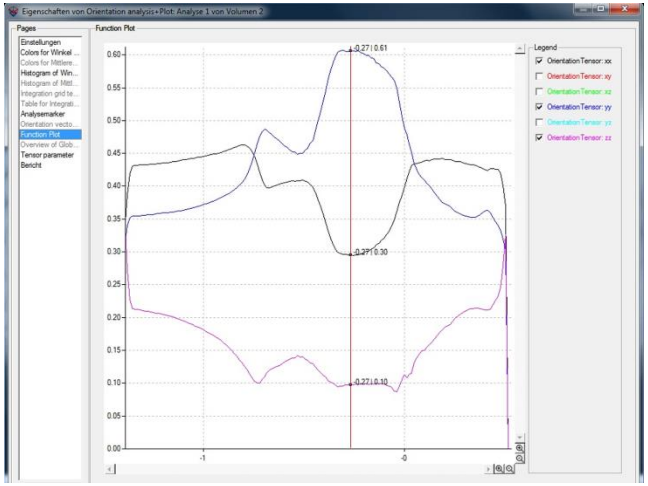
Flat projection of fibre reinforced tube by VGStudio





first layer



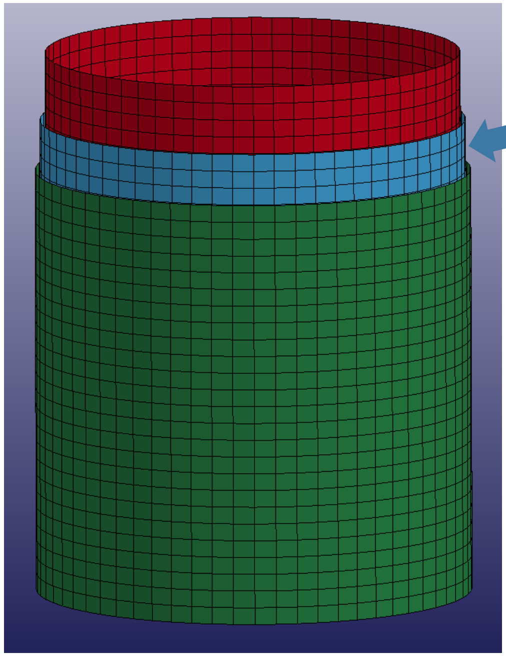


second layer (containing irregulary uniaxial arranged reinforcement fibres)

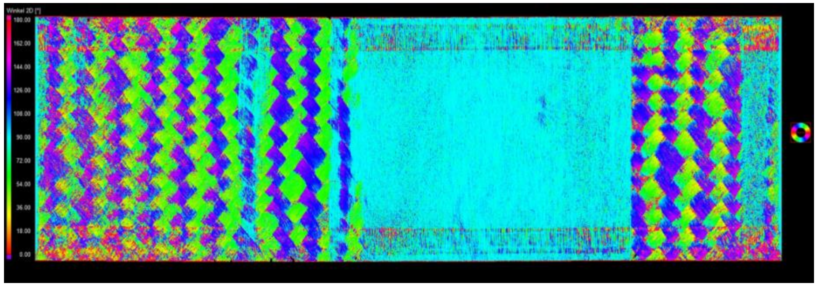
3. CT – important tool for FE-simulation
Fibre orientation analysis of high resolution CT-

Development of homogenization method:

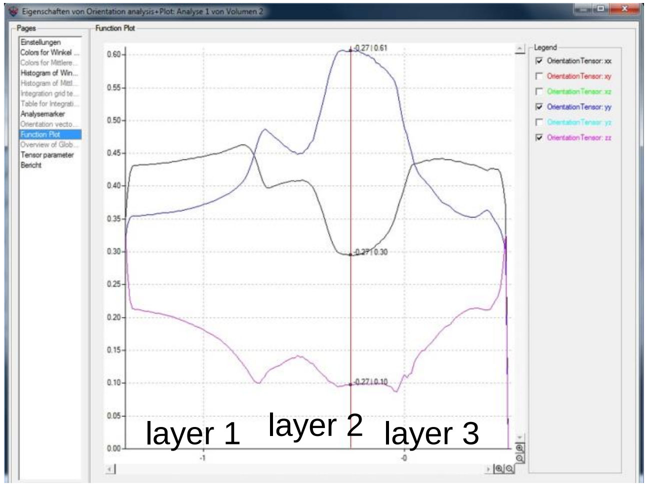
- Mapping exact fibre informations to suitable FE-models
- Useabable to compute larger parts



every single layer is represented by a single tube modeled by shell elements



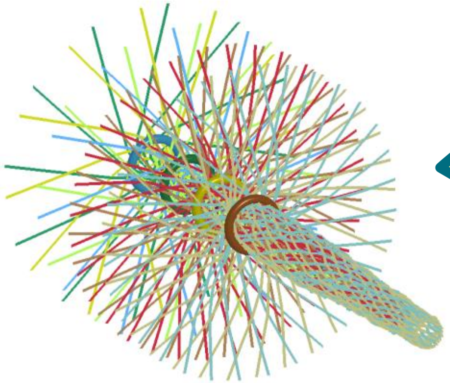
flat projection 2. layer (refers to red line in diagram below)



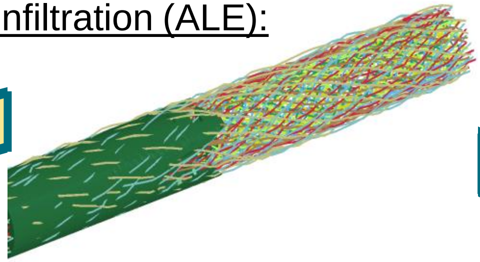
fibre orientation in all 3 main directions (x, y, z) over wall thickness

4. Conclusion & Outlook: Process chain

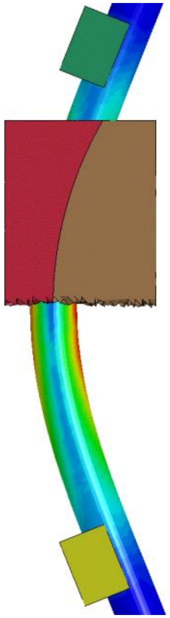
Braiding:



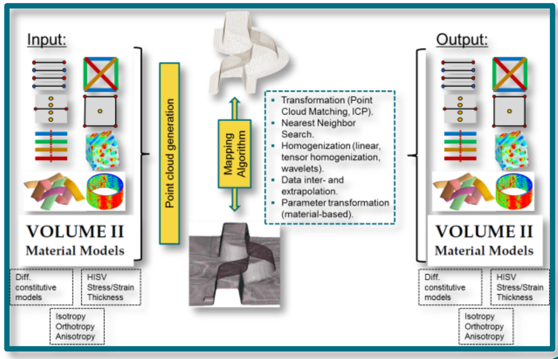
Infiltration (ALE):



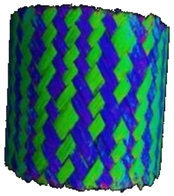
Forming (MAT_249):

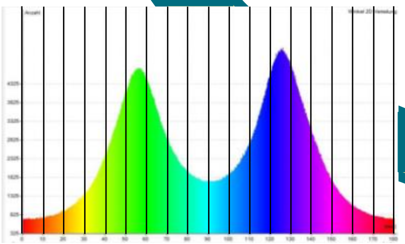


Mapping:



Experimental validation:





4. Conclusion & Outlook

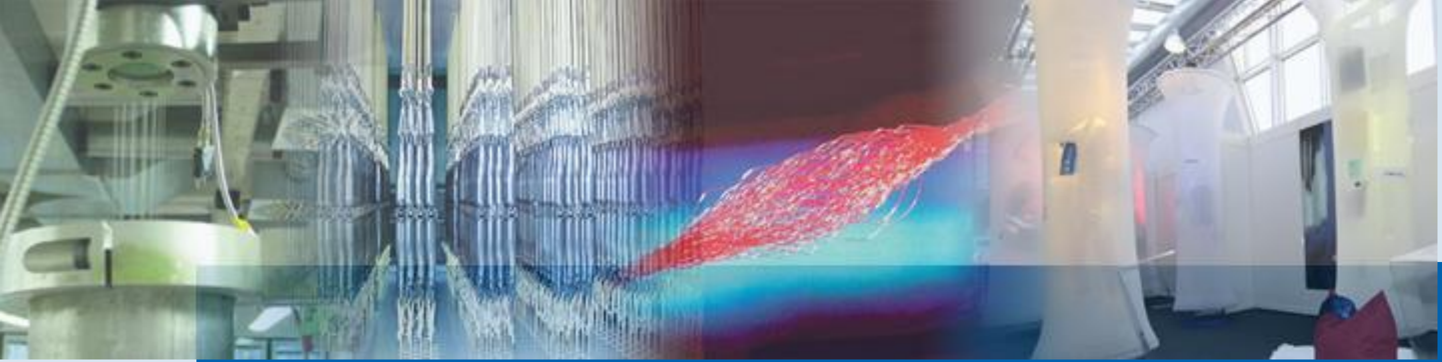
- Four methods were introduced which are capable to run braiding simulations with LS-DYNA: standard beam elements, using switch to rigid, seatbelt elements & a new *ELEMENT_BEAM_SOURCE.
- *ELEMENT_BEAM_SOURCE is easy to preprocess, simulations seem to be faster
- Braiding simulation with serveral braiding maschines are possible and will be performed real pultrusion line for real products.

➢ High resolution computer tomography leads to new possibilities in research & development tasks

➢ Finite-Element-simulation and computer tomography coming together will be an important part of developing composite technology

➢ fibre orientation analyses gives important informations for generating FE-simulation models for small (micro-modeling) and large models (abstracting on base of real data, homogenization)

➢ CT also used to get pemeability valuse for CFD-simulations



ITV DENKENDORF

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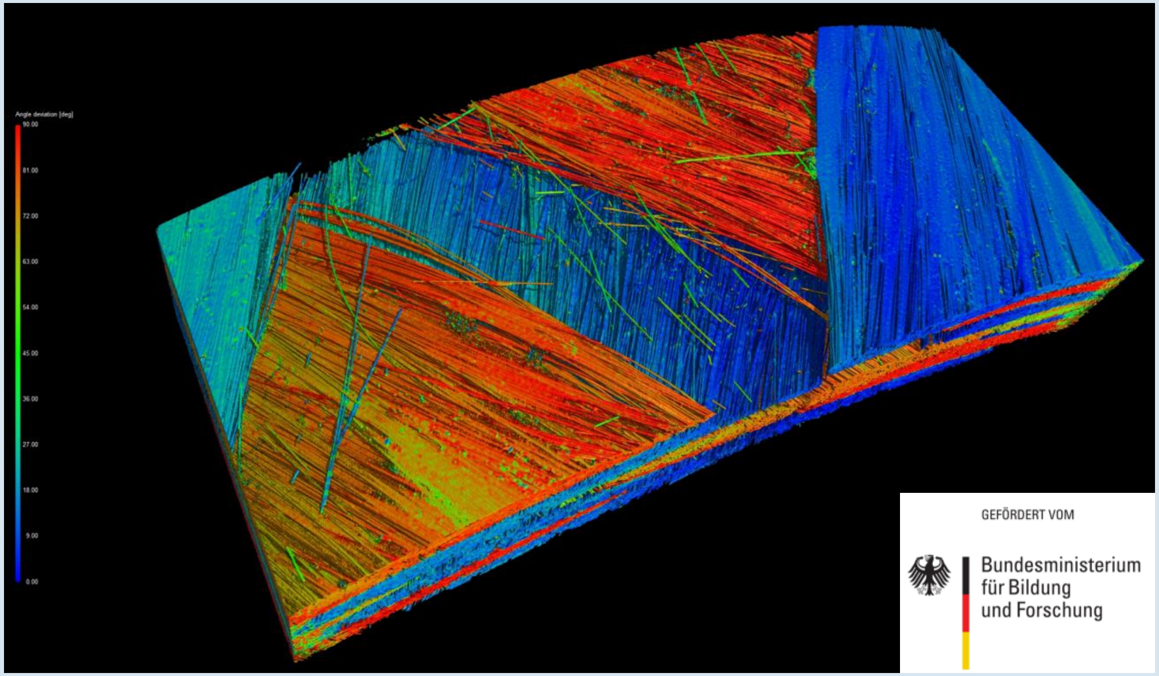
Thank you!



Hermann Finckh
Tel.: (0711) 9340-401
Email: hermann.finckh@itv-denkendorf.de

Christian Liebold
Tel.: (0711) 459600-263
Email: christian.liebold@dynamore.de