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Simulation and CT Technology in Textile LightWeight Design

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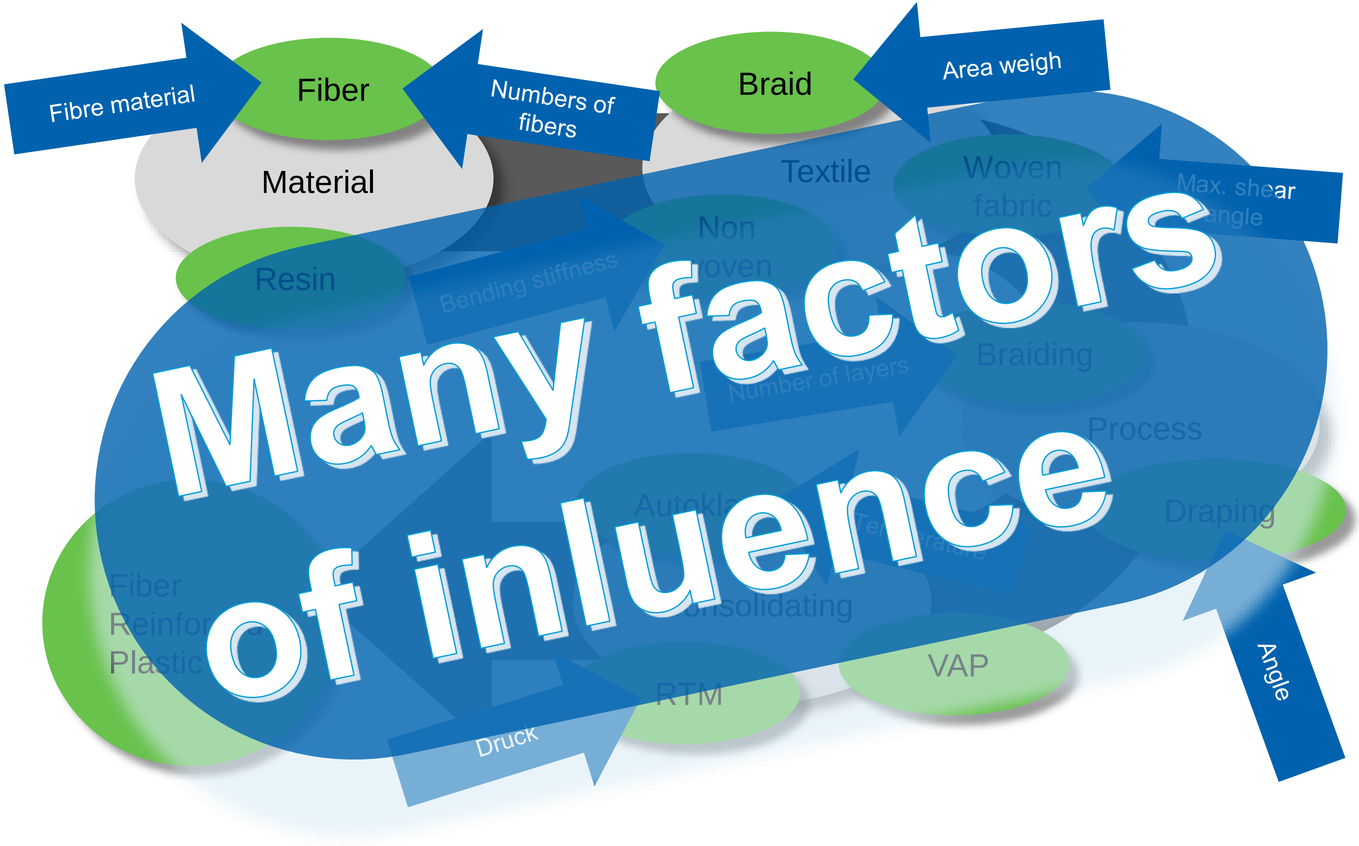
Deutsche Institute für Textil und Faserforschung Denkendorf

DYNAmore Infomationstag „ENVYO und Composite Berechnung“, 12.03.2018, Stuttgart

1. Motivation for process simulation



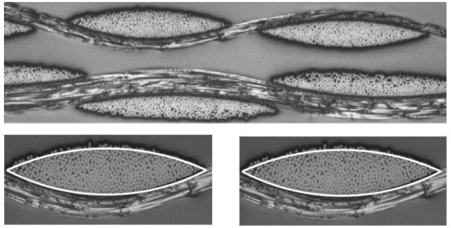
1. Motivation for process simulation

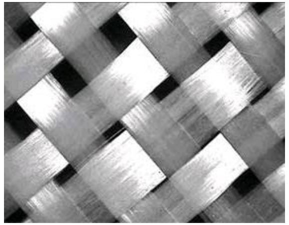
General:

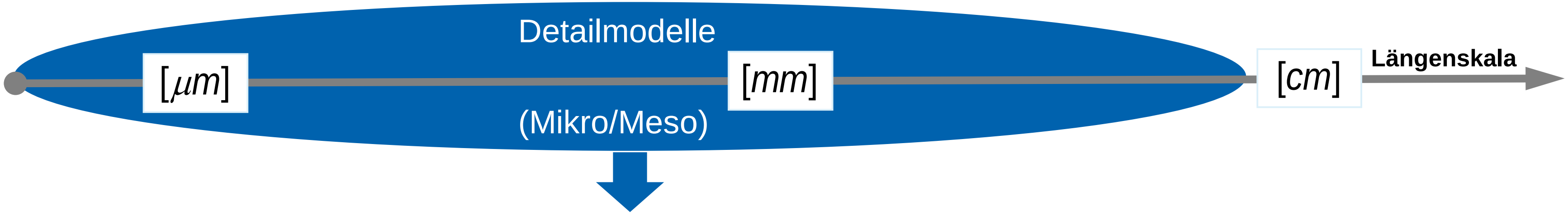
- Systematic analysis of boundary conditions and material properties.
- Variation of only one parameter possible, all other stay same: clear statements.
- Deep unterstanding of process.
- Optimization of reinforcement fabrics due to application requirements and more functionalibility (e.g. higher drapeability).
- Reduction of development time.
- Virtual product can be prooved for ability before it is produced.
- Ability to simulate mechanical properties of FRP more precise.

1. Motivation for process simulation

- **Getting precise simulation models refering structure, fibre orientation and fibre density for computation of FRP**



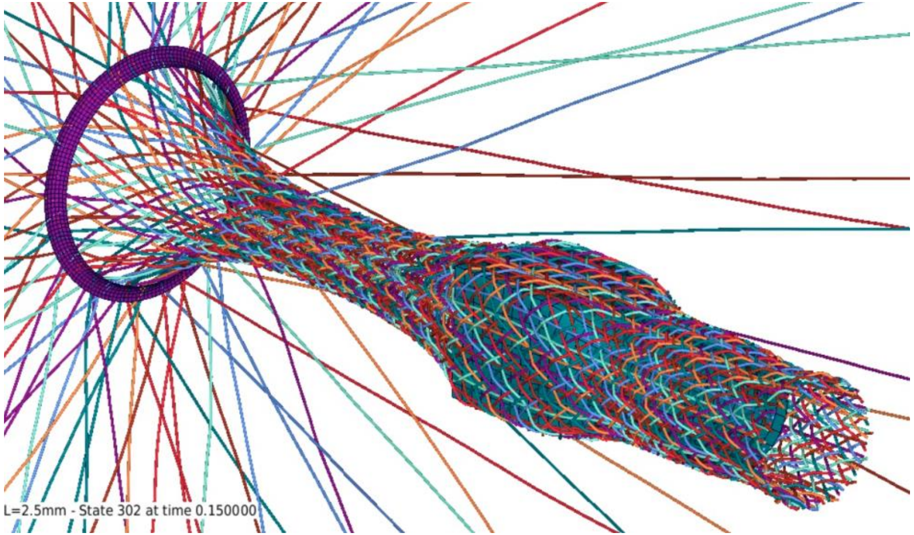


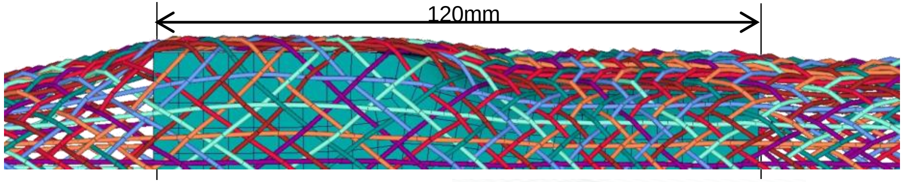


1. Models of reinforcement fabrics with simple structure by:
   - CAD-functions in FE-Programmen / special software
2. Models of compex structure and mutilfilament threads:
   - By process simulations
   - On base of high resolution CT-scans and high modeling effort (new possibilities now available)

2. Process Simulation Braiding

Braiding a part with changing geometrie





Triaxial-braid, detail

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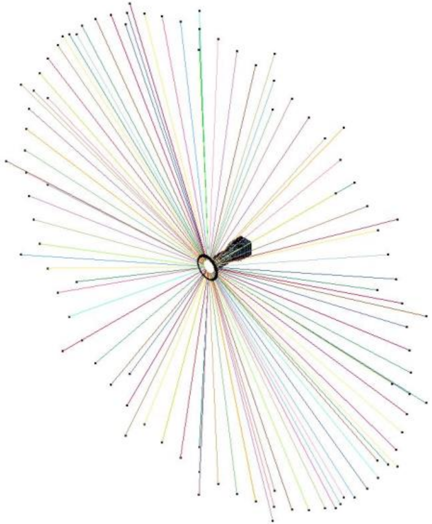
Braiding simulation using LS-Dyna

- bobbins: 64
- Uniaxial threads: 32
- Diameter: 1646 mm
- Part length: 120 mm
- Threads modeled by beams



„micro/meso modeling“

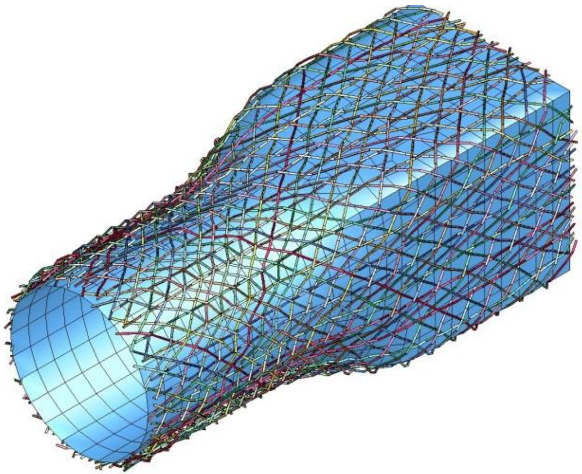
Simulation model at start

Curved part

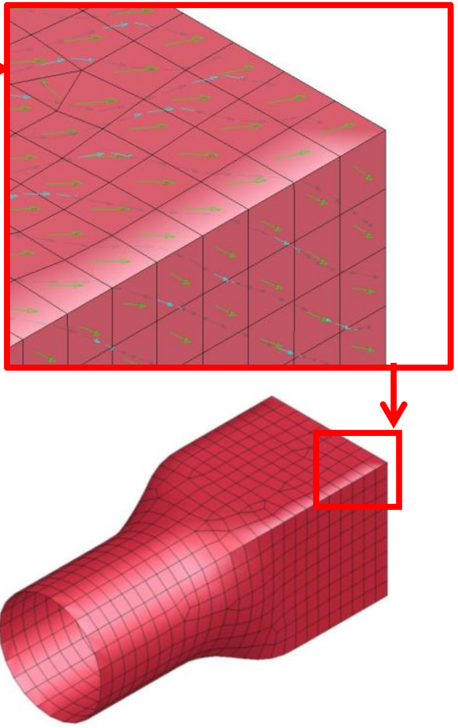
2. Process Simulation Braiding

Extraction und mapping of fiber orientation

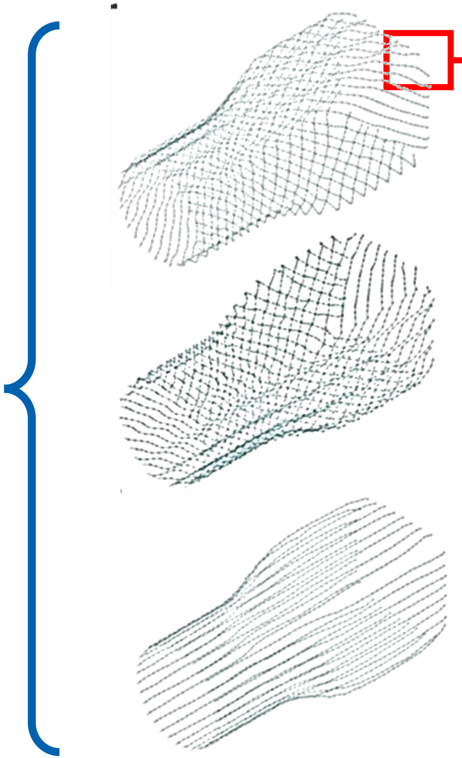
Result of braiding simulation



Mapping of fibre orientations e.g. using ENVYO



Extraction of fiber orientations



FE- homogenization model considering local fiber orientations

2. Process Simulation Braiding

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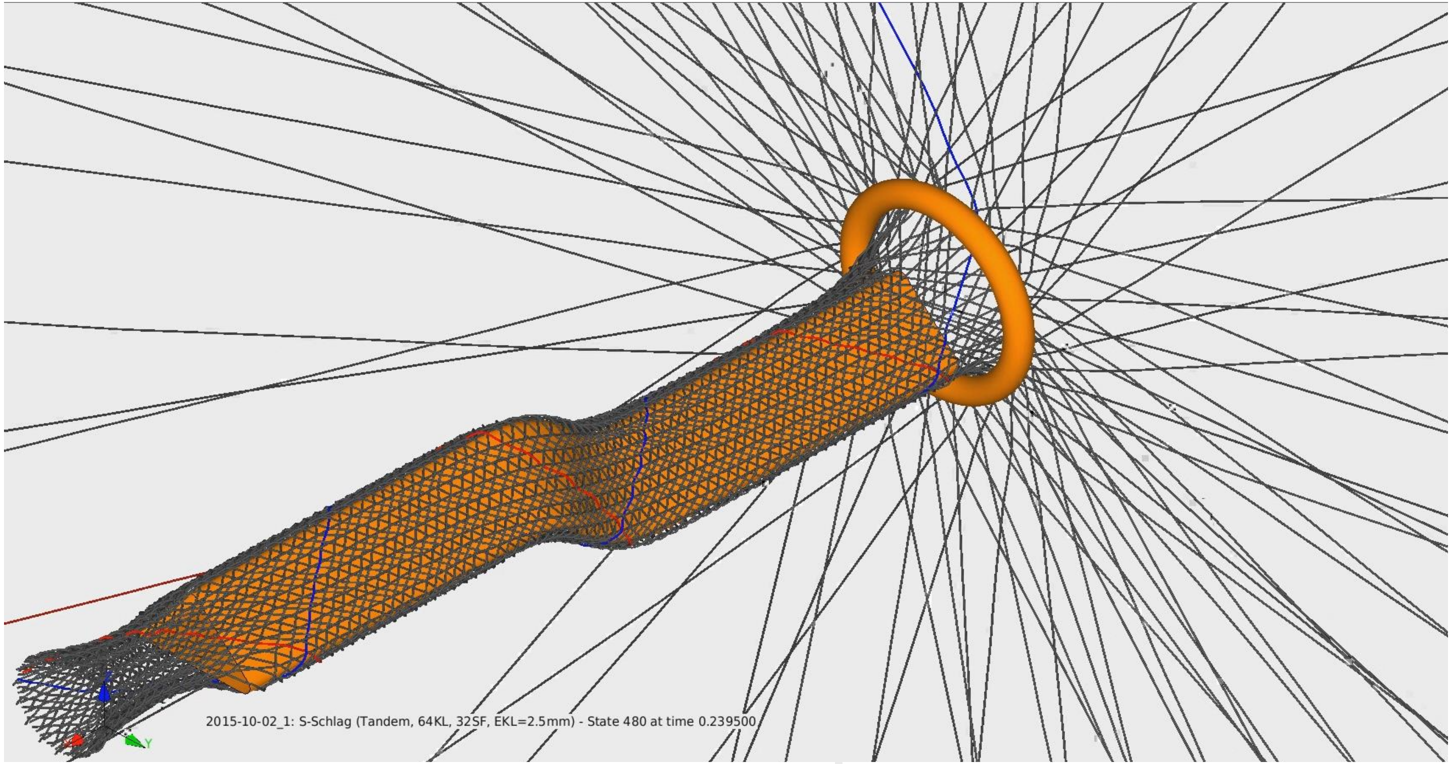

S-curved braiding part with triangle cross-section

- Using **seatbelt elements** computation time > 3 days
- Using **new Beam-Source-elements** computation time < 1 day

(12 Intel XEON cores with 2,7GHz)

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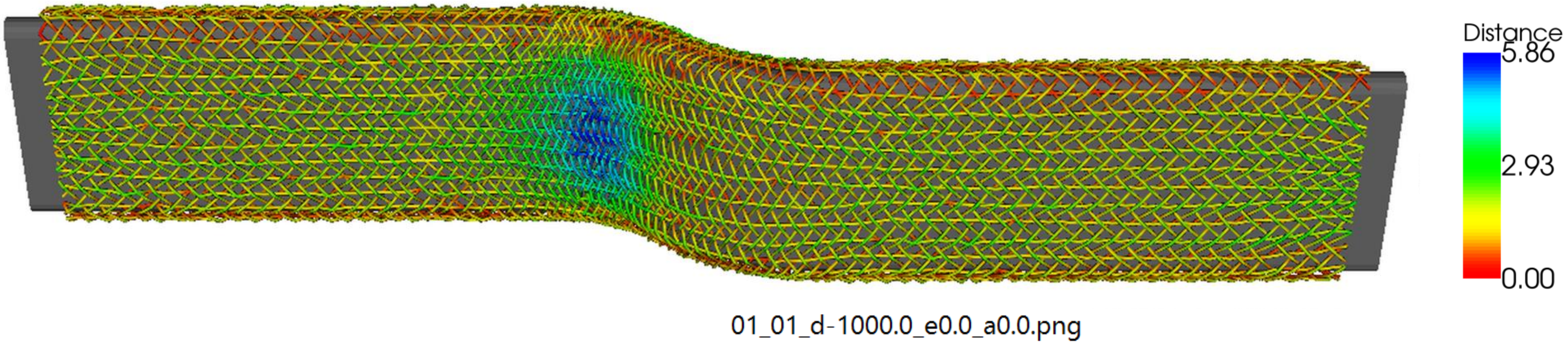
2. Process Simulation Braiding

- Comparison of two extreme sets of friction

Yarn to Core – friction   μ = 0,05
Yarn to Yarn – friction   μ = 0,05



S-curved braiding part with triangle cross-section

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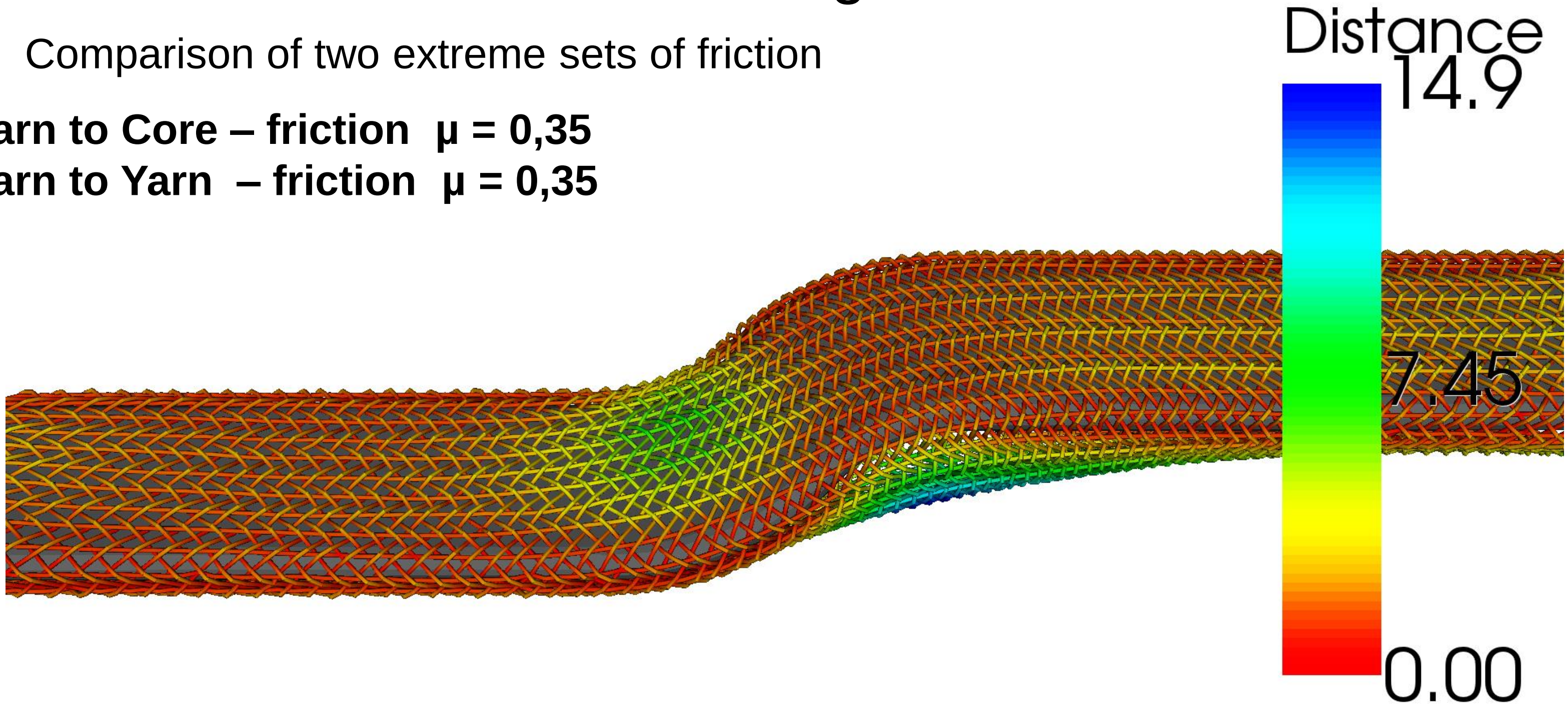

S-curved braiding part with triangle cross-section

2. Process Simulation Braiding

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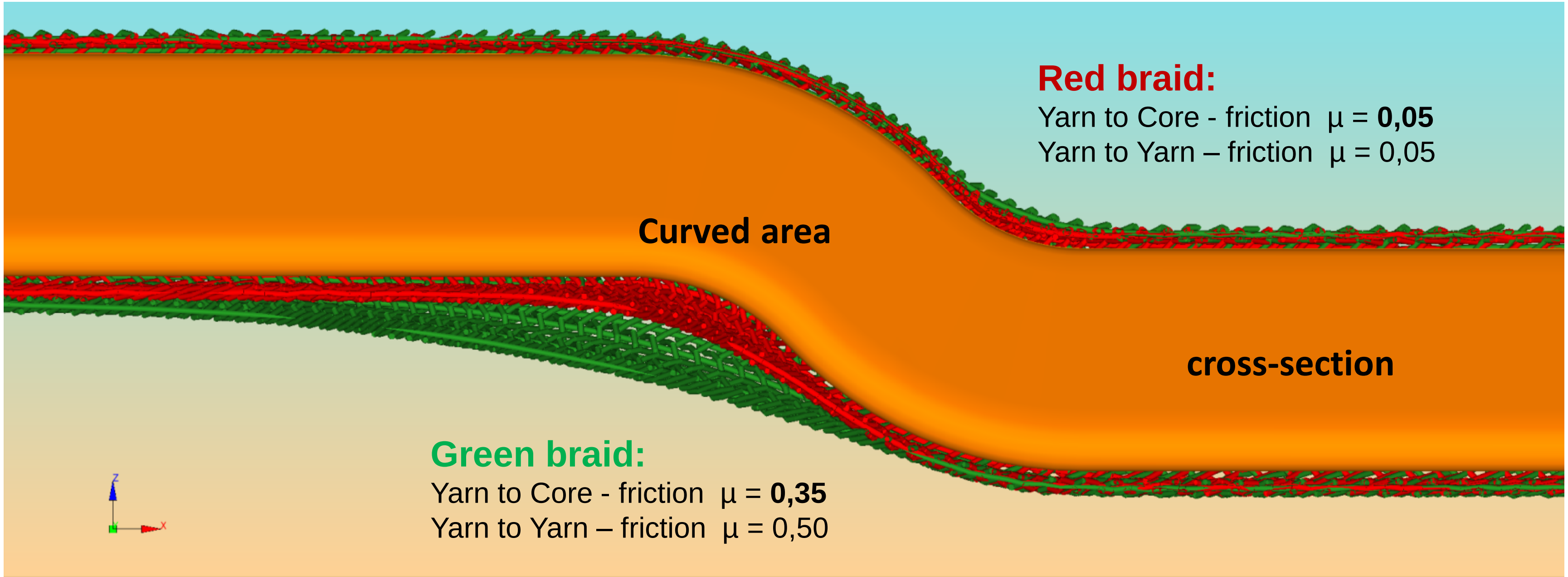

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S-curved braiding part with triangle cross-section

2. Process Simulation Braiding

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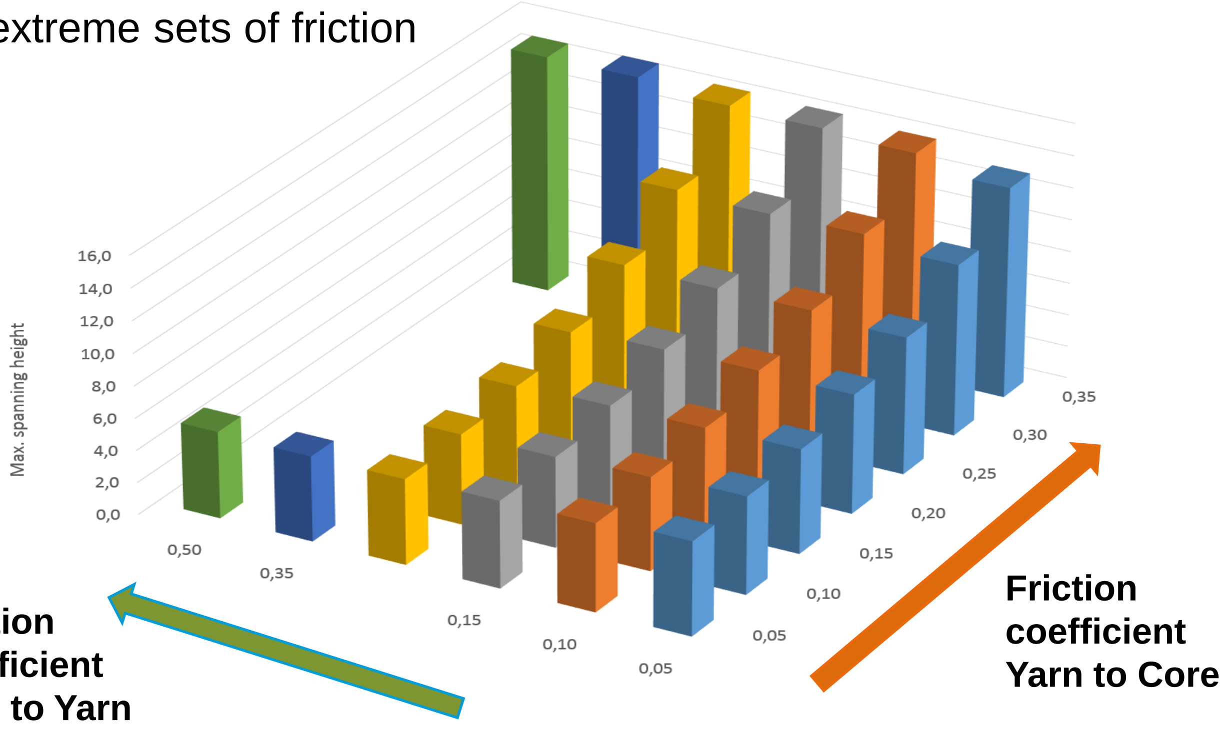
- Comparison of two extreme sets of friction



S-curved braiding part with triangle cross-section

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2. Process Simulation Braiding

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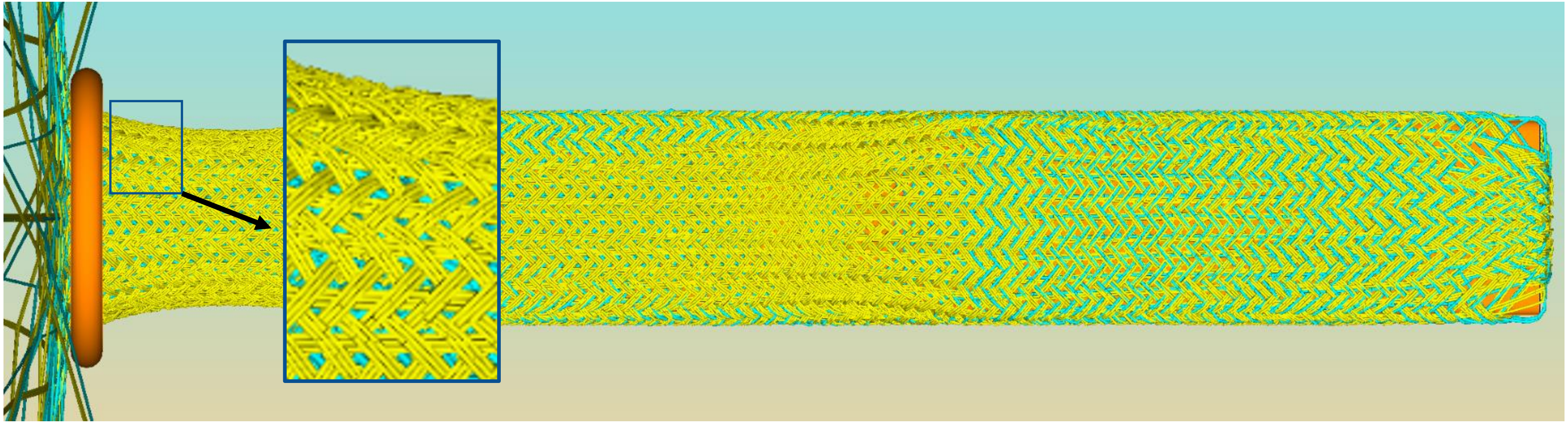
- First braiding simulation using multifilament yarn models

➢ yarn to yarn friction seems to have small influence.
➢ reason could be monofilament modeling, developments refering suitable multifilament models are ongoing.



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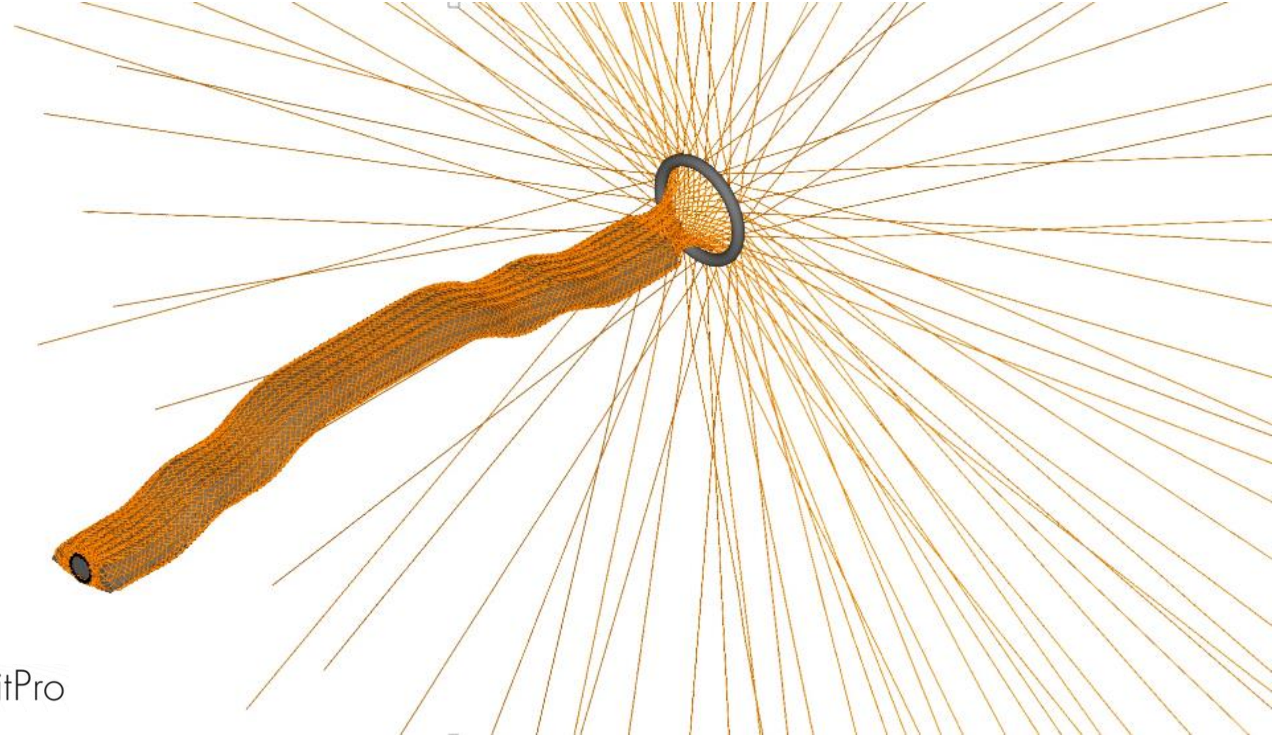
S-curved braiding part with triangle cross-section

2. Process Simulation Braiding

- First braiding simulation for complex generic demonstration part
- Model will be extended to 3 layers carbon rovings as in reality using multifilament model



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3. Use of high resolution X-ray CT technology

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µ-Computertomograph
nanotom m

Phönix | X-Ray
GE Sensing & Inspection
Technologies GmbH

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

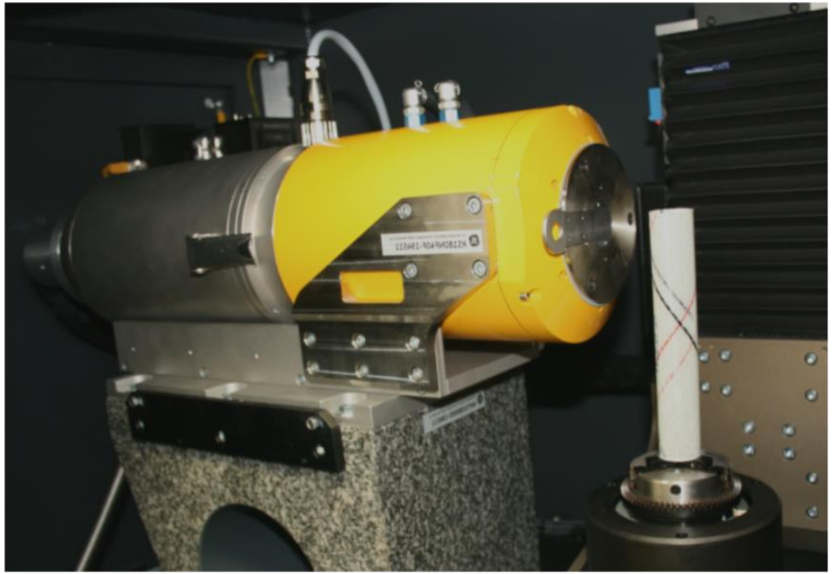
- 180kV/15W nanofocus-Röntgenröhre with **tube cooling**
- **Temperaure stable digital detector**:
  - ➢ DXR-Flächendetector with **3072 x 2400 Pixel,** Pixel: **100 µm**
  - ➢ Minimum Voxel: 300 nm
  - ➢ **14bit** Detektordynamic (2^{14} =16384 grey values)
- Sample dimension: **250 mm x 240 mm**
- Using two proffessional CT-analysis software:
  - ➢ **VGStudioMax (Volume Graphics GmbH)**
  - ➢ **AVIZO (Thermo Fisher Scientific)**

Perfect suitable to textile- und plastic based materials

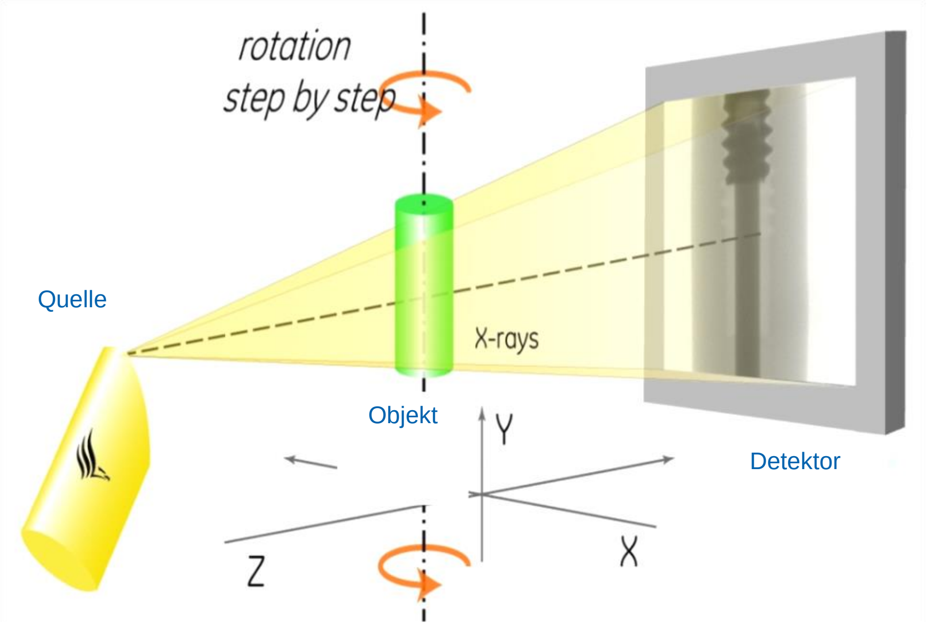
New possibilities to analyse µCT-3D scans:

- ➢ using new developed insitu-loading test stand by ZIM project (Kammrath&Weiss/DITF)
- ➢ Extracting threads out of 3D µCT scan using **Avizo** (Thermo Fisher Scientific)

3. Use of high resolution X-ray CT technology



GE „nanofocus“ tube ready to scan



- Sample rotates 360°
- to 4500 2D-scans (each up 19MB) are taken.
- 2D-pictures are used to compute a 3D-CT-model

3. Use of high resolution X-ray CT technology

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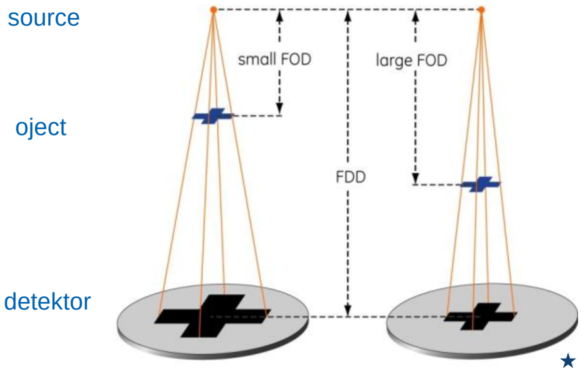
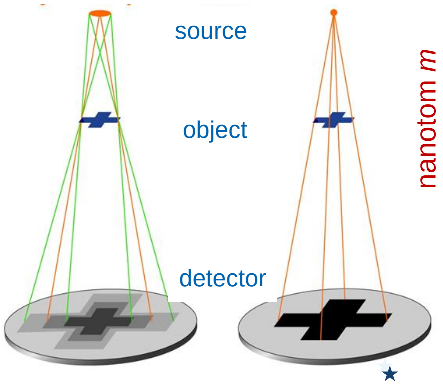
- magnification and blurring



small magnification | big magnification

F big | F small (0,9 µm)

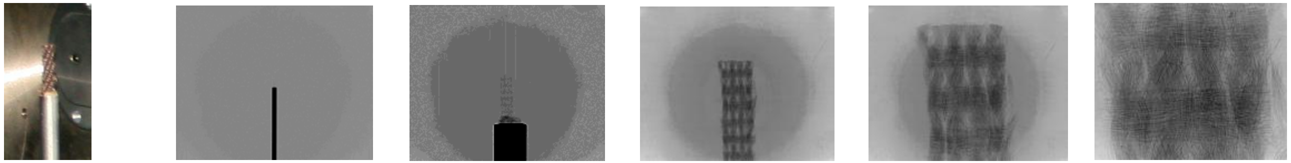


„big“ blurring | „small“ blurring

Geometrical magnification M =FDD/FOD

Geoemtrical blurring by size of focus spot F

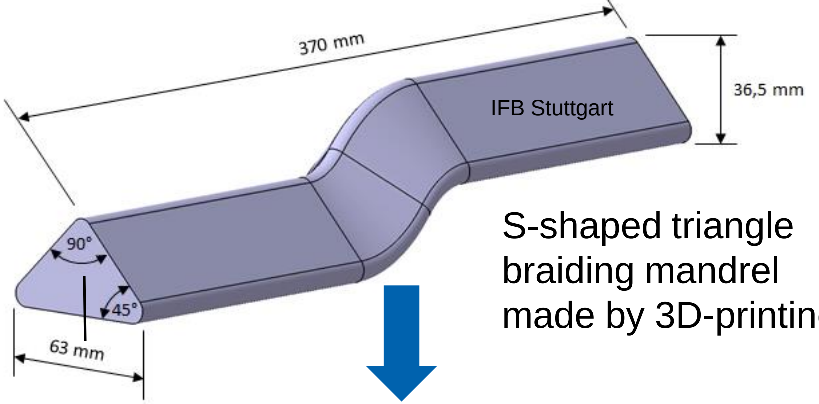
2D picture



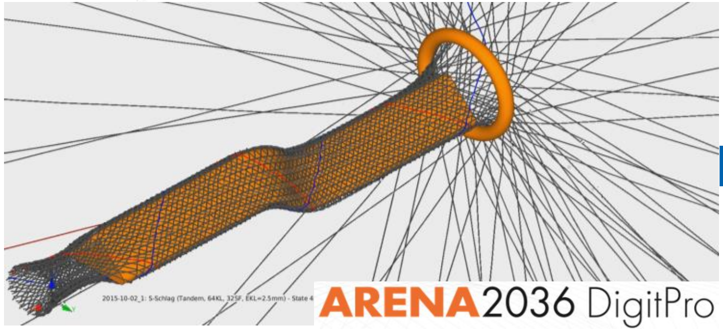
Woven Fabric	FOD = 400mm	FOD = 50mm	FOD = 20mm	FOD = 8mm	FOD = 4mm
	Voxel:66³µm³	Voxel:8,3³µm³	Voxel:3,3³µm³	Voxel:1,3³µm³	Voxel: 0,66³µm³

3. Use of high resolution X-ray CT technology

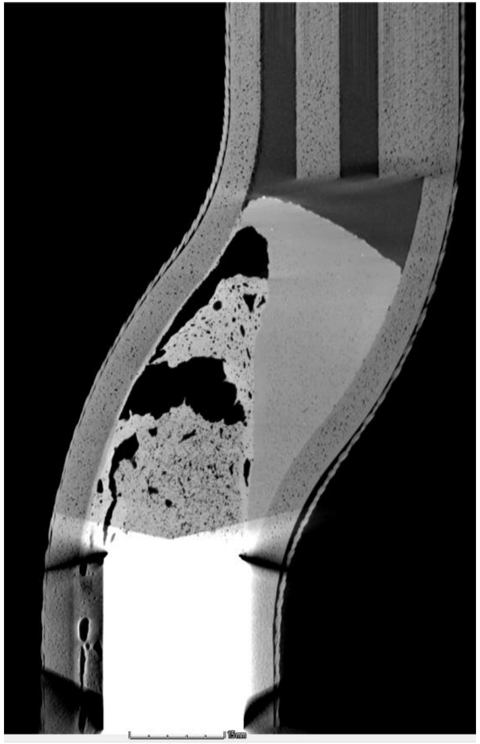
- Verification by high resolution CT-scan



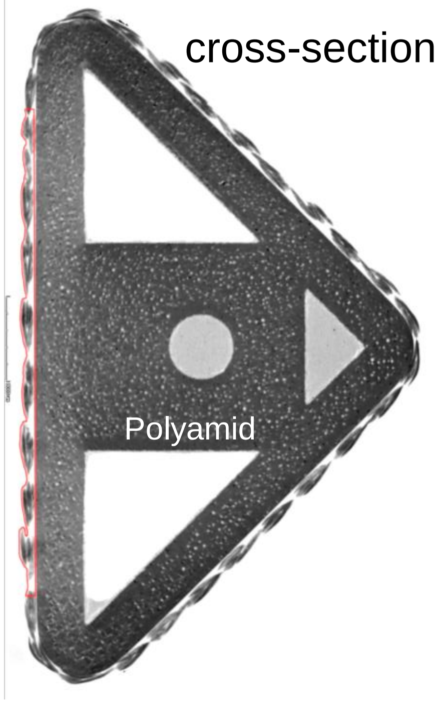
S-shaped triangle braiding mandrel made by 3D-printing



Real braiding and **FEM** process simulation



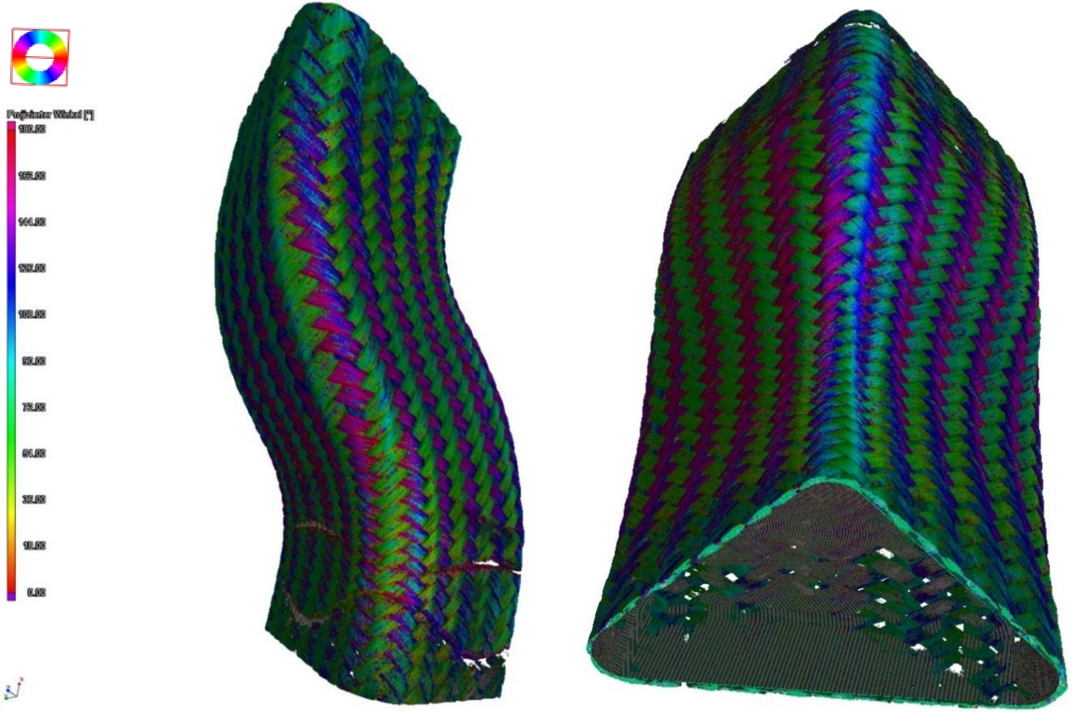
CT-scan of produced part (resolution with 40 µm)



red ROI shows analyzed area

3. Use of high resolution X-ray CT technology

- Verification of simulation by comparison between reality and simulation results:



- ➢ Direct comparision of braiding angles at various “hot spots”
- ➢ Exporting fibre orientation tensor, importing and visualization of extracted orientations in FE-software LS-PrePost containing simulation model

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Result of the fiber orientation analysis to 3D-CT model using VGStudio Max (Volume Graphics)

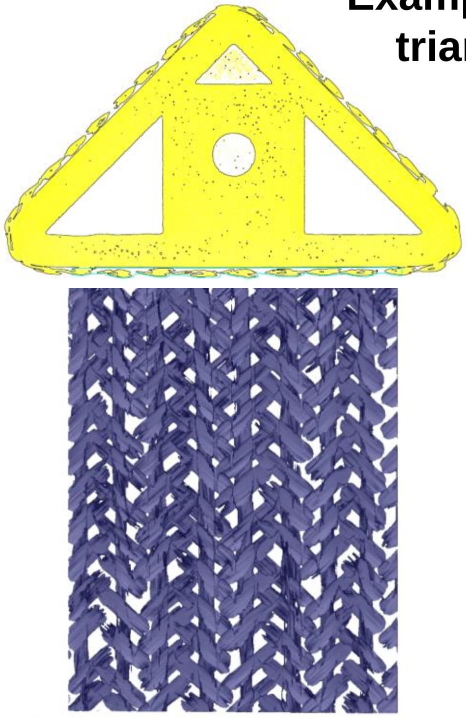
3. Use of high resolution X-ray CT technology

- Computing of permeability as important material data for infiltration simulation

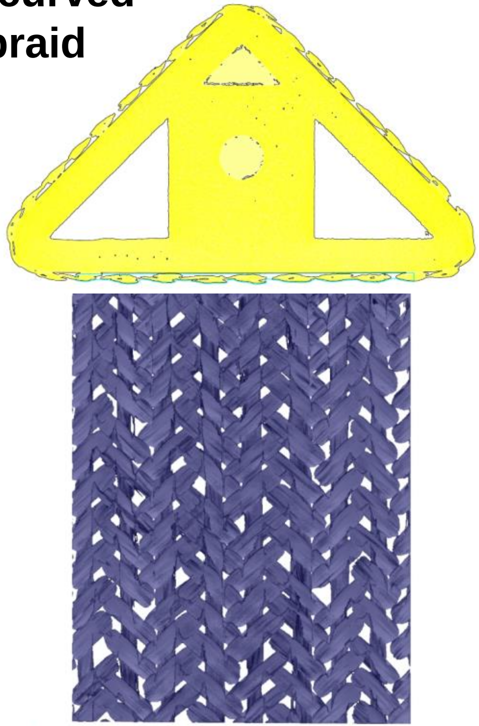
Example S-curved triangle braid

Result of the surface determination:

“**sharp**” and “**well balanced**”



surface “sharp” defined



surface “well balanced” defined

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3. Use of high resolution X-ray CT technology

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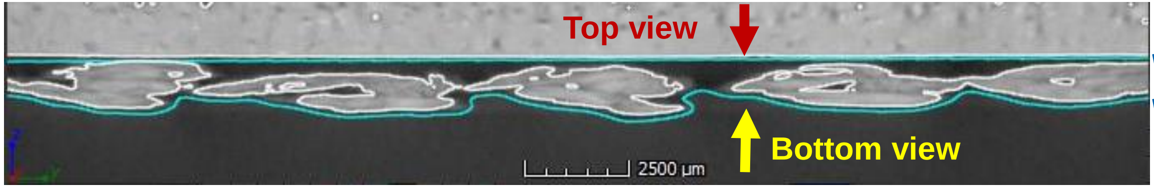
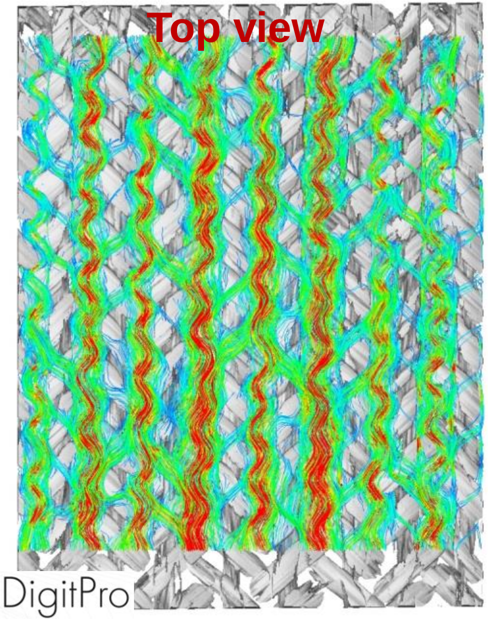
- Computing of permeability



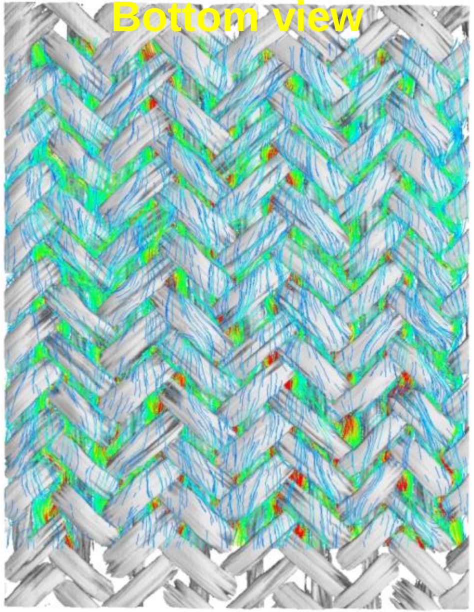
Blue lines define region of interest (ROI):
mandrel (here mould)
represents vacuum foil

In-plane flow:

distinct flow in gaps between braid and mold



flow direction



In-plane flow:

reduced flow as vacuum foil fits to the fabric considered by ROI

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3. Use of high resolution X-ray CT technology

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- Computing of permeability

Influence of surface detection and cell size referring permeability computation

	absolute permeability (10^{-9} m²)	absolute permeability (10^{-9} m²)
simulation cell size (grid)	48 µm	60 µm (1,5 x Voxel)
surface detection sharp	2,03	1,99
surface detection well balanced	0,91	0,88

- large influence of surface detection
- setting grid size same as CT-resolution leads to more precise results, but requires:
  - high amount of RAM (considered area with 40µm exceeds 256GB), now 1TB RAM available ➡ ongoing investigations
  - very long computation time (serveral hours)

- computed permeability for this example considers the fabric and the space between core and fabric.
- permeability to use for infiltration simulation for the real performed resign infusion.

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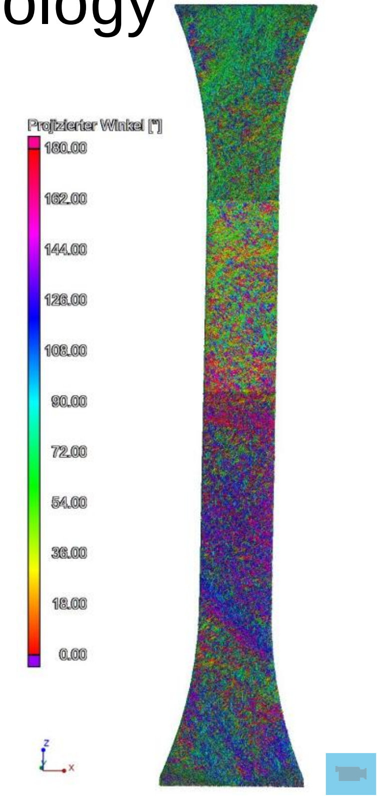
3. Use of high resolution X-ray CT technology

- Analyzing fibre orientation in Fibre Reinfored Plastic

tensile specimen of short fibre reinforced plastic

➢ Mapping of orientation tensor to FE-model



“Validation of Failure of Long Fiber Thermoplastics by Digimat Analysis Coupled to Micro Computer Tomography”, Seyfart, Finckh, Krämer, Dierig, Weidinger, 6. Fachtagung Composite Simuation, 02/2017,Fellbach

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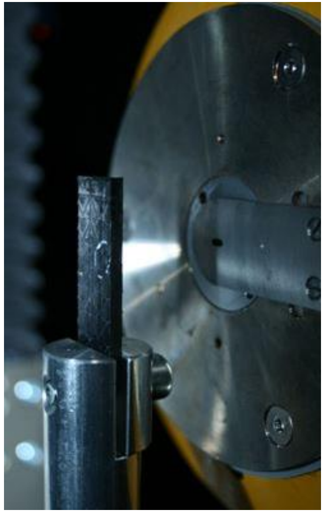
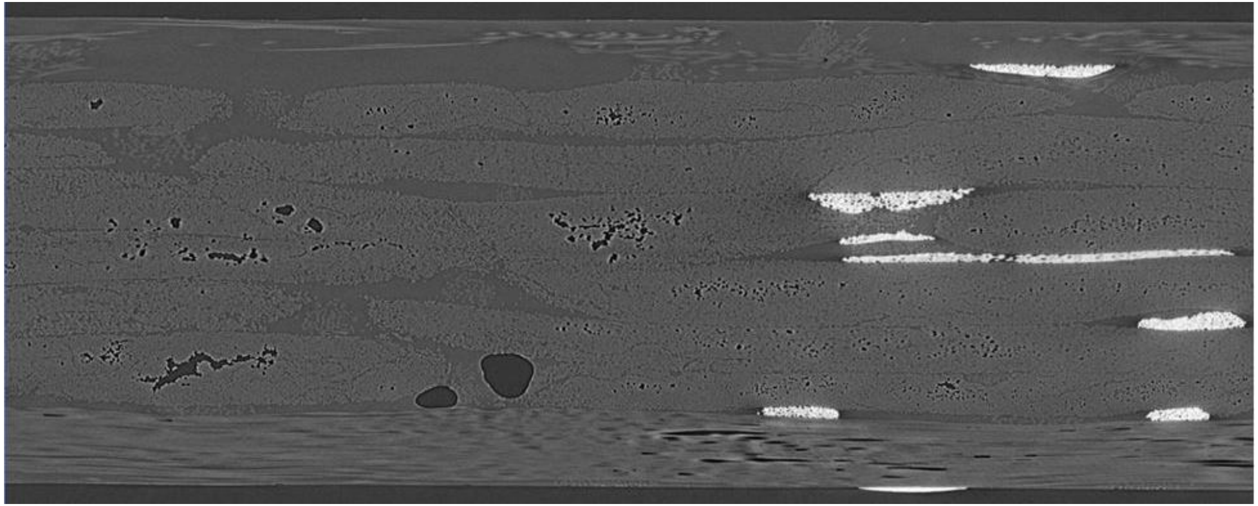
3. Use of high resolution X-ray CT technology

- Analyzing fibre orientation

tensile specimen of long fibre reinforced plastic: carbon rovings and exopy matrix



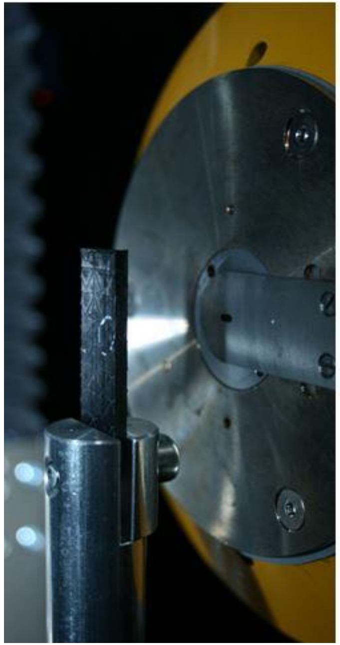


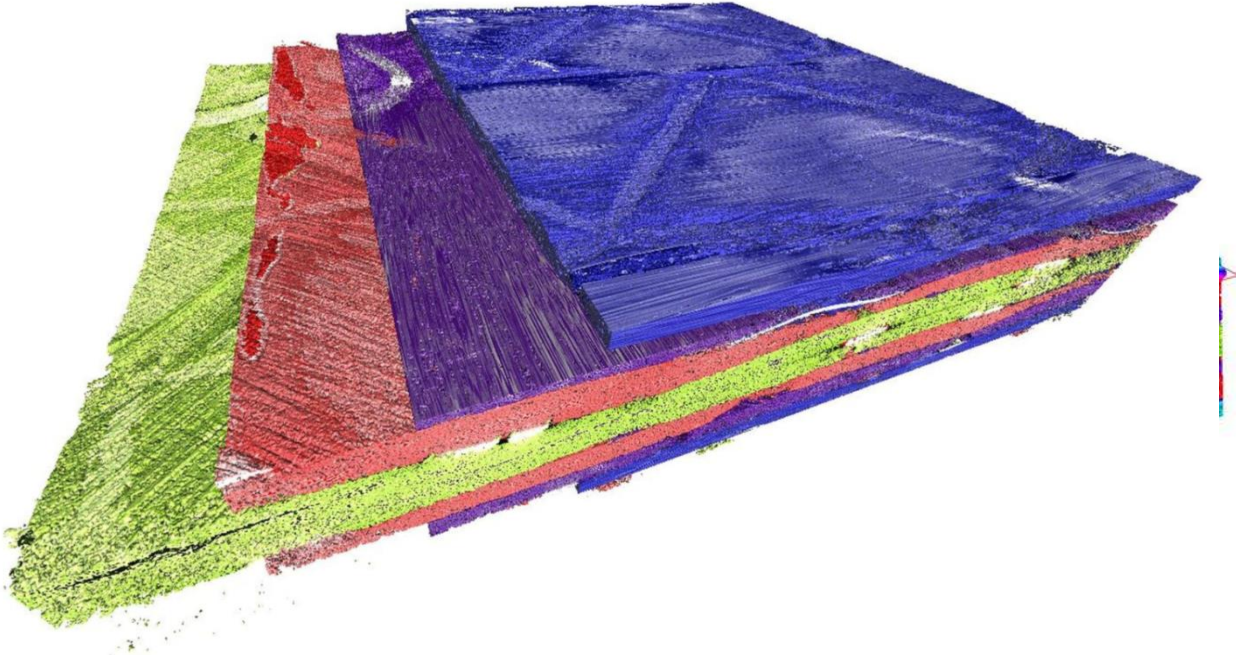
- ➢ CT-scan shows complete structure, layers, imperfections, air pockets
- ➢ Enables extraction of relevant fiber information (orientation, distribution, fiber volume content)

3. Use of high resolution X-ray CT technology

- Analyzing fibre orientation

tensile specimen of long fibre reinforced plastic: carbon rovings and exopy matrix





- using fibre orientation analysis of VG all 8 layers of the UD-fabric can be extracted: 0/90/+45/-45/-45/+45/90/0° fibre orientation.

3. Use of high resolution X-ray CT technology

- Faliure analysis for Fibre Reinfored Plastic

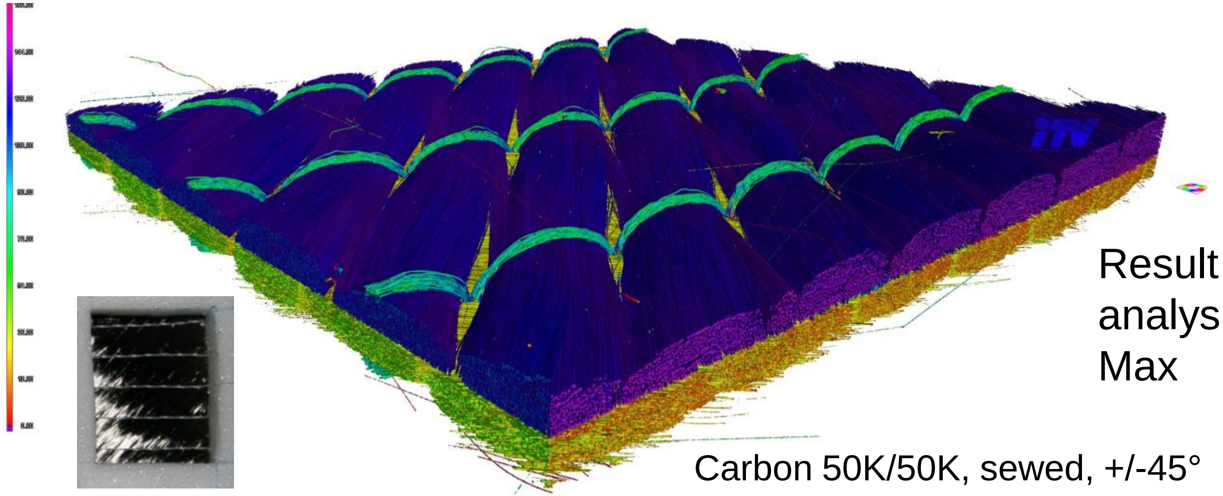
Plate consisting of 12 layer carbon fabric and rubber layer in the middle: damage after impact loading

FRP- Platte without rubber layer

FRP- Platte with rubber layer in the middle (Kraibon)
(10µm resolution, 30mm x 24mm x 6mm)

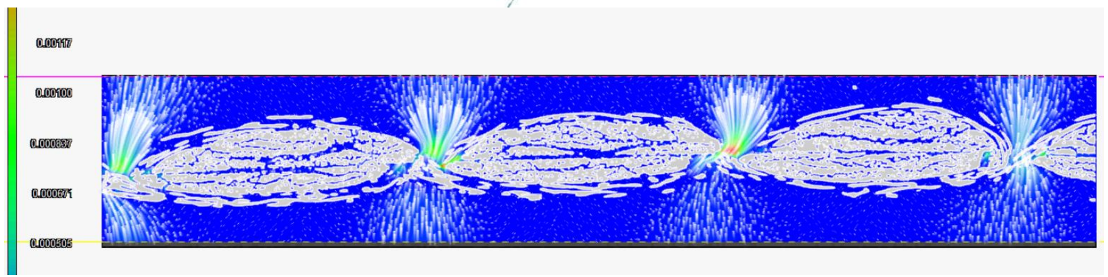
3. Use of high resolution X-ray CT technology

- µ-CT example: fiber orientation analysis to non crimp fabric



Carbon 50K/50K, sewed, +/-45°

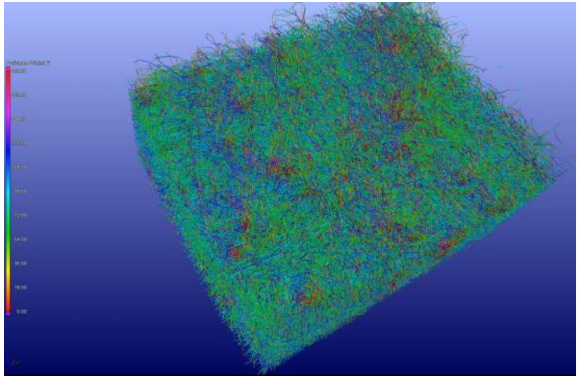
Result of the fibre orientation analysis performed with VGStudio Max

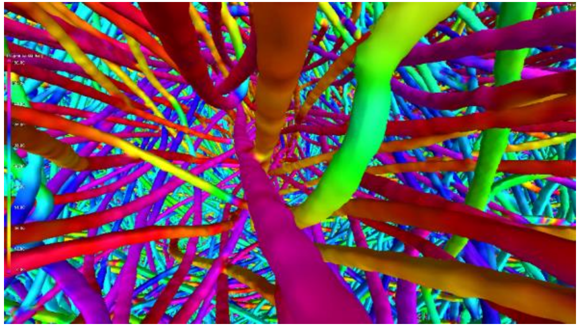


steady flow computation of an incompressible fluid through „gaps“ of „porous“ material: Result is permeability

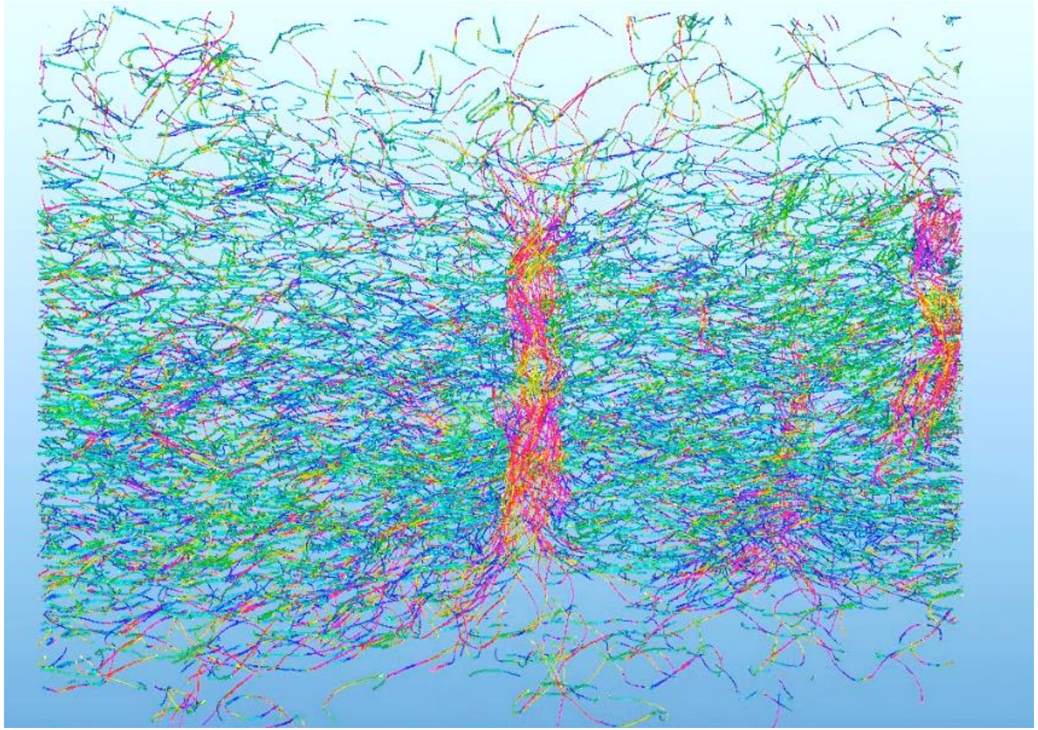
3. Use of high resolution X-ray CT technology

- µ-CT example: fiber orientation analysis to 3D-CT model of non woven





Inside the non woven



Cut through the area where a needle went into the non woven

3. Use of high resolution X-ray CT technology

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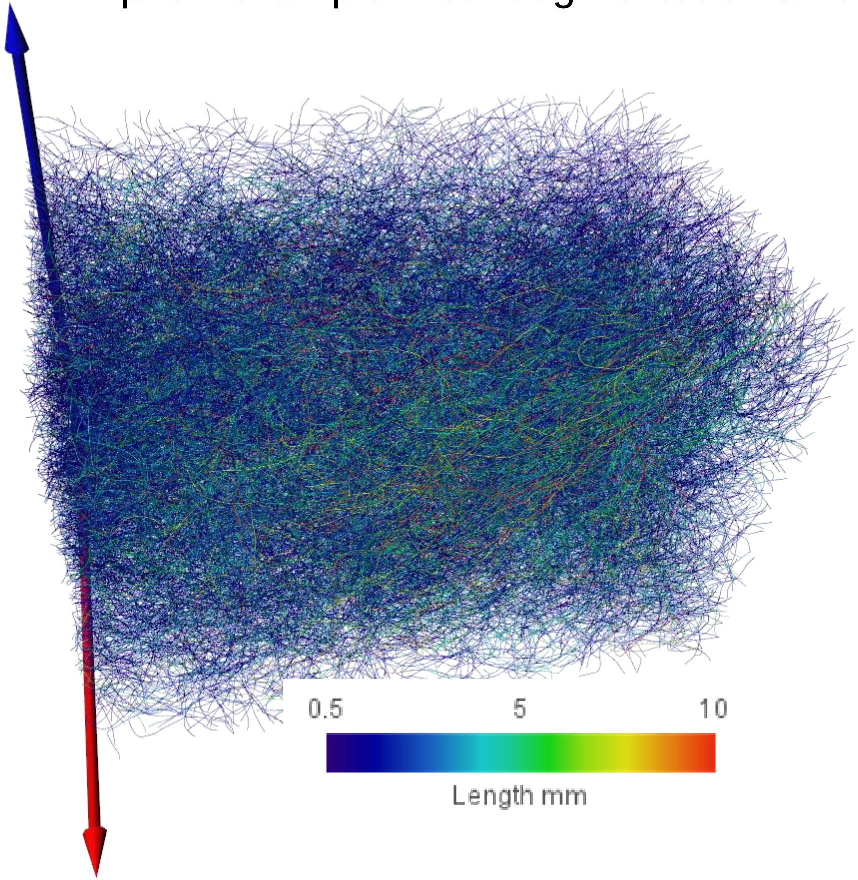
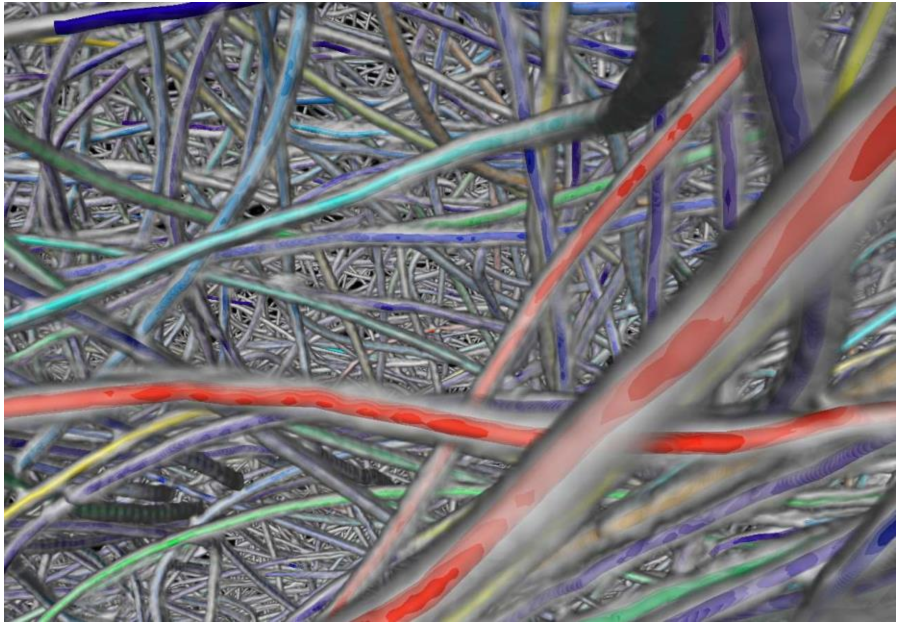
- µ-CT example: fiber segmentation an analysis of fiber lenght





fiber segmentation and determination of fiber length by 3D-analyzing software Thermo Scientific Avizo

3. New Possibilities of µCT getting fabric models out of 3D-CT-model

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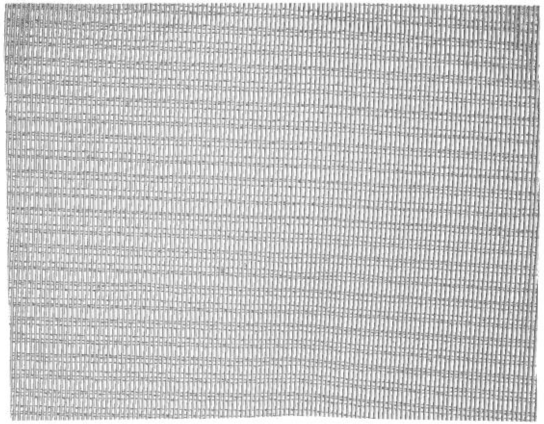
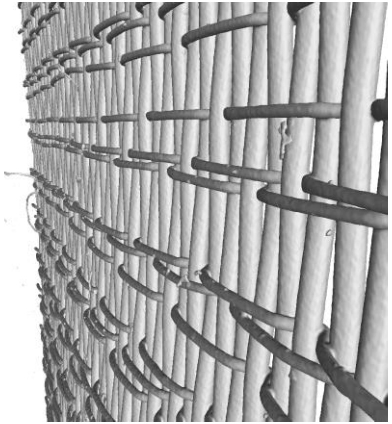
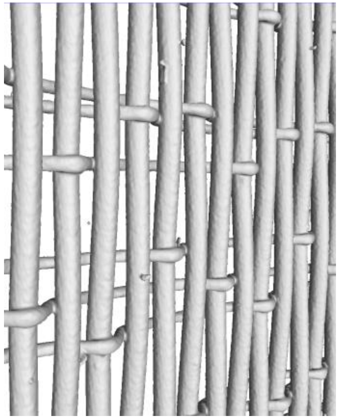
- Computation of center lines and cross-section of yarns using 3D analysis software Avizo Software for Industrial Inspection.
  - ➢ New possibilities to generate micro/meso simulation models for numerical computions (FEM, CFD) out of best quality µCT-3D-models.

Bilateral collaboration between DITF & Thermo Fisher Scientific (P. Westenberger):







Fabric out of monofilaments: CT-scan 16,5 mm x 20,9 mm, resolution 7,5 µm

4. New Possibilities of µCT getting fabric models out of 3D-CT-model

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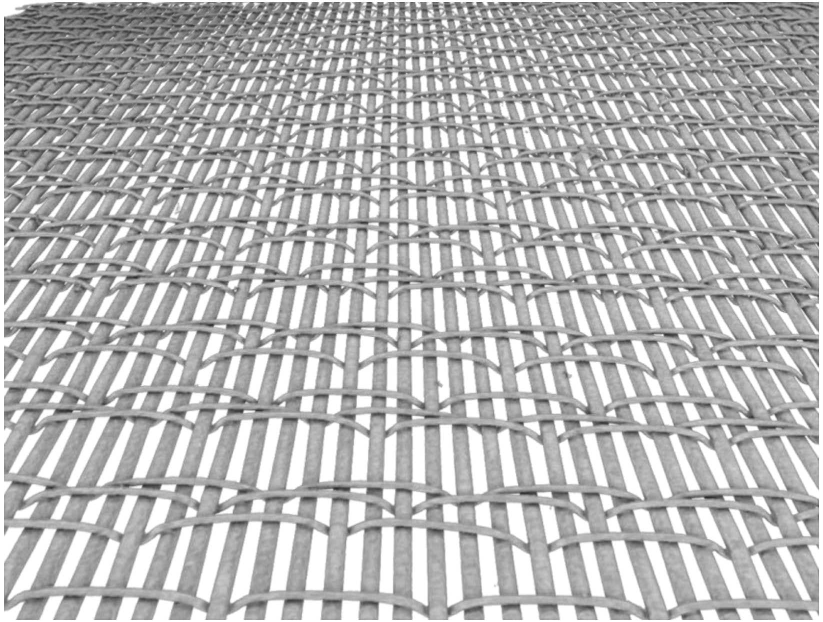
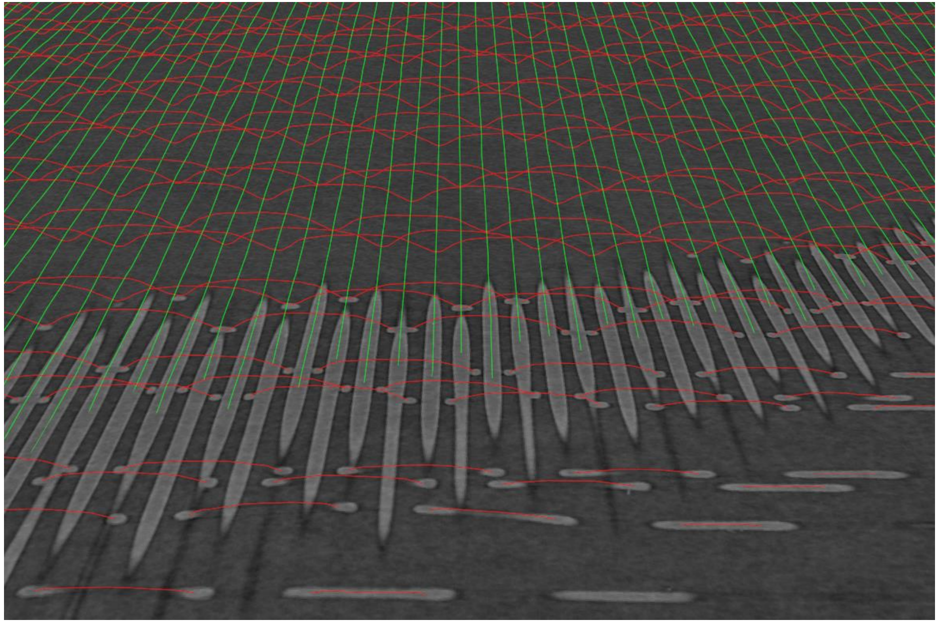
Bsp.: fabric consisting of monofilaments





Computation of center lines and thread models using 3D analysis software Thermo SCIENTIFIC Avizo

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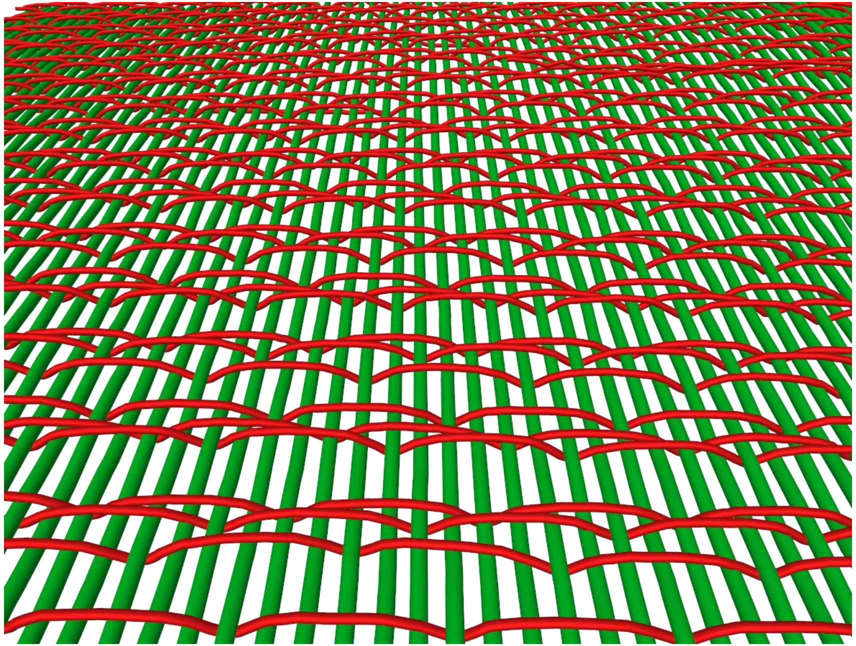
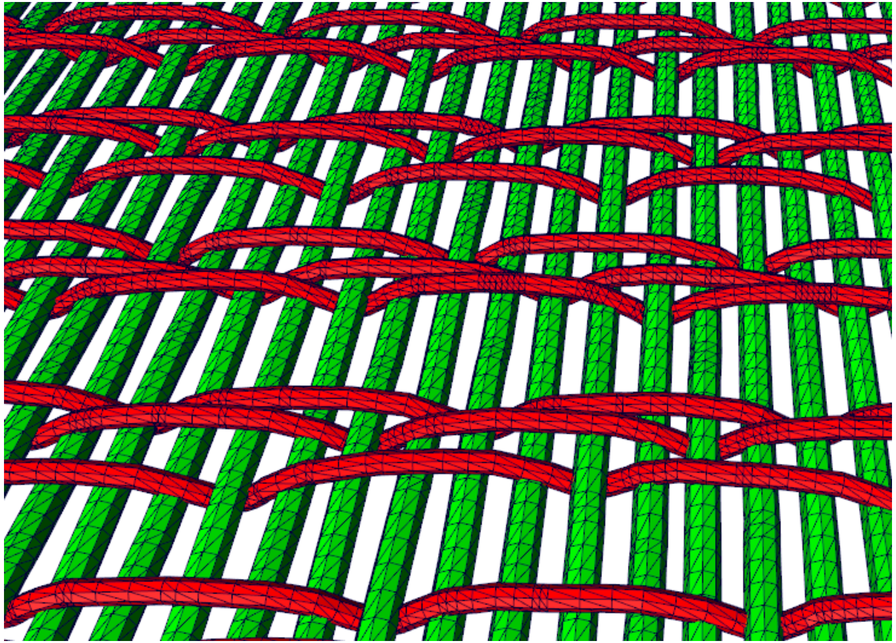
4. New Possibilities of µCT getting fabric models out of 3D-CT-model

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

Bsp.: fabric consisting of monofilaments



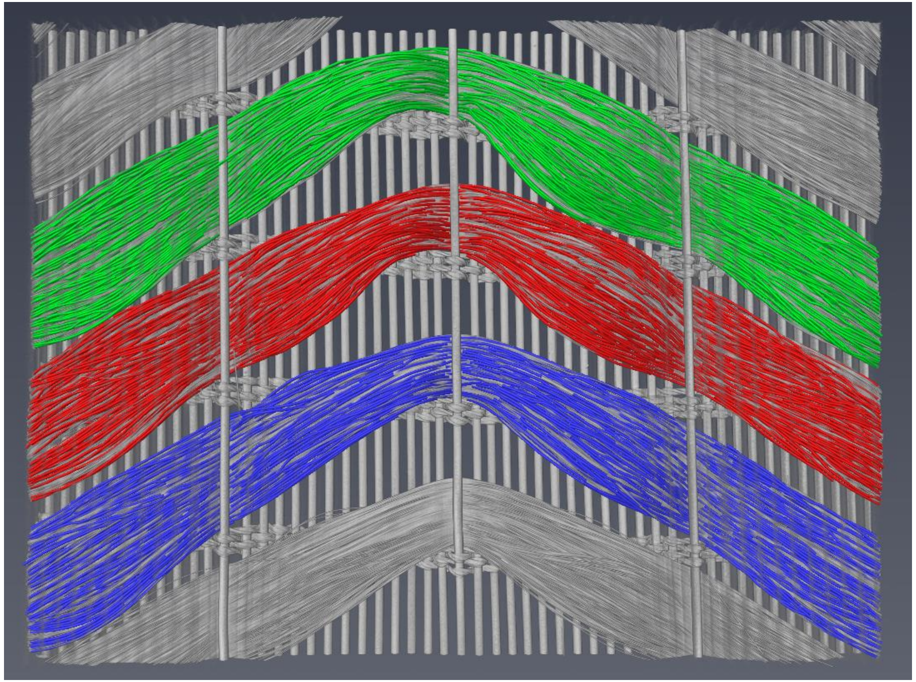


Computation of center lines and thread models using 3D analysis software Thermo SCIENTIFIC Avizo

4. New Possibilities of µCT getting fabric models out of 3D-CT-model

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

Bsp.: fabric with local reinforcement threads out of multifilament yarns (ORW)-fabric



Computation of center lines and thread models using 3D analysis software Thermo SCIENTIFIC Avizo

4. New Possibilities of µCT getting fabric models out of 3D-CT-model

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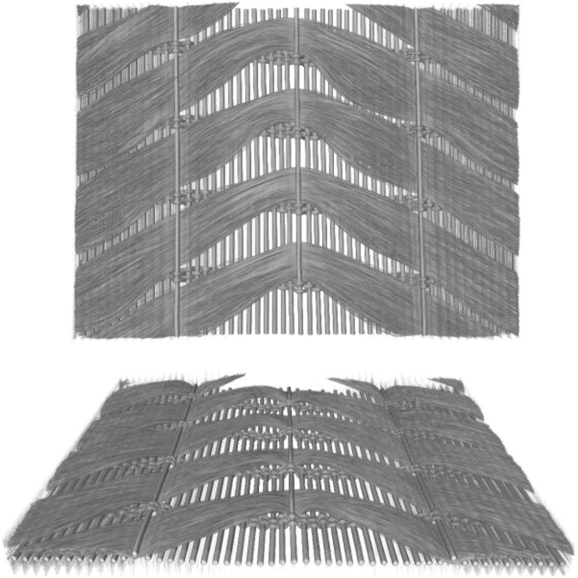
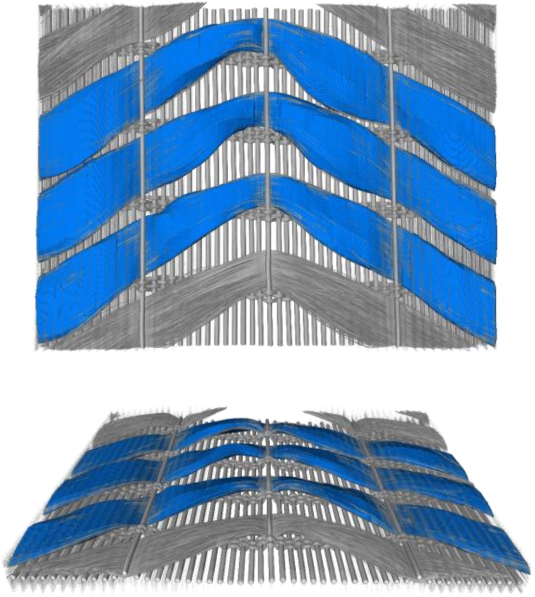
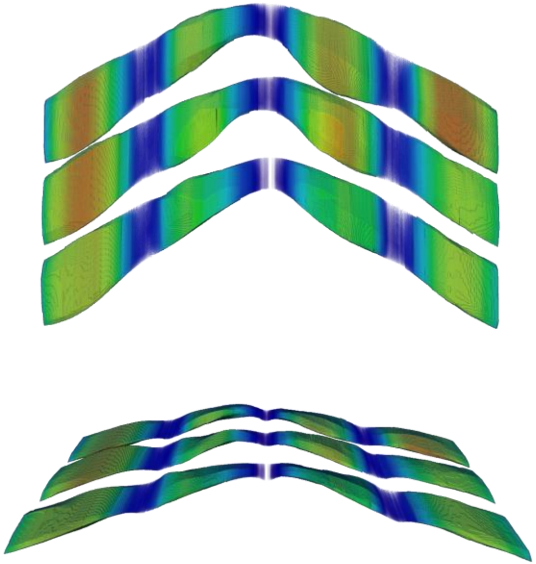
Bsp.: fabric with local reinforcement threads out of multifilament yarns (ORW)-fabric



µCT-mode of ORW fabric



Computation of thread surface

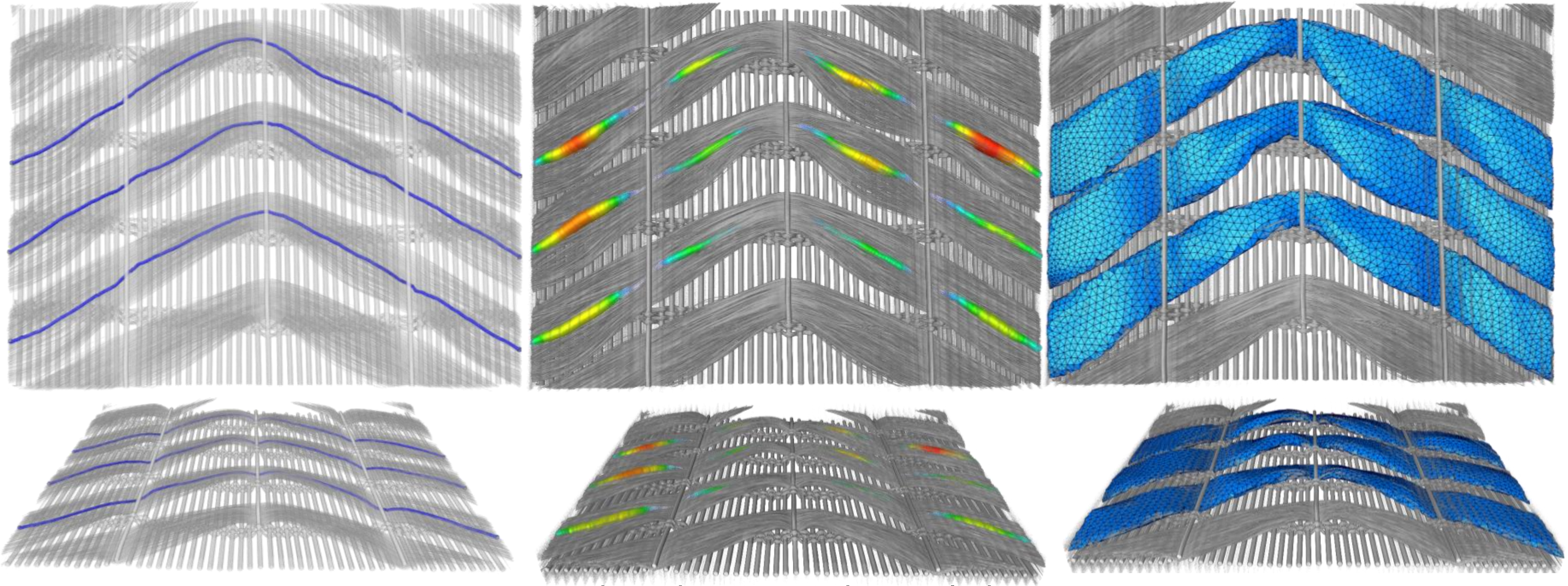


Cross-section area displayed in colors

Computation of surface of multifilament ORW-threads models using 3D analysis software Thermo SCIENTIFIC Avizo

4. New Possibilities of µCT getting fabric models out of 3D-CT-model

Bsp.: fabric with local reinforcement threads out of multifilament yarns (ORW)-fabric

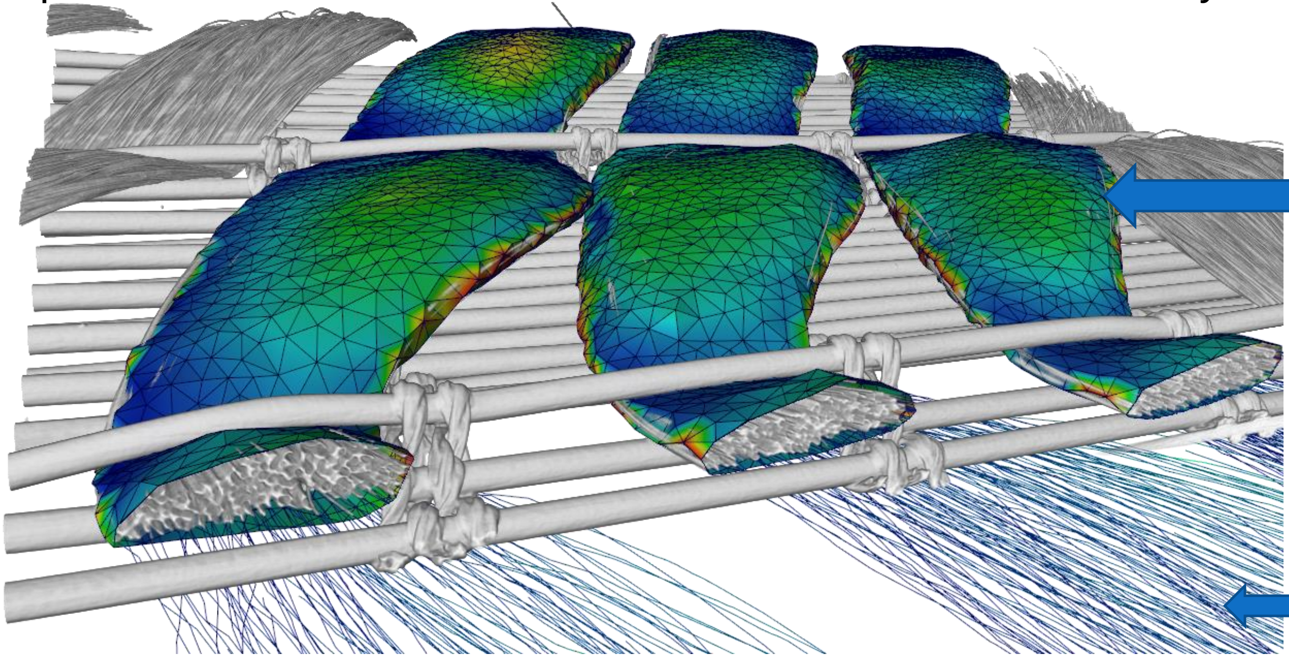


Computed center line | Thread cross-section scaled | Meshed thread surface

Computation of center lines and surfaces of multifilament ORW-threads and FE-modeling using Avizo

4. New Possibilities of µCT getting fabric models out of 3D-CT-model

Bsp.: fabric with local reinforcement threads out of multifilament yarns (ORW)-fabric



Surface model can be used for flow simulations

Reinforcement multifilament thread

Computation of center lines and surfaces of multifilament ORW-threads and FE-modeling using Avizo

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4. New Possibilities of µCT getting fabric models out of 3D-CT-model

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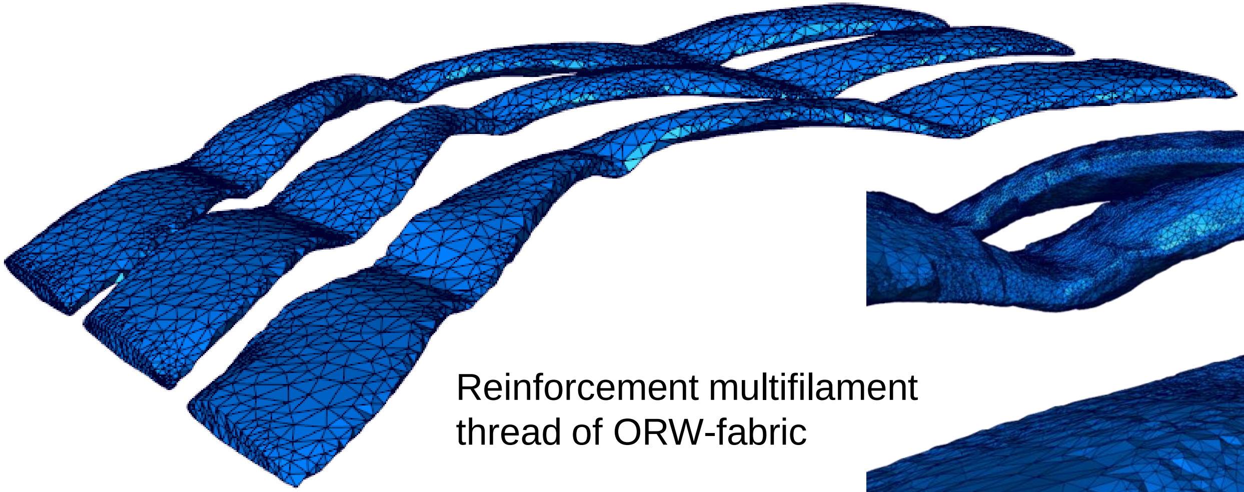
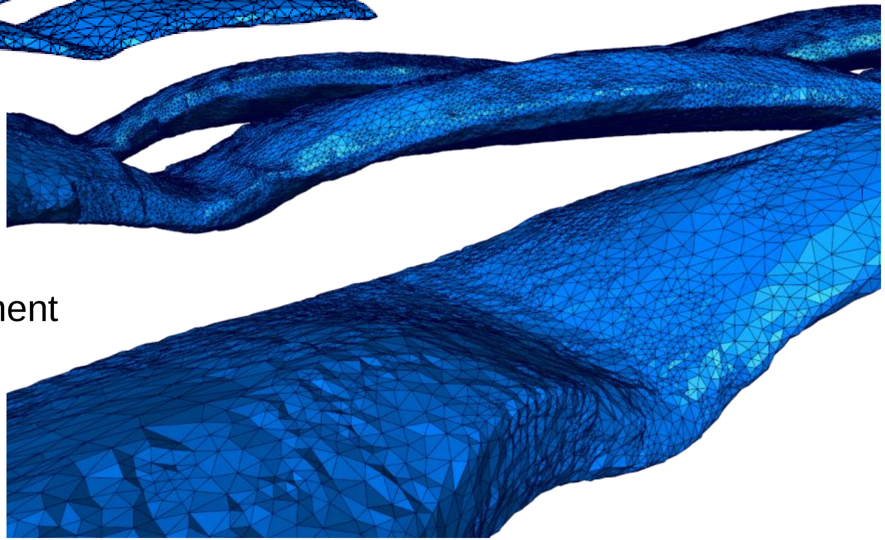
Bsp.: fabric with local reinforcement threads out of multifilament yarns (ORW)-fabric





Reinforcement multifilament
thread of ORW-fabric

In progress

FE-model of mulitfilament threads meshed by tetrahedra volume elements (coarse & fine) using Avizo

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5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

An important field of application could not be developed until now:
the high resolution CT analysis of loaded sample

Exact information about:

- How does the sample react unter tensile, compression, bending and torsion over the whole dimensions?
- What are the local displacements, transversal contraction from loading stage to next loading stage? ➡ 3D-strain analysis possible
- What happens inside the sample (how does the failure start and grow)

➢ Load testing machine for µCT with highest precision and reiability required as CT scan last up to serveral hours, where no change in µm must not be caused by test device .

5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

ZIM Project:
Entwicklung flexibler, hochpräziser Prüfvorrichtungen zur definierten Probenbelastung im CT ohne Qualitätsbeeinflussung hochaufgelöster µ-CT-Scans

- Tensile
- Compression
- Bending
- Torsion …

Kammrath Weiss GmbH Spezialentwicklungen für die Mikroskopie & DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

ZIM Zentrales Innovationsprogramm Mittelstand

Gefördert durch: Bundesministerium für Wirtschaft und Energie aufgrund eines Beschlusses des Deutschen Bundestages

- Development of a load-testing-machine without any influence to scan quality (no parts except sample are in the x-ray).
- Force sensors are exchangeable for optimal adaption to application (up to 5kN).
- Integration in for µCT nanotom m (GE sensing & inspecting GmbH),
- Development of Hard- and Software.
- Also useable for a Computertomograph of another company.
- Easy build in and out of µCT.

5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

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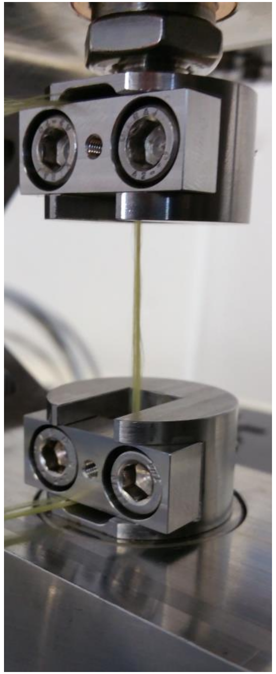
- Extreme stiff test stand which leads to 24 kg.
- Force acts symmetrically, as one travers moves up the other down.
- Interessing area of sample remains in focus.
- Force sensor easily exchangeable (10 N upt to 5 kN)
- 5kN (100N) resolution 1N (0,01N).
- Torsional sensor max. 3 Nm.
- 360° sample rotation by two indepentable driven rotation units.
- sample loading is adjusted exact by software and keeps konstant during whohle long-lasting CT-scan.
- Sample loading
  - Tensile & Compression load (speed: 0,1-20 µm/s, clamping length lo_{max}: 100mm, displacement 50mm at lo_{50mm})
  - Torsion (max. 360°)
  - Bending
  - Shearing (test device in development)

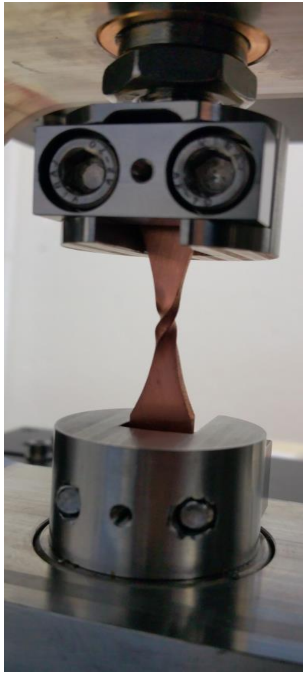
Developed prototyp of insitu-CT-load-testing-machine

5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

Built in and out the testing machine in the µCT using developed lifting device



Tensile load



Torsional load

5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

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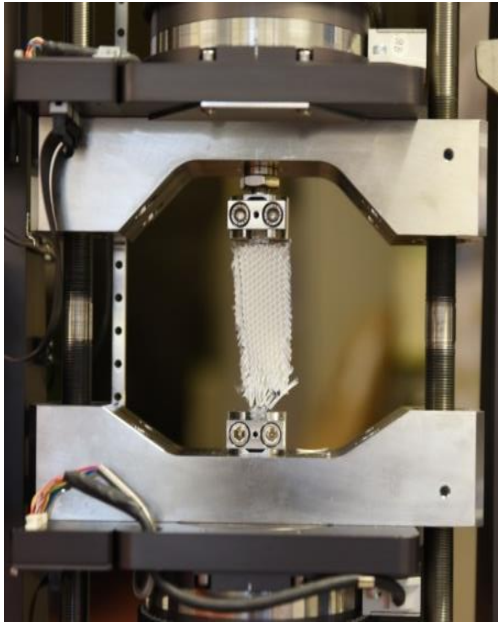
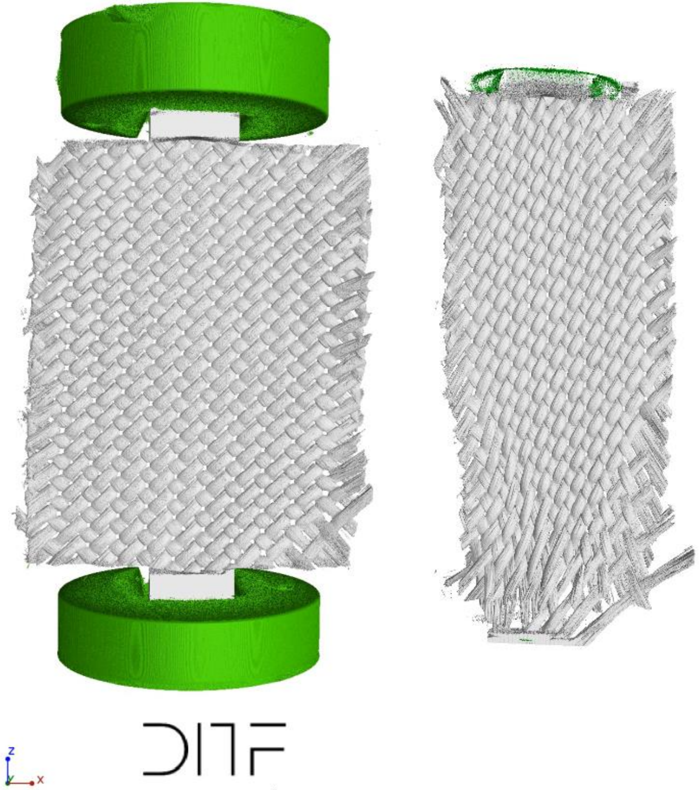
CT-Analysis of a woven fabric loaded at different tensile stages

- 8 CT-Scans: elongation
  0, 2, 5, 8, 13, 17, 22, 25%
- Fabric orientation: ±45°
- Sample width: 40 mm
- Clamping width: 10 mm
- Clamping length: 62 mm

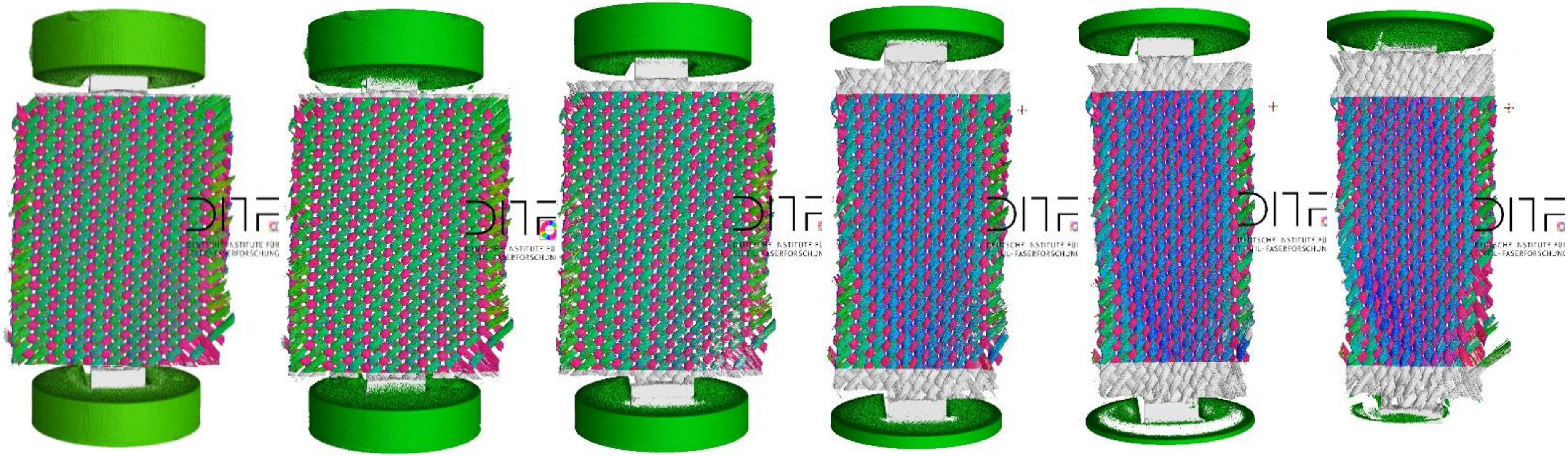


ORW Woven fabric out of glassfibre at 25% strain



5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

strain: 0% strain: 5% strain: 8% strain: 17% strain: 22% strain: 25%



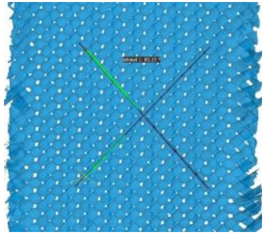
CT-Analysis of an Open Reed Woven (ORW)-fabric out of glasfiber rovings loaded at different tensile stages, color show fibre orientation angle

5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

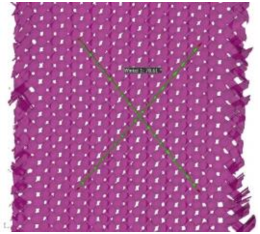
DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

CT-Analysis of a ORW-woven fabric loaded at different tensile stages

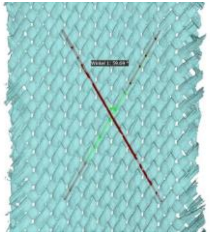
strain: 0%



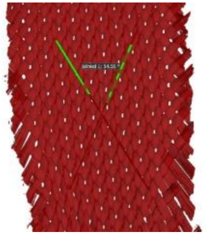
strain: 5%



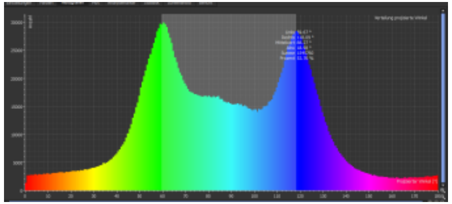
strain: 17%



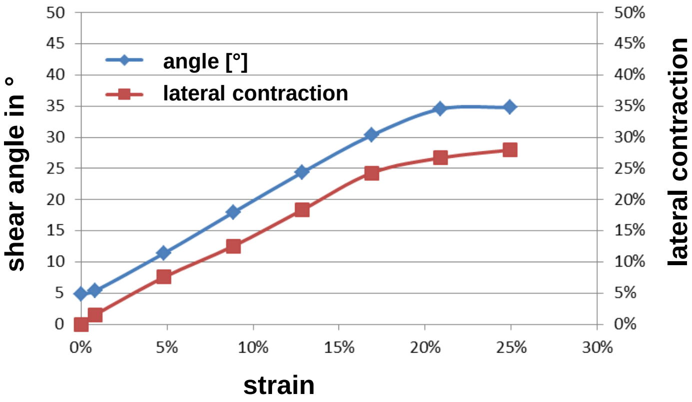
strain: 25%

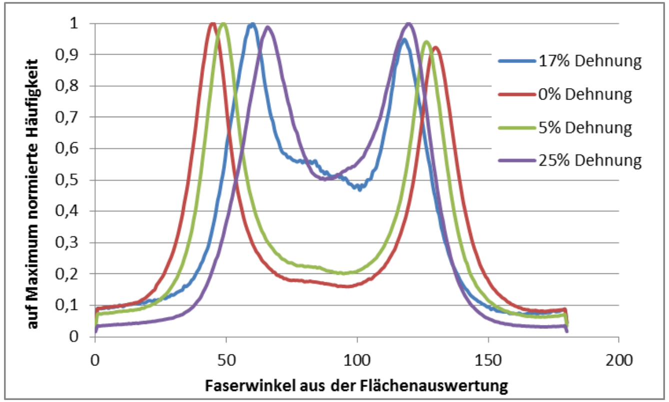


Histogramm of fibre angle distribution as an result of fiber orientation analysis



shear angle and lateral contraction over strain





5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

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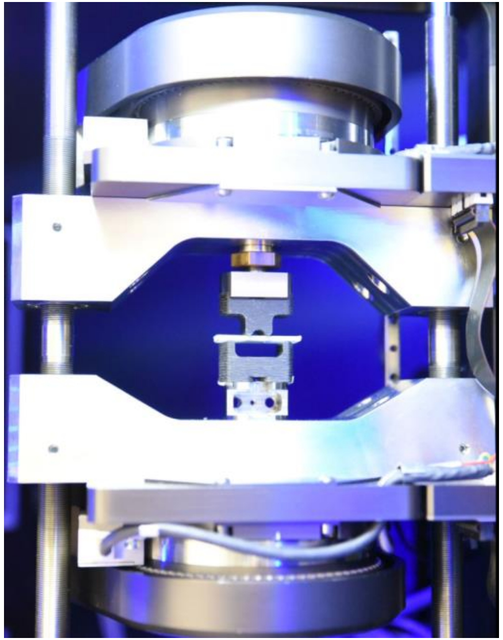
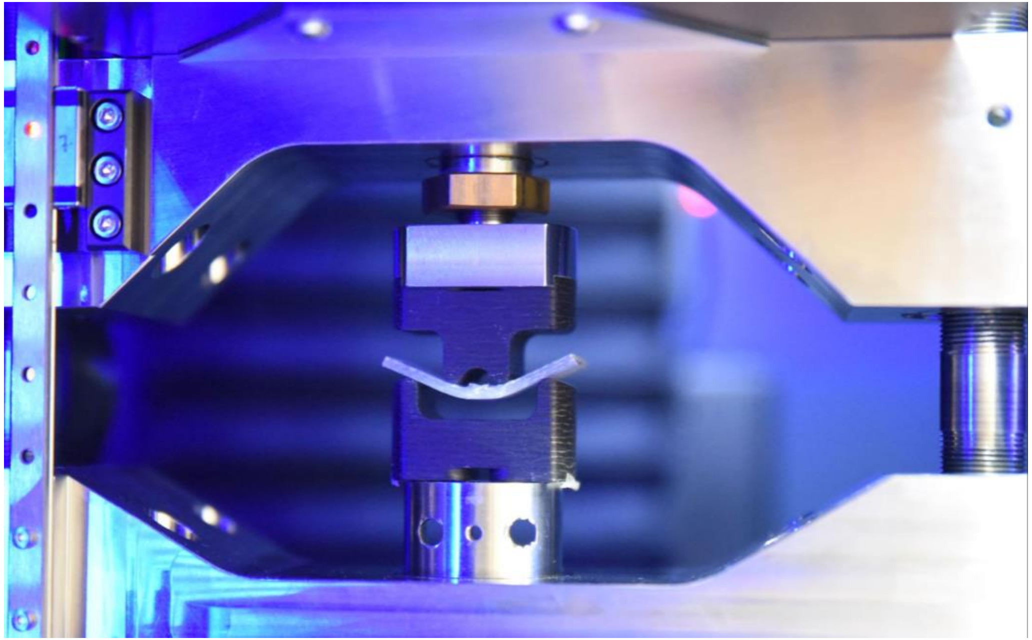
4-point bending test with composite made of 3 layers ORW-woven fabric



CT-Scan of unloaded composite



CT-Scan of loaded composite

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5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

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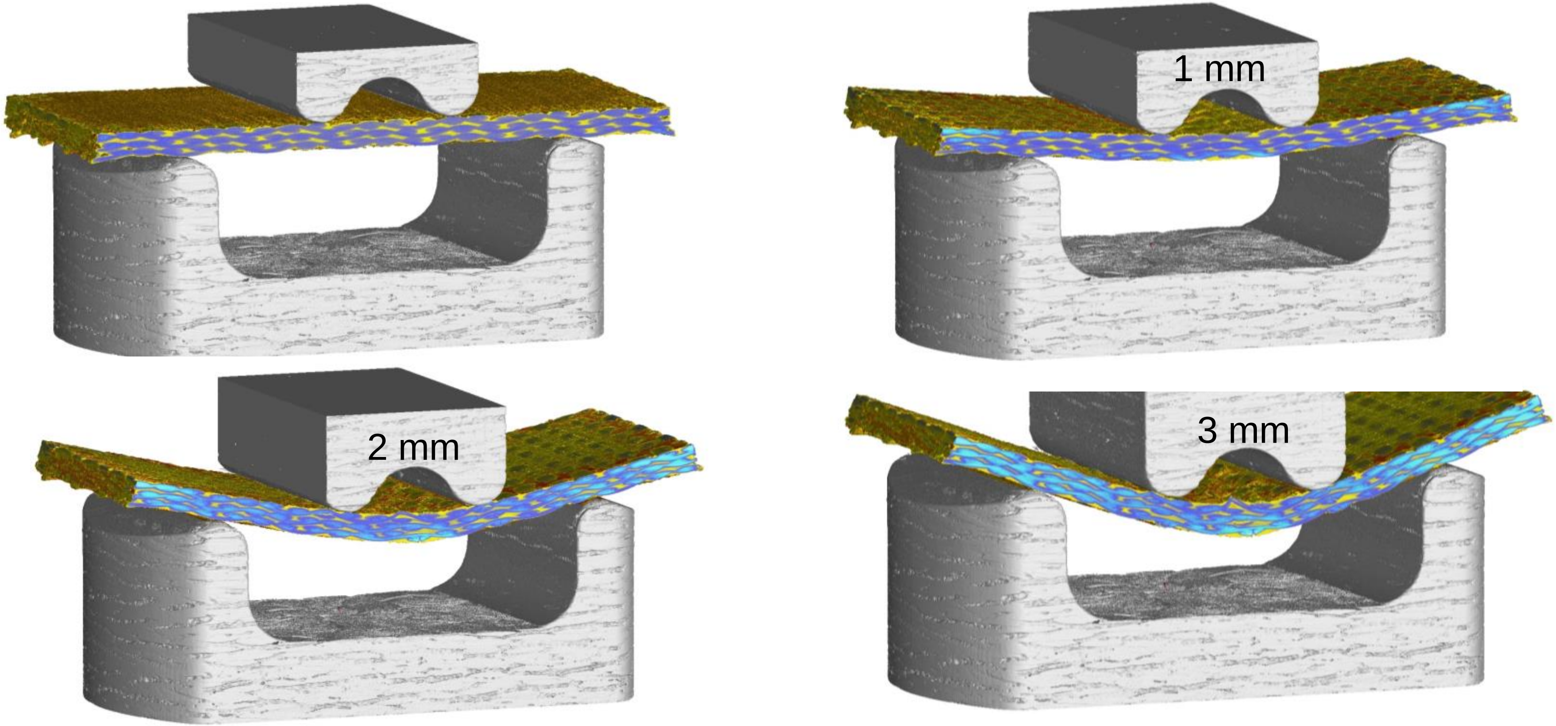

Analysis of four µCT-Scans: unloaded and at 1-3mm deflection of the sample

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5. New Possibilities of µCT using new developed insitu-CT-load-testing-machine

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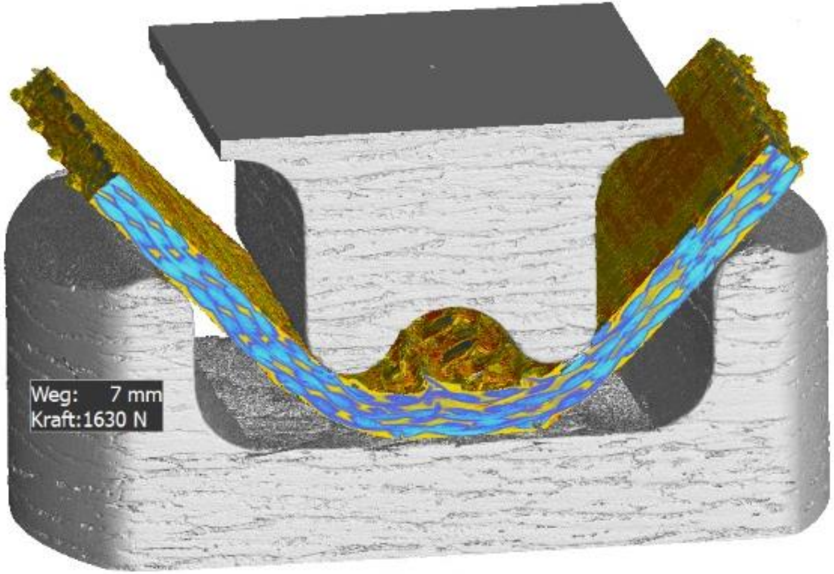

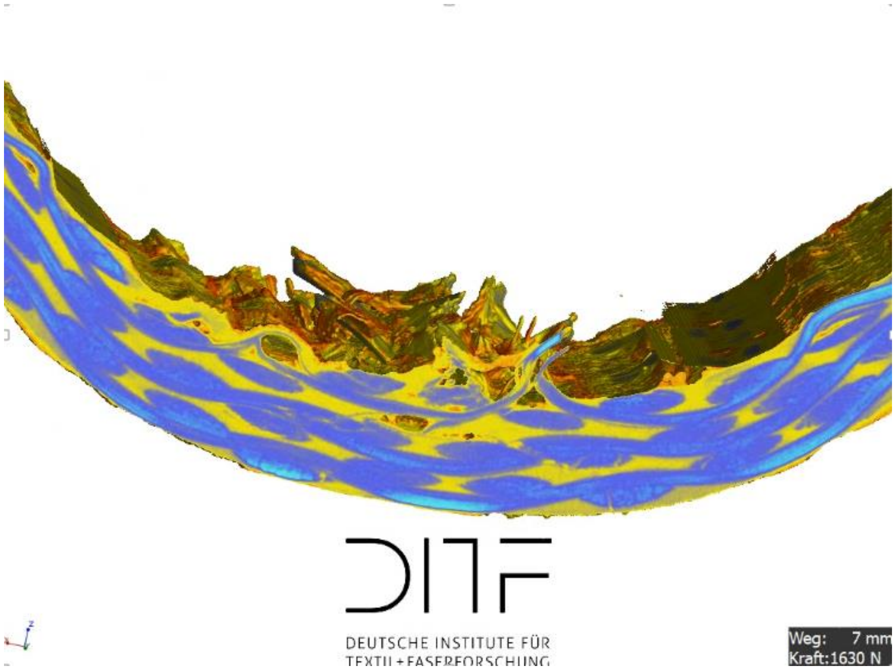

Danksagungen

DEUTSCHE INSTITUTE FÜR TEXTIL+FASERFORSCHUNG

- Die Entwicklung der insitu-CT-Belastungsprüfvorrichtung wurde wurden im Forschungsprojekt „ Entwicklung flexibler, hochpräziser Prüfvorrichtungen zur definierten Probenbelastung im Computertomograph (CT) ohne Qualitätsbeeinflussung hochaufgelöster µ-CT-Scans“: im Rahmen des ZIM Projekts, über die AiF Projekt GmbH als Projektträger des BMWi betreut. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt beim Autor.” Wir danken für die finanzielle Förderung des Forschungsvorhabens.

AiF

Gefördert durch:
Bundesministerium für Wirtschaft und Energie
aufgrund eines Beschlusses des Deutschen Bundestages

ZIM Zentrales Innovationsprogramm Mittelstand

- Die unter ARENA2036 DigitPro vorgestellten Arbeiten wurden im Forschungsprojekt „DigitPro“ im Rahmen des Forschungscampus ARENA2036 durchgeführt. Dieses Forschungs- und Entwicklungsprojekt „DigitPro“ wird mit Mitteln des Bundesministeriums für Bildung und Forschung (BMBF) im Forschungscampus „ARENA2036“ *(02PQ5011)* gefördert und vom Projektträger Karlsruhe (PTKA) betreut. Die Verantwortung für den Inhalt dieser Veröffentlichung liegt beim Autor.” Wir danken für die finanzielle Förderung des Forschungsvorhabens.

PTKA Projektträger Karlsruhe
Karlsruher Institut für Technologie

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

FORSCHUNGS CAMPUS
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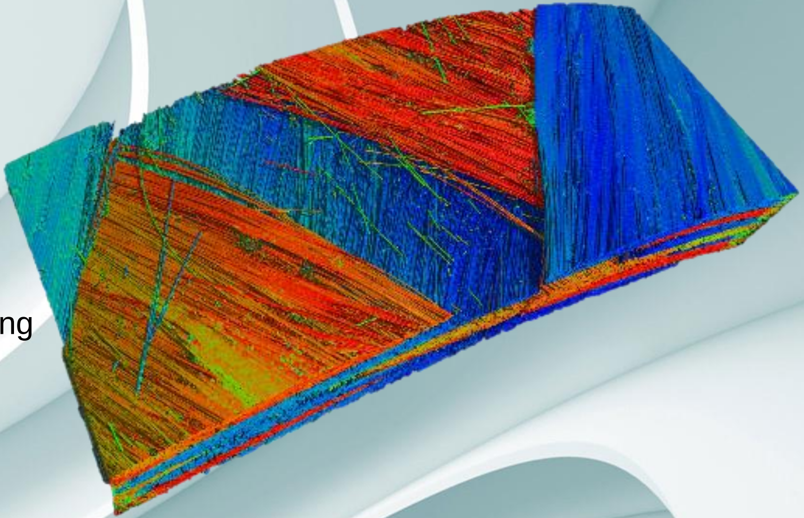

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