Using the local fiber orientation and fiber to volume fraction in µCT data to improve the simulated failure location and strain at break of Long Fiber Thermoplastic (LFT) parts.

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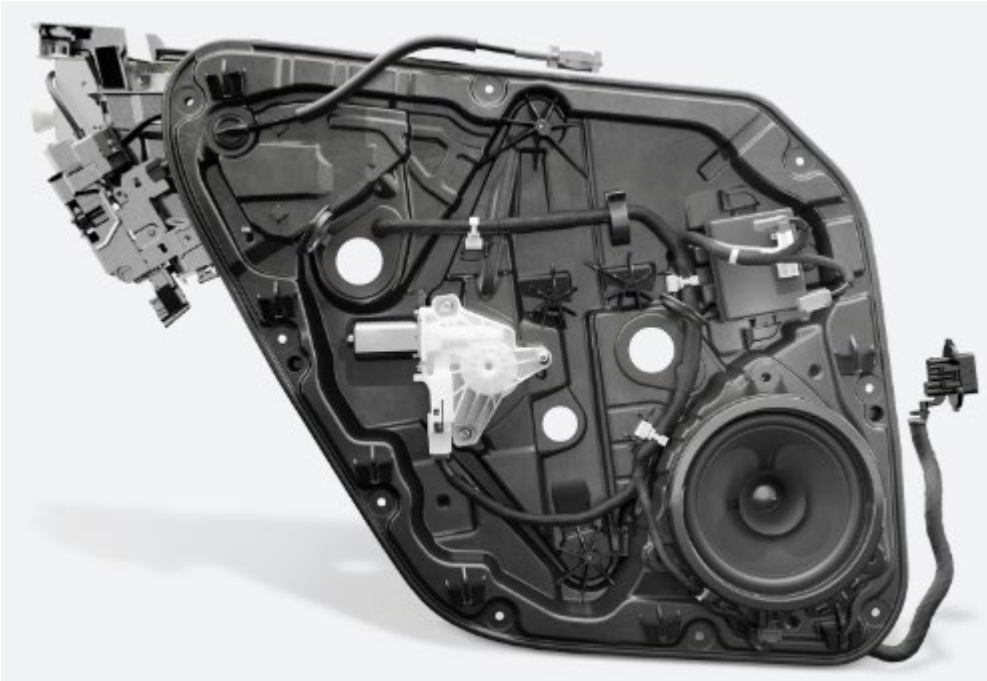
Objective

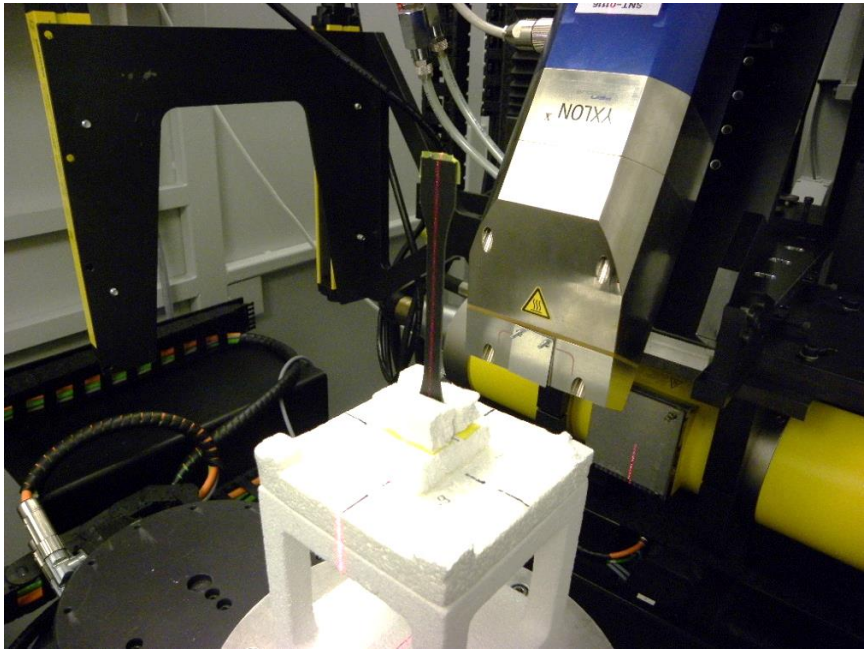


- Thermoplastic composites parts for automotive interior components (glass fabric reinforced with complex structure)
- Injection molded
- Subject to mechanical loads
- Mechanical simulation based on simulated fiber orientations does not match well with test results

Objective: Improve Mechanical Simulation by using Measured Fiber Orientations

Initial CT Scans (at Brose)

- Tensile specimen
  - Height: 150 mm
  - Width: 10 mm
  - Thickness: 1.8 mm
- Positioning of the tensile specimen with a polystyrene holder
- Complete tensile specimen was scanned **two** times in **seven** sub-scans (resolution: **12.5 *µm*; 50 µm**)
- Total scanning time: **30 h**
- Difficulty: **stability of the x-ray-tube over a period of 30 h**

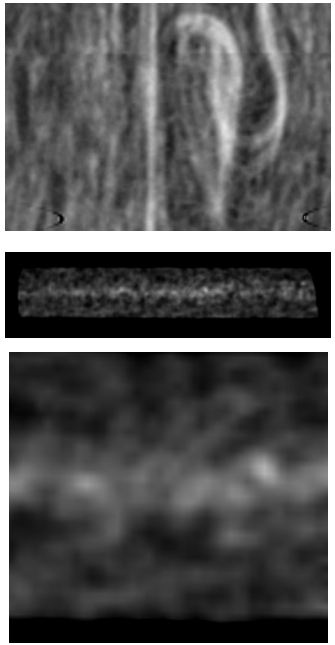


Final CT Scans (at DITF)

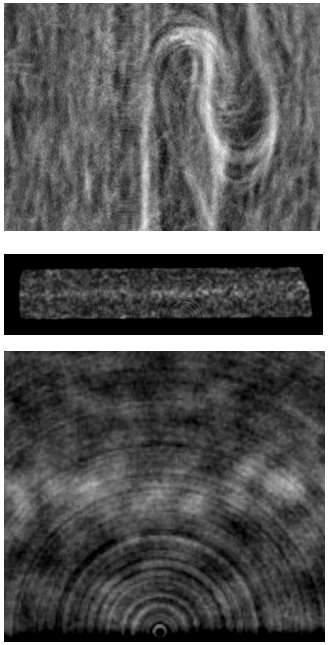
- Positioning of the tensile specimen with a mounting
- Dimensions of the tensile specimen:
  - Height: 150 mm
  - Width: 10 mm
  - Thickness: 1.8 mm
- Complete tensile specimen was scanned in **four sub-scans** (resolution: **12.5 µm**)
- Total scanning time: **8 h**
- Advantage of the CT at DITF:
  - **More modern scanner, designed for high resolution scans and analysis of fiber composite material**

Comparison of CT Scans

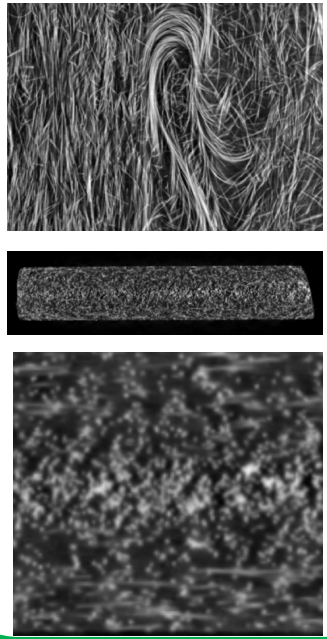
First Scan 50 µm
Brose, Low resolution



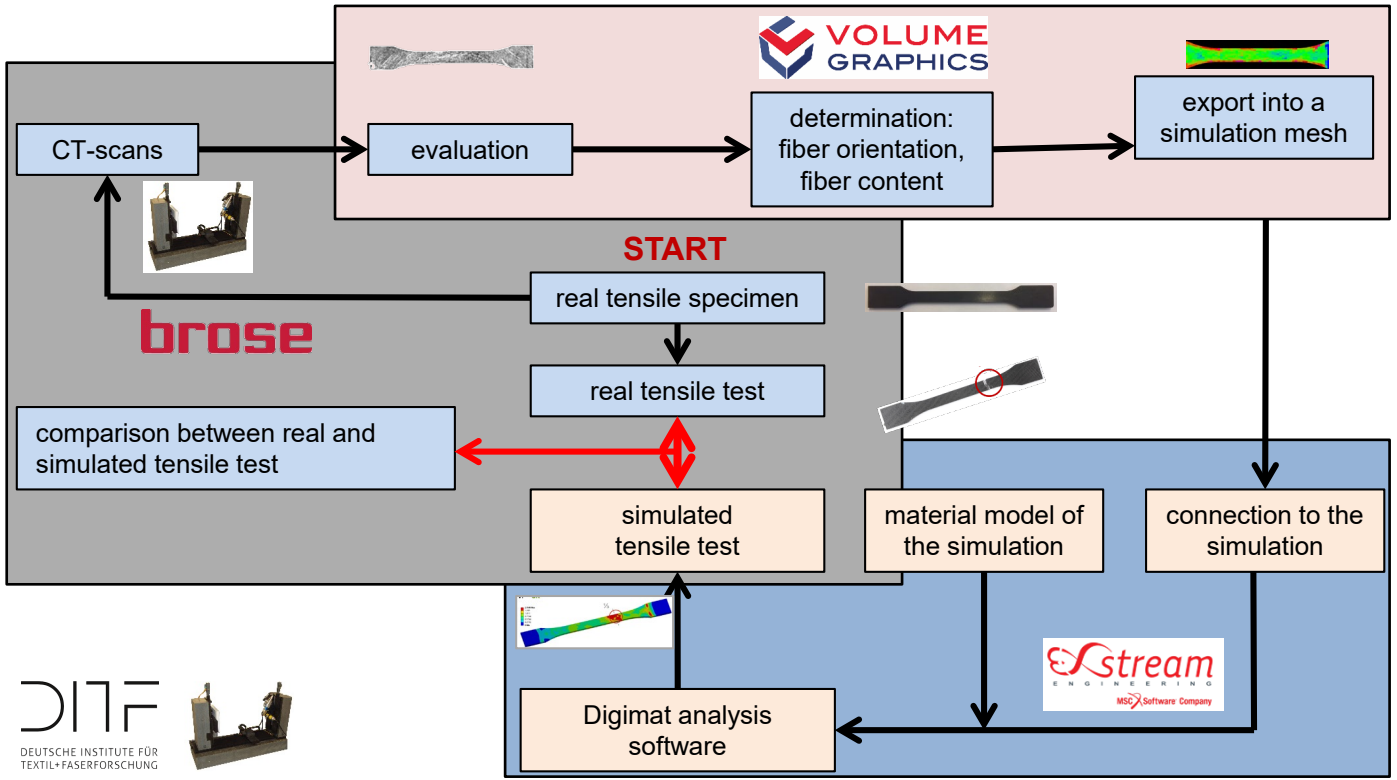
Second Scan 12,5 µm
Brose, High nominal resolution,
but noise and center artefacts



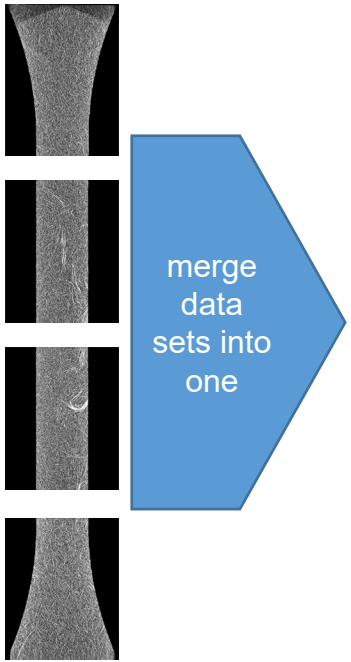
Third Scan 12,5 µm
DITF, High resolution,
low noise, no artefacts



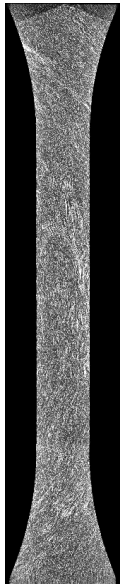
Overall Workflow



Analysis of CT Data using VG STUDIO MAX (1)



merge data sets into one

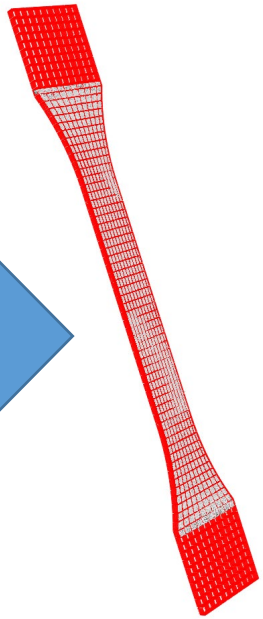


1 CT data set

register CT data, CAD and mesh into one coordinate system

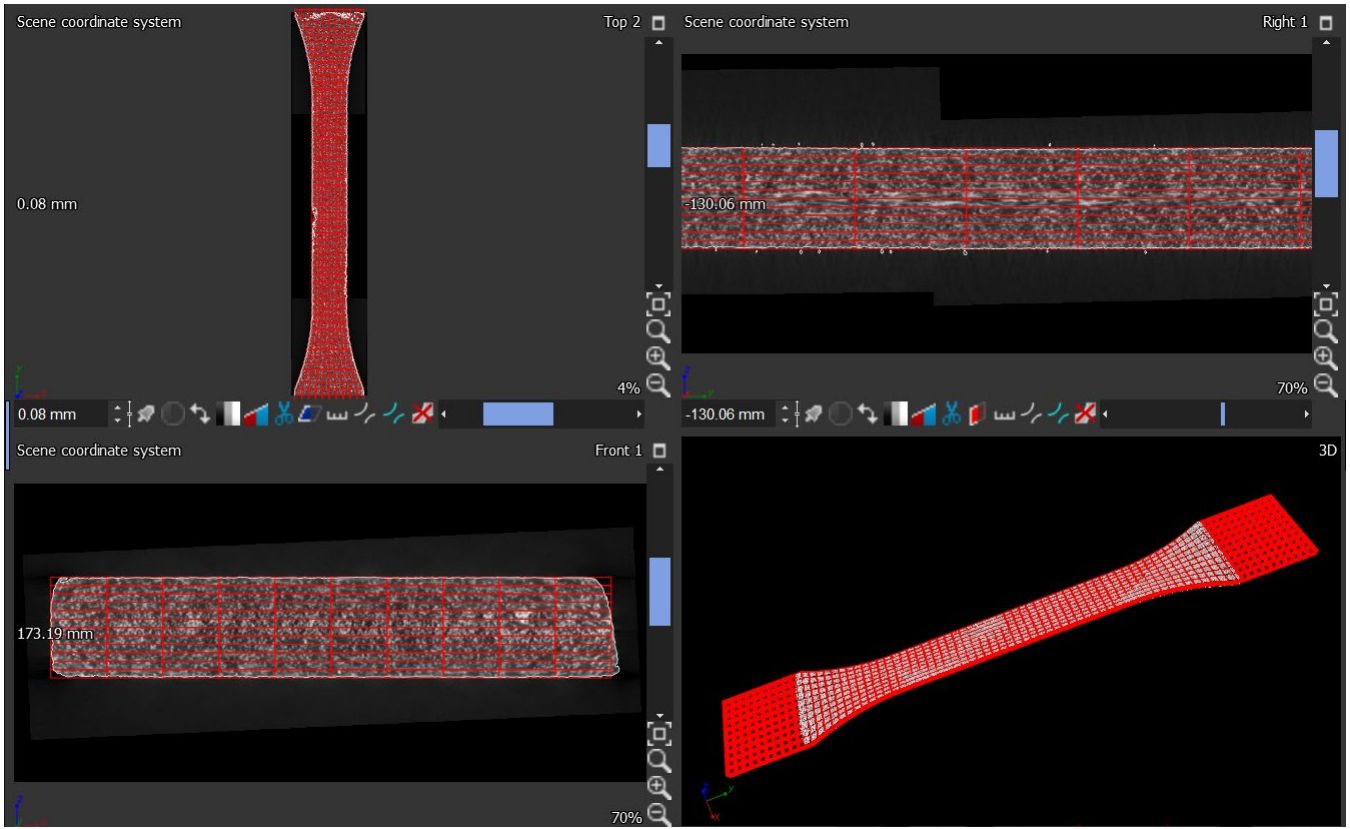
import CAD

import simulation mesh

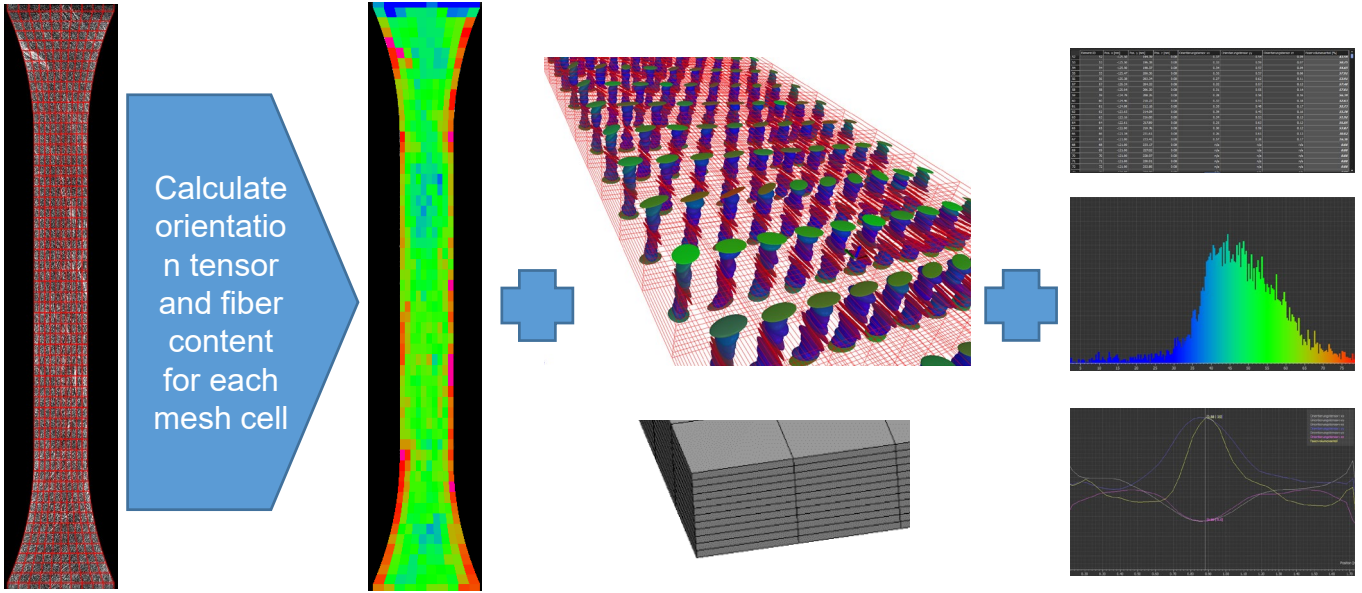


3D scene with CT data, CAD and mesh

CT Scan, CAD and Integration Mesh



Analysis of CT Data using VG STUDIO MAX (2)



false color coding of fiber content

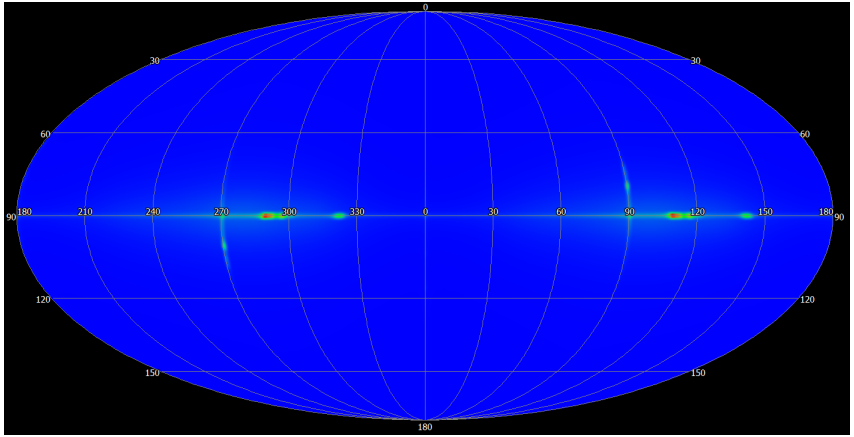
3D visualization of orientation tensor as ellipsoid

Tables, Histograms, Plots and many more

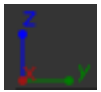
CSV Export of all results

Fiber Orientations (1): Overview

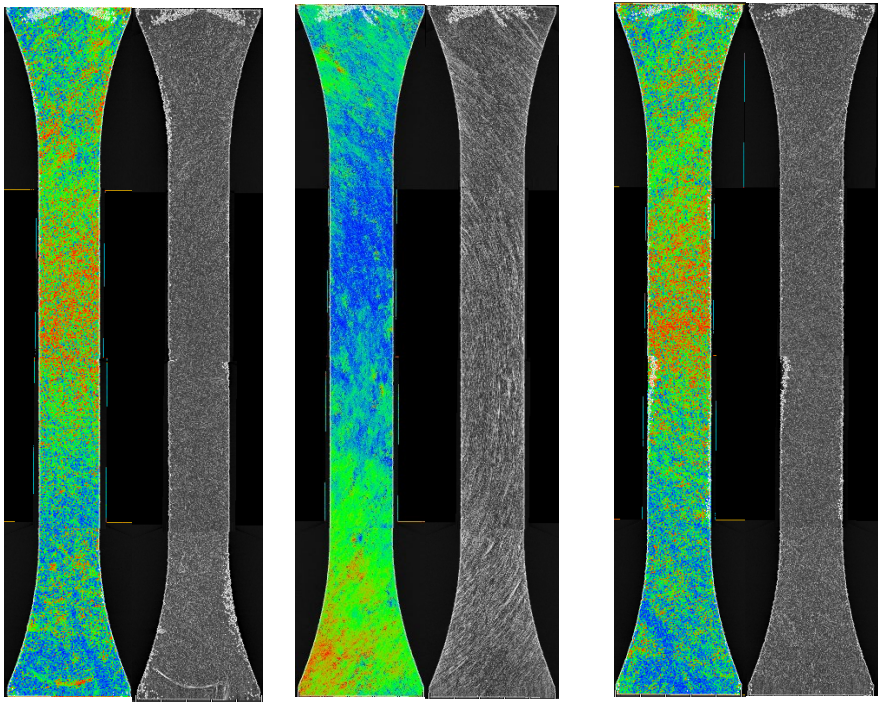
Orientation Histogram (Equatorial Plot)

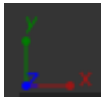


Colour code indicating frequency of fiber orientations
θ = latitude, peak 90 deg = xy plane
φ= longitude, peak 109 deg = 19 deg off y axis



Top **Middle** **Bottom**

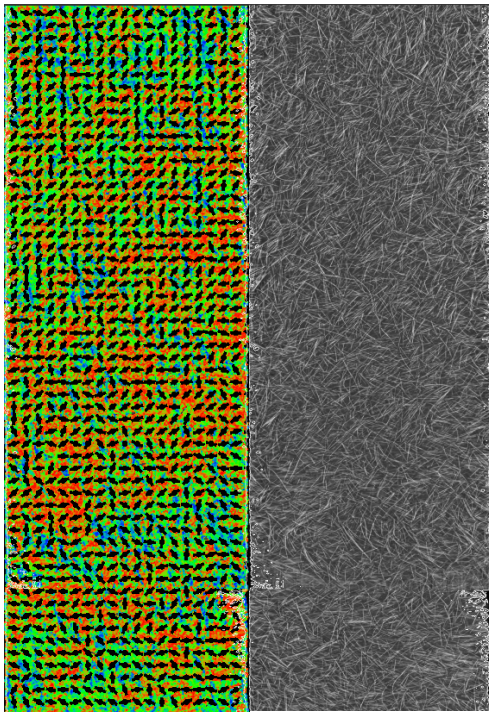




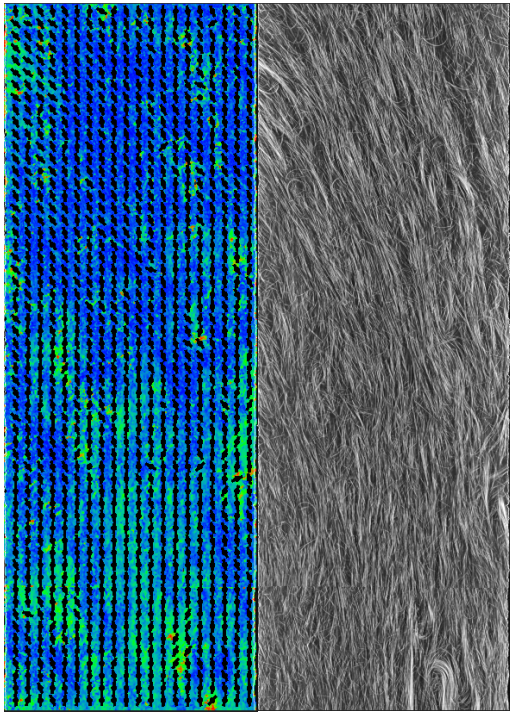
Color code indicating deviation from most frequent orientation
(blue = 0 deg, red = 90 deg)

Fiber Orientations (2): Critical Zone

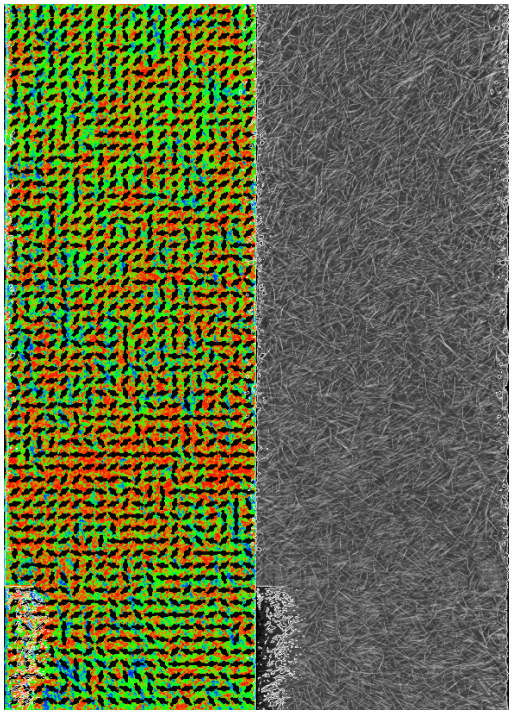
Top Layer (z = 1.73 mm)



Middle Layer (z = 0.84 mm)

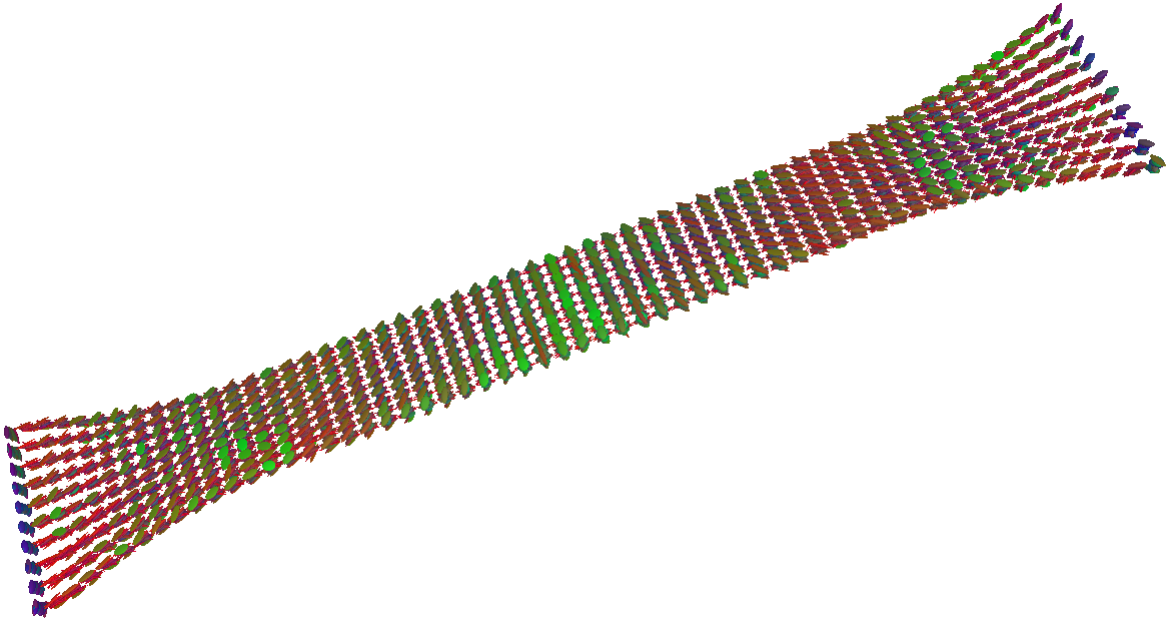


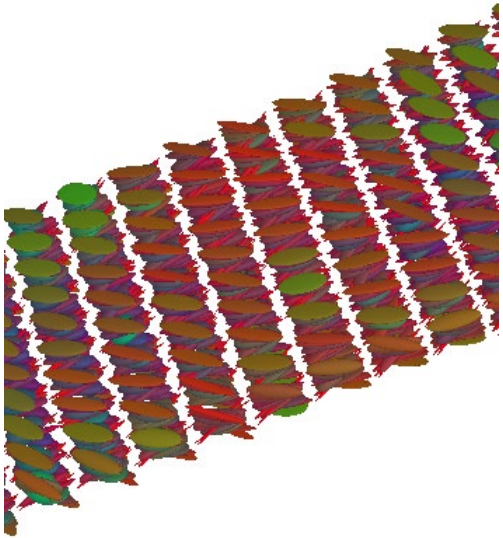
Bottom Layer (z = 0.08 mm)



Color code indicating deviation from most frequent orientation (blue = 0 deg, red = 90 deg)

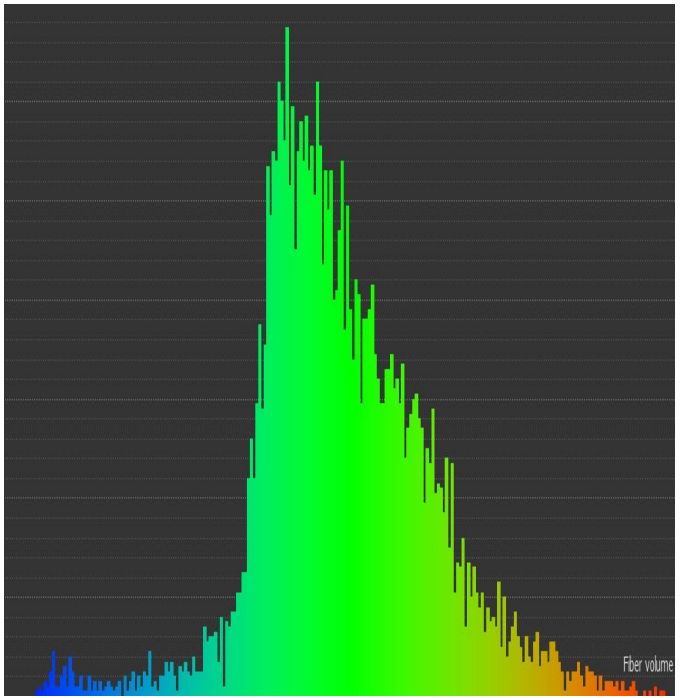
Fiber Orientations per Mesh Cell

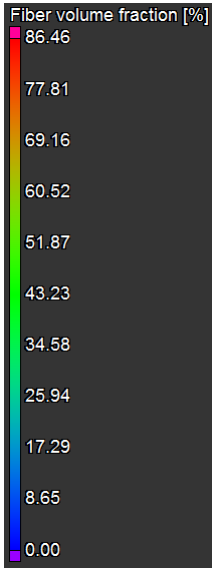




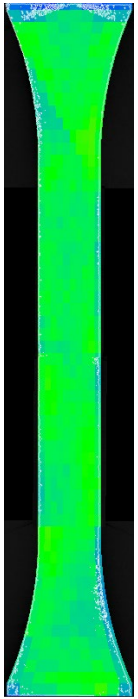
Fiber Volume Fractions per Mesh Cell

Histogram

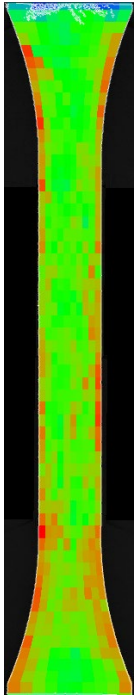




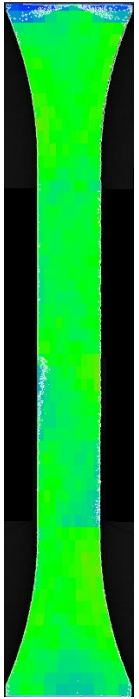
Top



Middle

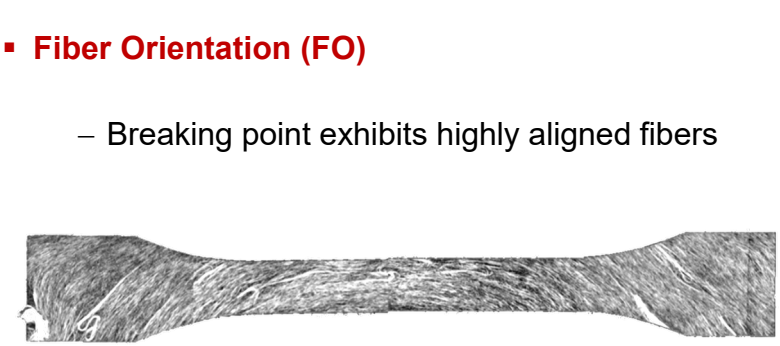


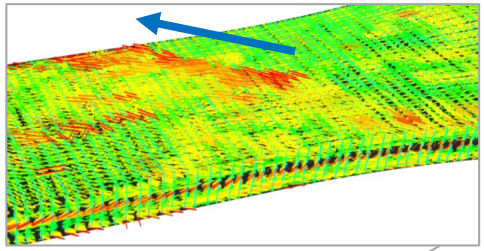
Bottom

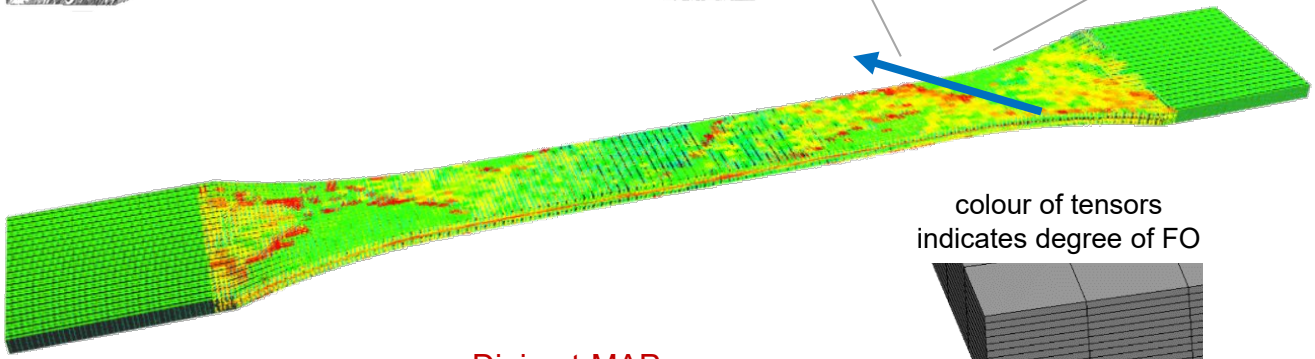


Fiber Orientations Imported to Digimat

- **Fiber Orientation (FO)**
  - Breaking point exhibits highly aligned fibers





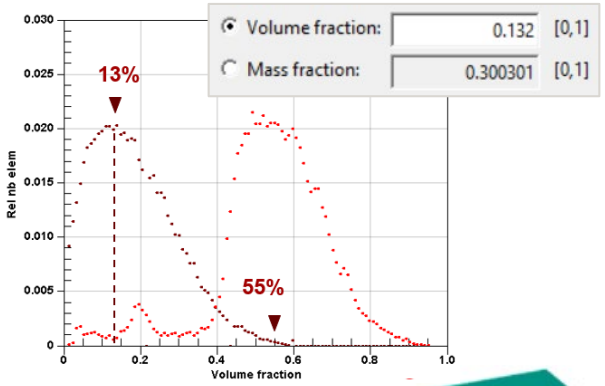


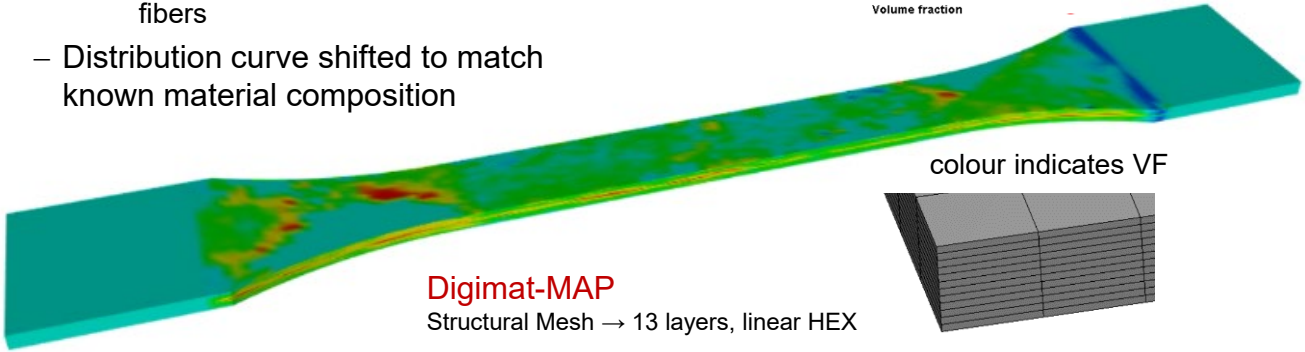
colour of tensors
indicates degree of FO

Digimat-MAP
Structural Mesh → 13 layers, linear HEX

Adjustment of the Meshed Fiber Volume Fraction

- **Volume Fraction (VF) of Fibers**
  - Distribution over tensile specimen
    - High values in middle layer
  - First over-estimation by CT
    - Due to CT resolution not sufficient to separate fiber bundles into individual fibers
  - Distribution curve shifted to match known material composition





colour indicates VF

Digimat-MAP

Structural Mesh → 13 layers, linear HEX

Multi-Scale Simulation

Micromechanical Simulation (Homogenization): Digimat-MF

Macro Simulation: Ansys

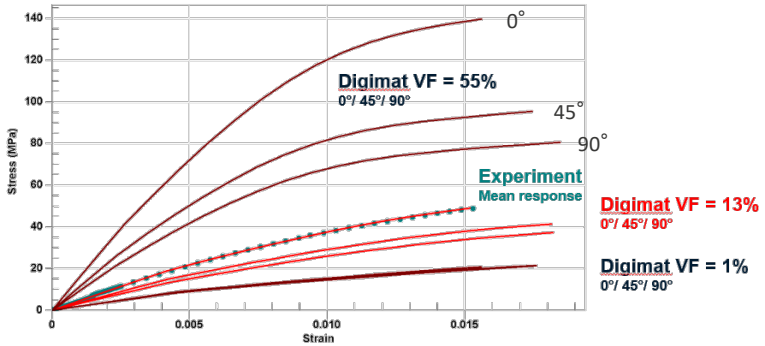
Single-phase Material Properties

- Thermoplast
- Fibers

Microstructure Morphology

- Fiber orientation
- Fiber volume fraction
- Fiber aspect ratio

Homogenized Material Model
as a function of fiber volume fraction and main orientation



Tensile Probe

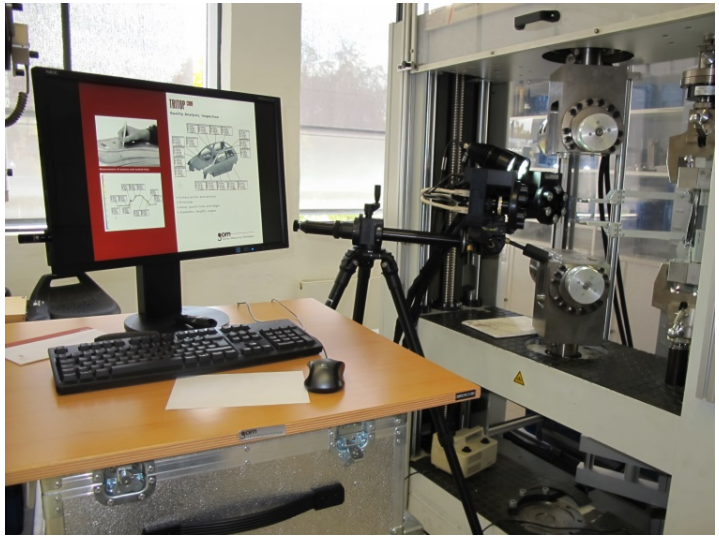
Input:

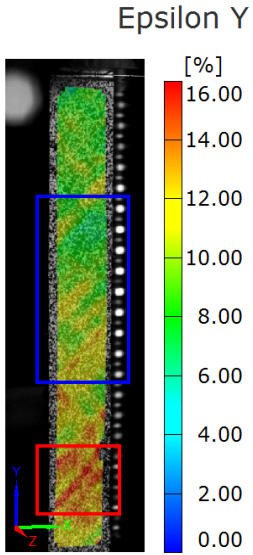
- Dimensions
- Material model per mesh cell
- Tensile force

Output:

- Local strains
- Local stresses
- Local failure indicator

Tensile Test with Optical Strain Measurement

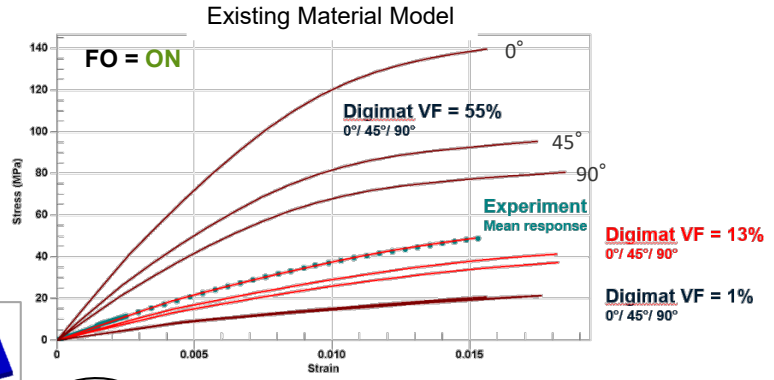


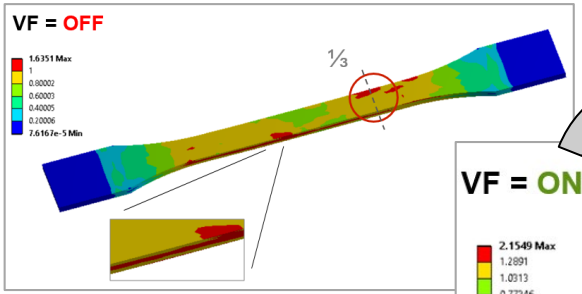


- Contactless and material independent measurement
- Optical 3-D-deformation- and video analysis
- Strain measurement in the measuring range from 0.01 % up to >100 %

Simulation vs. Experiment (1): Failure Location

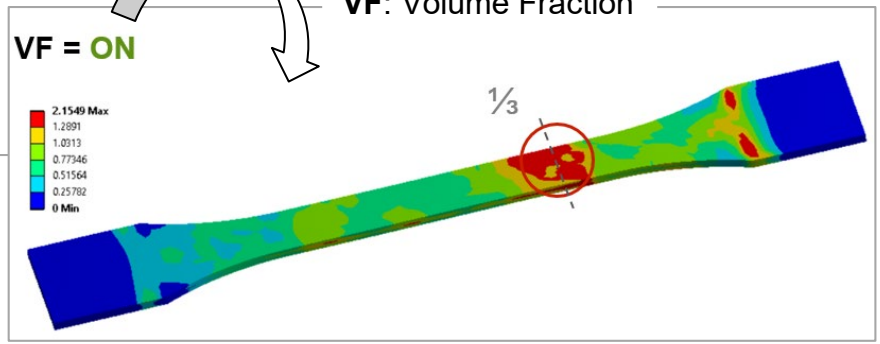
- **Failure**
  - **FO = ON**
  - Good prediction of **failure location** based on complete CT data





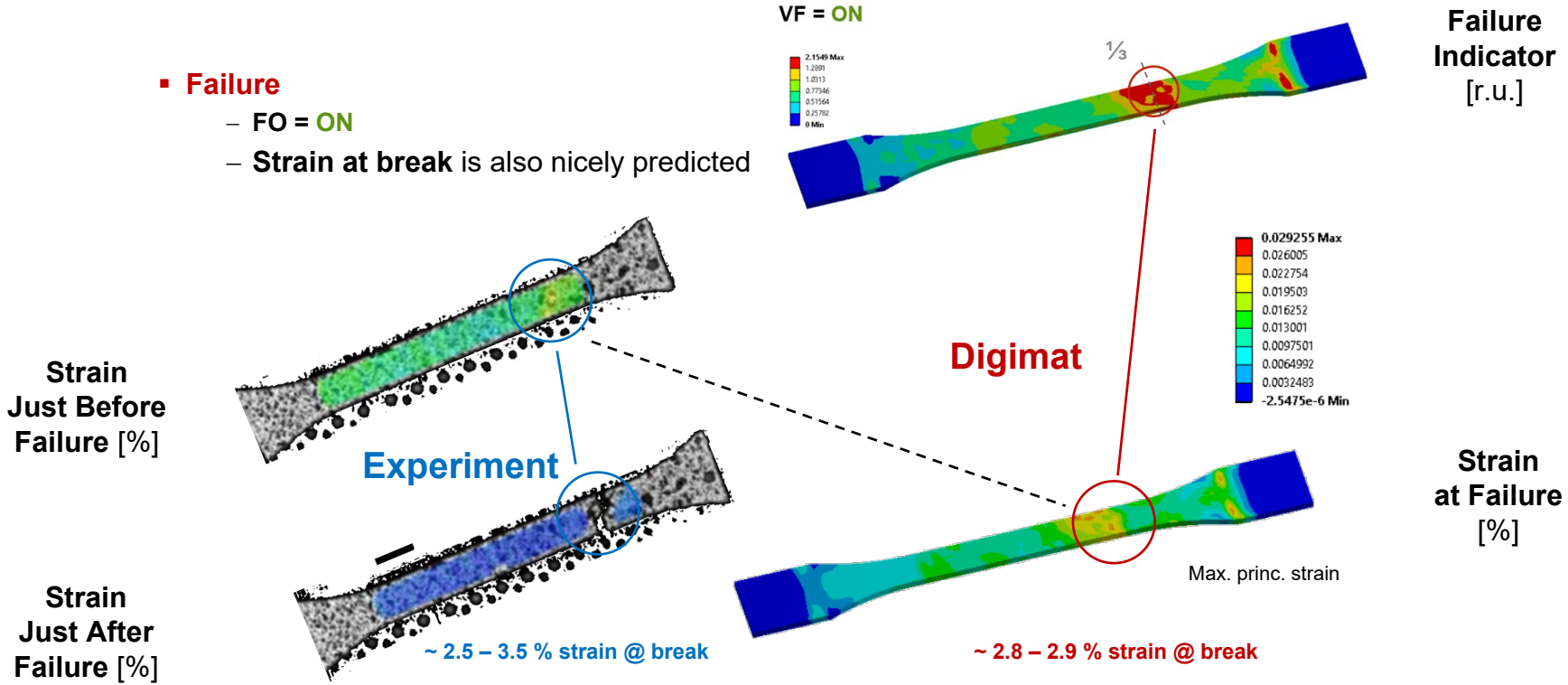
- Without VF failure still arises from the mid-plane

VF: Volume Fraction



Simulation vs. Experiment (2): Failure Strain

- **Failure**
  - **FO = ON**
  - **Strain at break** is also nicely predicted



Conclusion

> Simulation of the mechanical properties of LFT (long-fiber thermoplastics) components with complex structure requires an **empirical determination of material properties** on the basis of µ-CT

> For this purpose, µ-CT scans with **high geometric and high contrast resolution** are required

> Fiber orientations and fiber volume fractions were determined and mapped onto a volume mesh with VGSTUDIO MAX and exported to Digimat for mechanical simulation

> Accurate mechanical simulation allows to significantly **shorten the time** required for assessment of design or material alternatives **in the development process**

VOLUME GRAPHICS

Thank you