

# MICROMECHANICAL MODELING AND SIMULATION OF A MULTIFUNCTIONAL HYBRID COMPOSITE

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# What is GeoDict?

**GEO-DICT® IS**

**DATA-DRIVEN DIGITAL MATERIAL DESIGN**

**IN AN EASY-TO-USE SOFTWARE SOLUTION**

The innovative and easy-to-use material simulator GeoDict® is the most complete solution for multi-scale 3D image processing, modeling of materials, visualization, material property characterization, simulation-based material development, and optimization of processes.



# Core capabilities of GeoDict



MODEL & DESIGN MATERIALS



ANALYZE & SIMULATE MATERIAL PROPERTIES



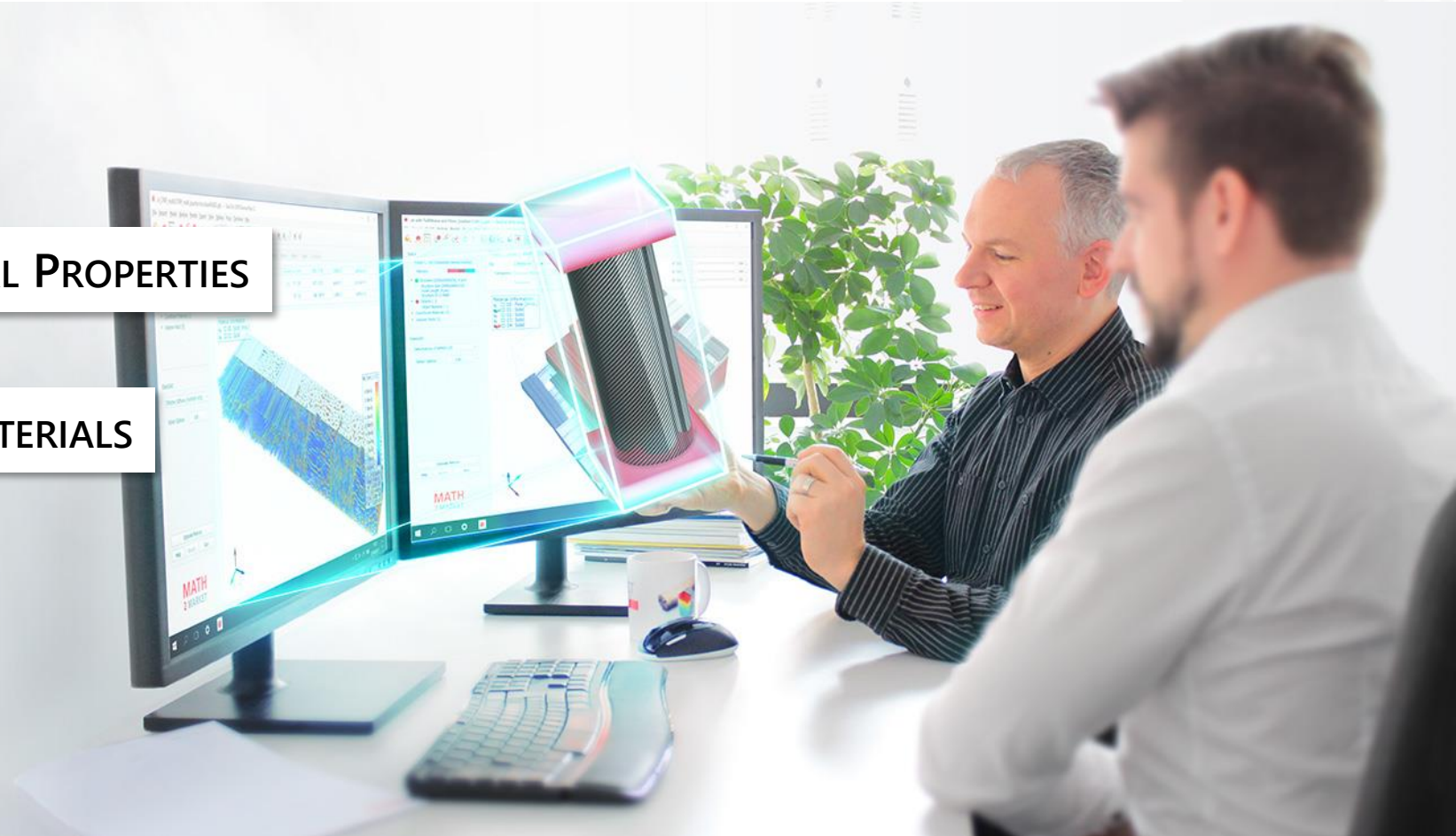
EXPLORE THE BEHAVIOR OF MATERIALS



DEVELOP NOVEL MATERIALS



OPTIMIZE PROCESSES



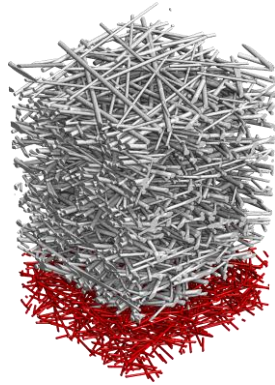
# The GeoDict Workflow

## IMPORT



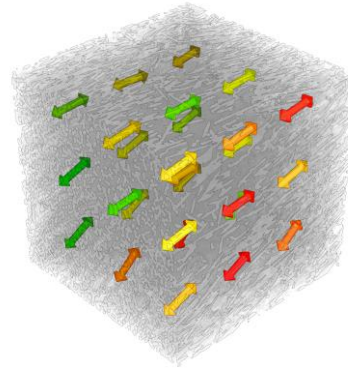
Diverse ways to import materials for modeling

## MODEL



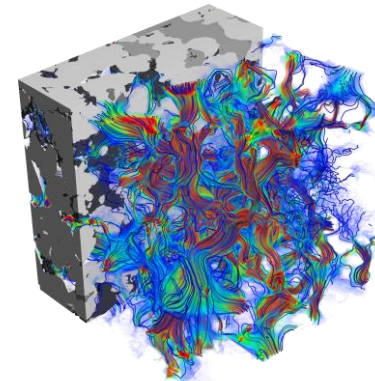
Detailed material models created in 3D

## ANALYZE



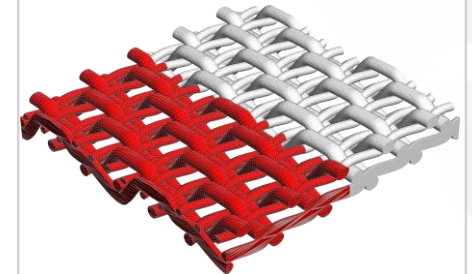
Extensive analysis and evaluation of structural material properties

## PREDICT



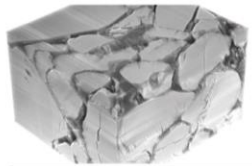
In-depth analysis and prediction of material behavior

## EXPORT

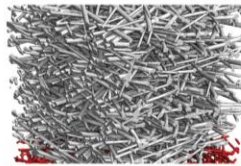
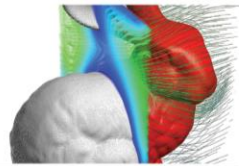
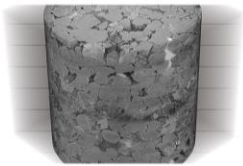


GeoDict models made available for standard workflows

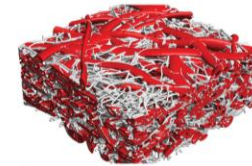
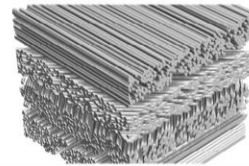
# GeoDict Module Overview



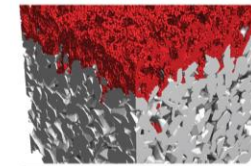
IMPORTGEO



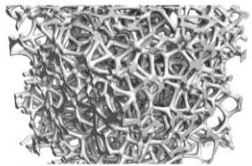
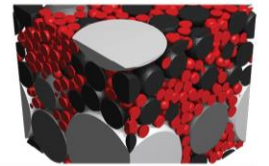
FIBERGEO



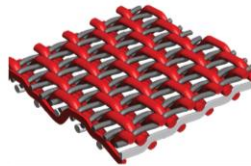
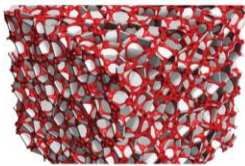
PAPERGEO



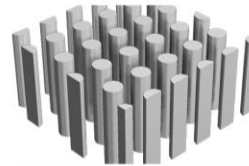
GRAINGEO



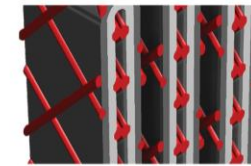
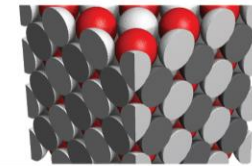
FOAMGEO



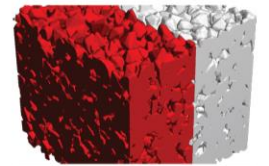
WEAVEGEO



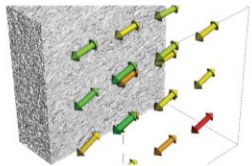
GRIDGEO



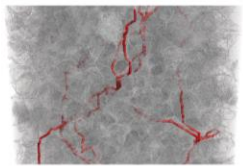
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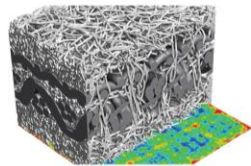
EXPORTGEO



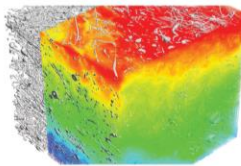
FIBERGUESS



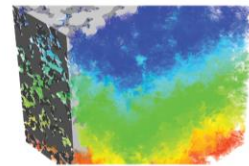
PORODICT



MATDICT



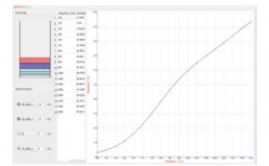
CONDUCTODICT



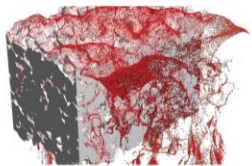
DIFFUDICT



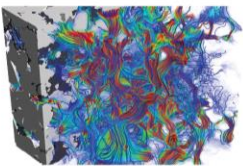
ELASTODICT



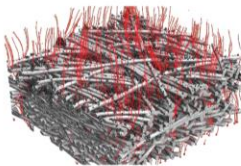
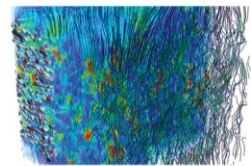
ACOUSTODICT



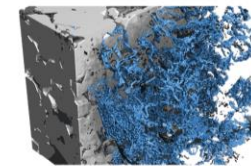
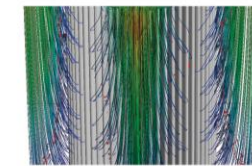
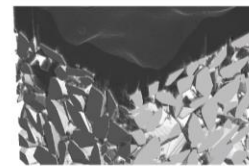
ADDIDICT



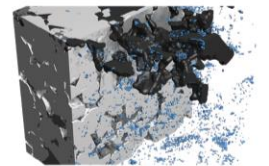
FLOWDICT



FILTERDICT MEDIA & ELEMENT



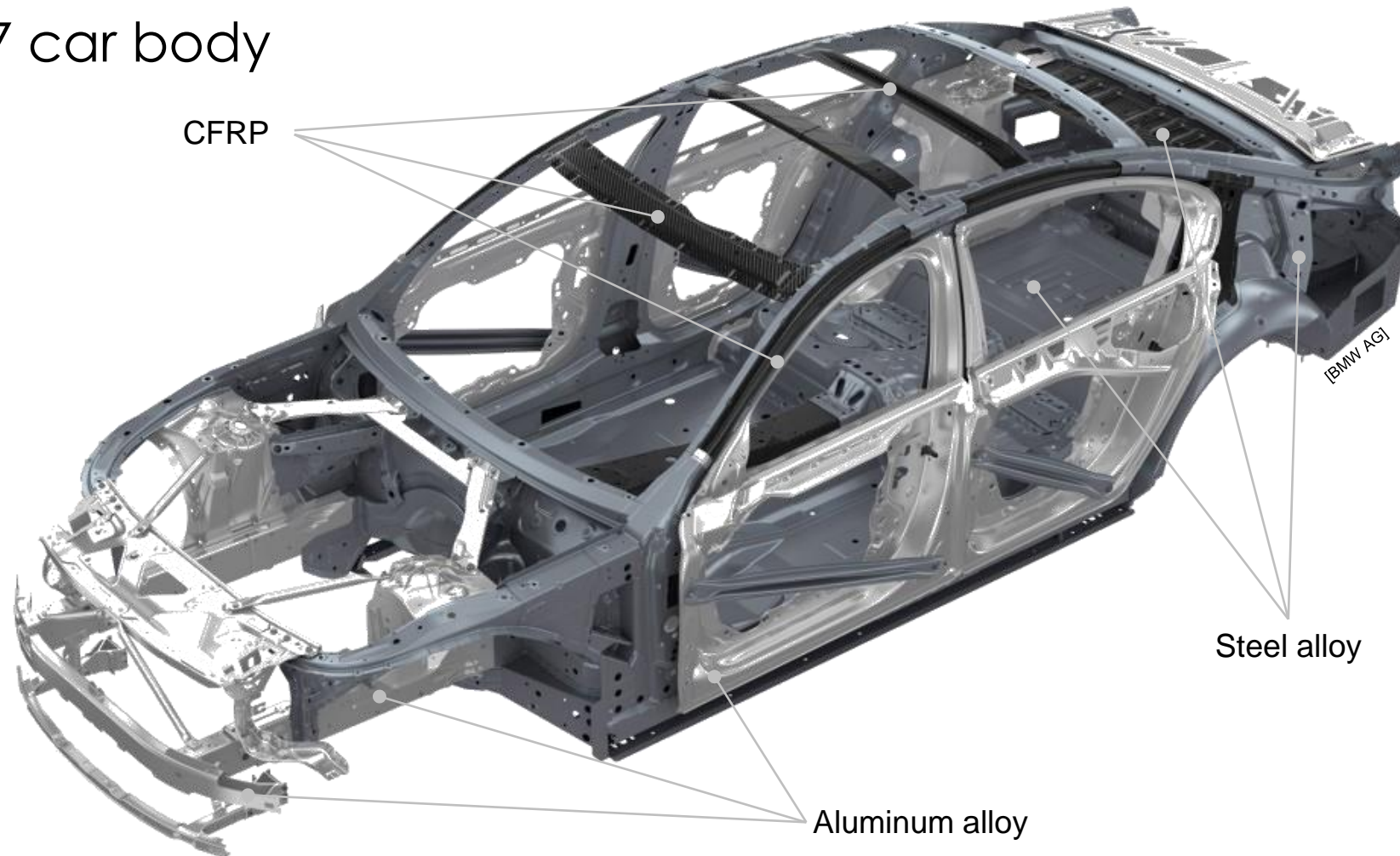
SATUDICT



# Motivation

# Motivation – Multi-Material-Design on Component Level

new BMW 7 car body



# Motivation – Multi-Material-Design on Material Level

## CFRP

+

High stiffness

+

High strength

+

Very low density

-

Brittle failure

-

Poor energy absorption in tension

+

High energy absorption in compression

-

Limited structure integrity in crash

-

Poor electrical conductivity

-

High cost

## New hybrid material

+

High stiffness

+

High strength

+

Acceptable density

+

Optimized failure

o

Good energy absorption in tension

+

Good energy absorption in compression

+

Good structure integrity in crash

+

Sufficient electrical conductivity

o

Acceptable cost

## Metal

+

High stiffness

+

Good strength

-

High density

+

Ductile failure

+

High energy absorption in tension

+

Good energy absorption in compression

+

Superior structure integrity in crash

+

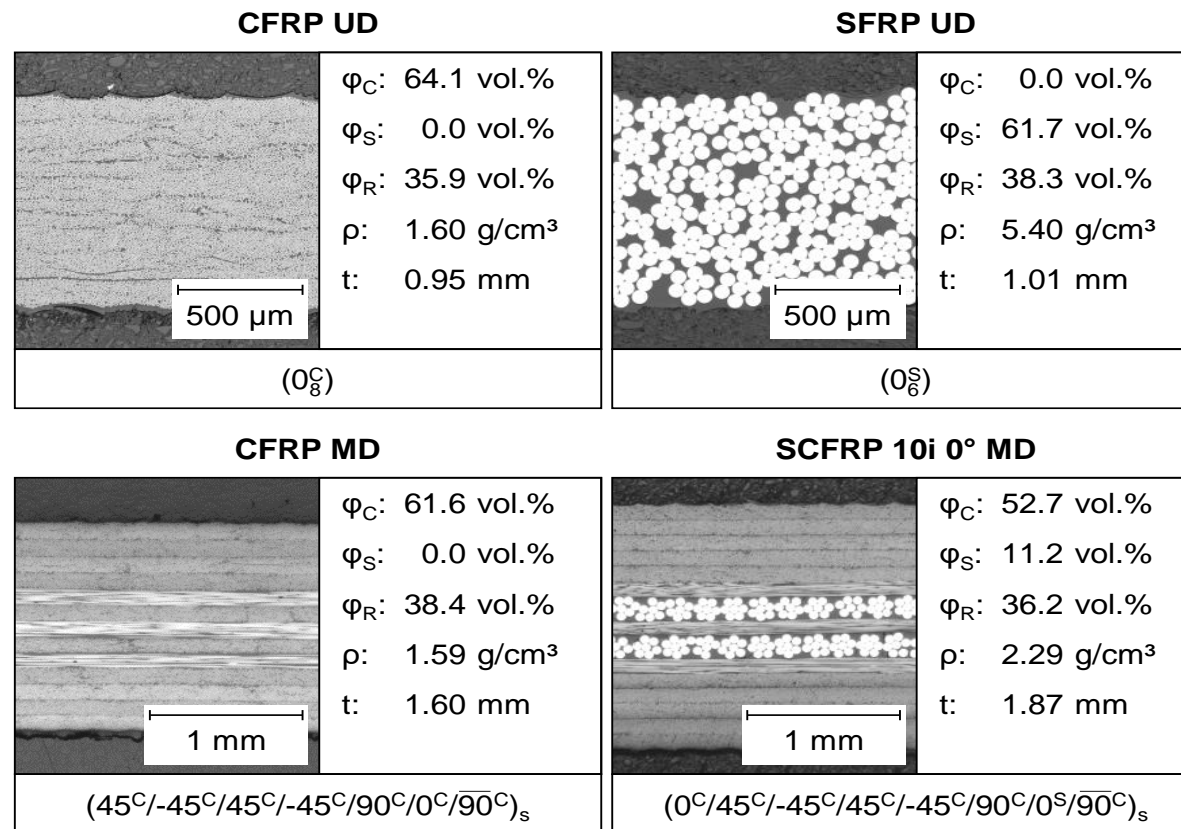
High electrical conductivity

+

Low cost

# Motivation – Multi-Material-Design on Material Level

micrograph section of the analyzed materials



C: Carbon, S: Steel, R: Resin,  $\varphi$ : Volume share,  $\rho$ : Density, t: Laminate thickness

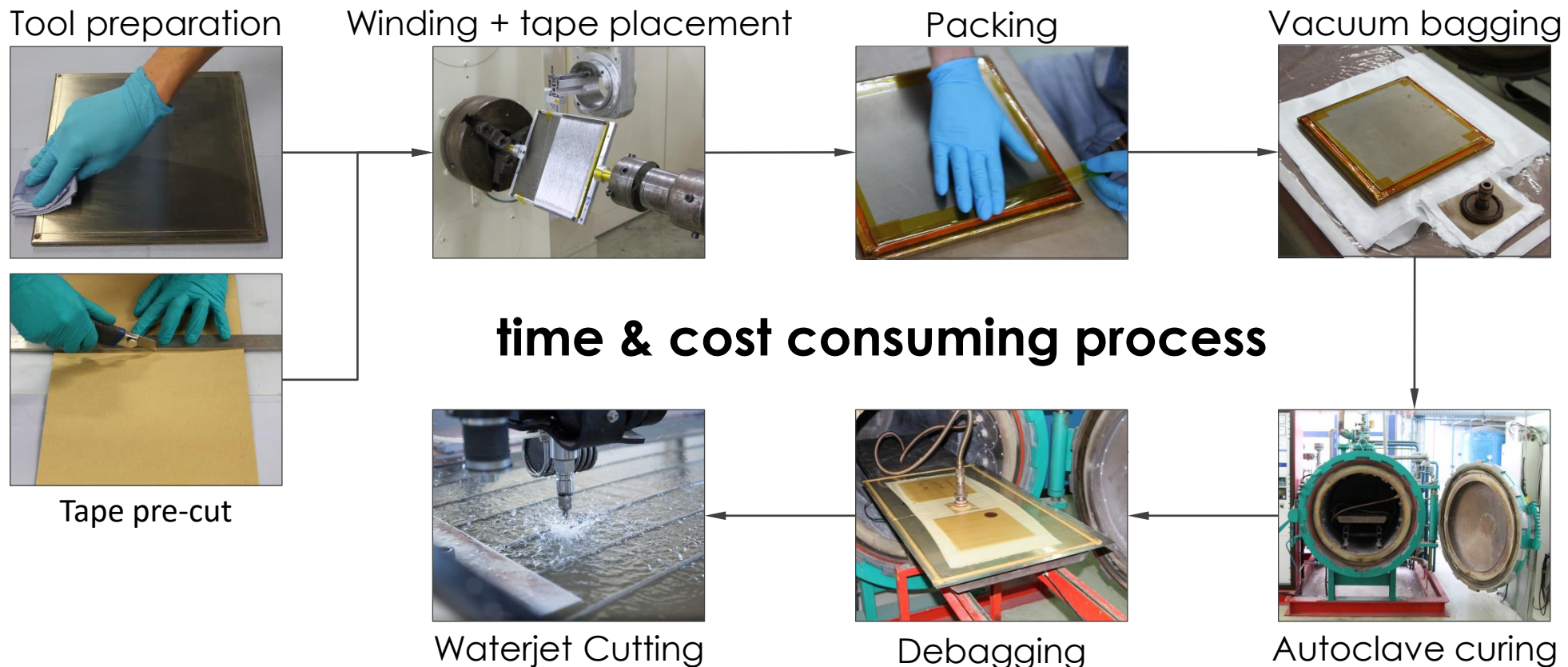
# Motivation – Multi-Material-Design on Material Level

constituent material properties

Property	Carbon fiber	Stainless steel fiber	Epoxy resin
Supplier	Toho Tenax	-	Cytec
Type	HTS40 F13 12k	-	Cycom 977-2
Density $\rho$ / g/cm <sup>3</sup>	1.77	7.95 ± 0.01	1.31
Young's modulus E / GPa	240	176 ± 7	3.52
Offset yield strength $\sigma_{p0.2}$ / MPa	-	504 ± 5	-
Ultimate tensile strength $\sigma_{max}$ / MPa	4300	897 ± 2	81.4
Strain at failure $\epsilon_{max}$ / %	1.80	32.31 ± 2.01	-
Specific electrical resistance $\rho^*$ / $\Omega$ m	1.6 x 10 <sup>-5</sup>	6.970 x 10 <sup>-7</sup>	> 10 <sup>13</sup>
Filament diameter $d_f$ / $\mu$ m	7	60.0 ± 0.4	-
Filaments per bundle $n_f$	12k	7	-

# Motivation – Multi-Material-Design on Material Level

manufacturing process



# Experimental Characterization

# Experimental Characterization – Test Setup

- tensile tests based on DIN EN ISO 527-4/5
- optical strain measurement by digital image correlation
- test velocity 1 mm/min
- rectangular specimens: 250 mm x 25 mm
- 5 specimens tested for each material

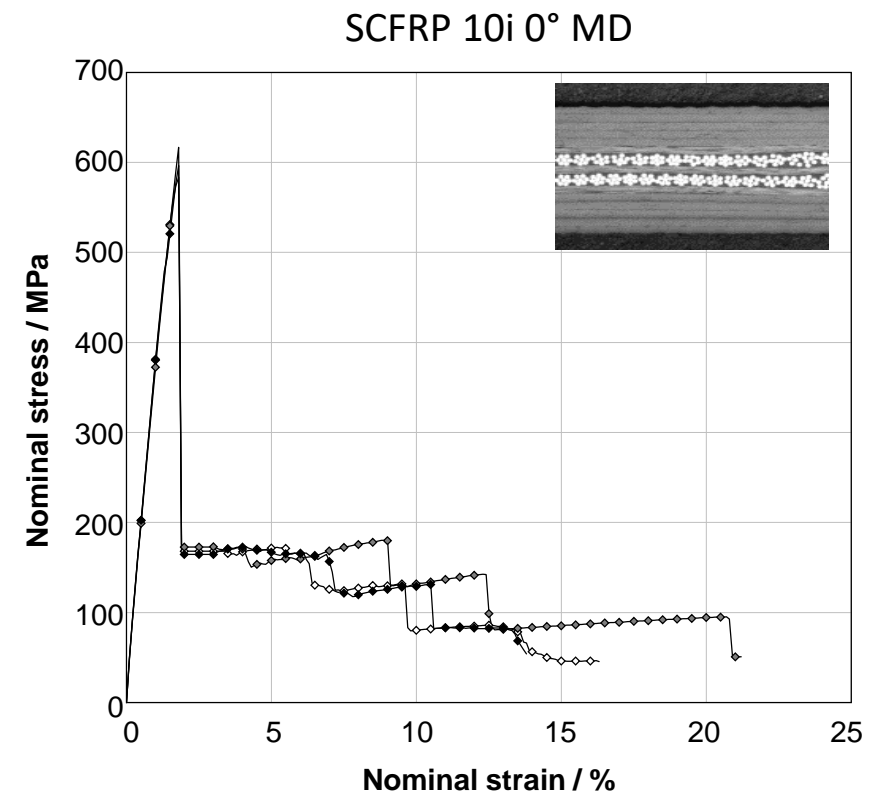
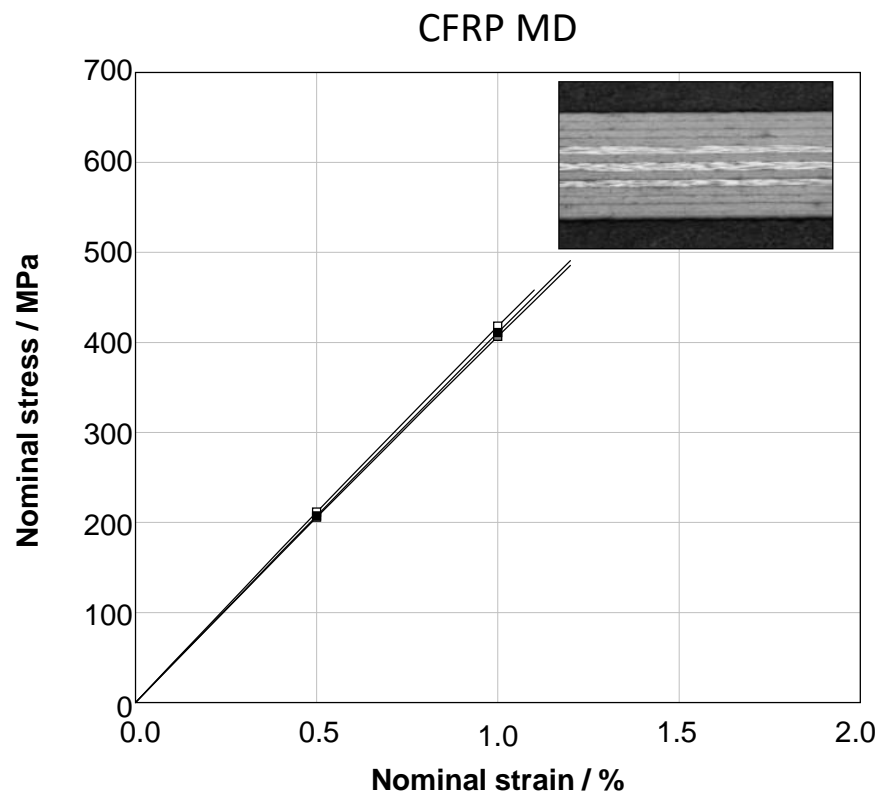
# Experimental Characterization – Results

engineering parameters

Property	CFRP UD	SFRP UD	CFRP MD	SCFRP 10i 0° MD
Young's Modulus E / GPa	146.1 ± 5.2	136.9 ± 2.9	42.2 ± 0.7	36.7 ± 0.2
Tensile strength $\sigma_{\max}$ / MPa	2492 ± 85	514 ± 7	510 ± 19	597 ± 13
Strain at failure initiation $\epsilon_{\sigma\max}$ / %	1.61 ± 0.06	14.32 ± 0.93	1.23 ± 0.06	1.84 ± 0.06
Ultimate strain at failure $\epsilon_{\max}$ / %	1.61 ± 0.06	14.32 ± 0.93	1.23 ± 0.06	11.77 ± 4.95

# Experimental Characterization – Results

stress-strain-curves



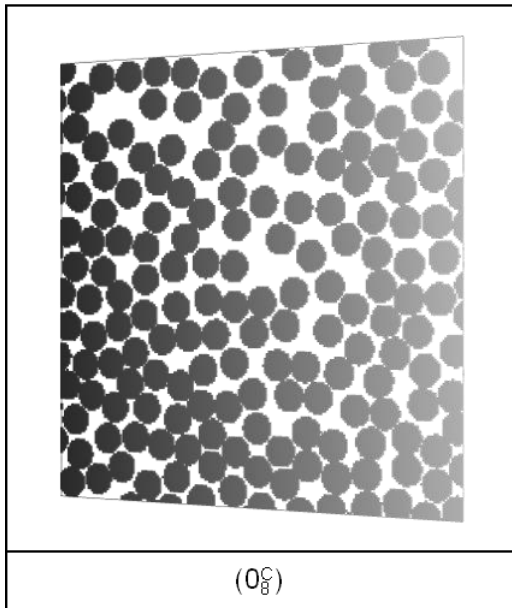
**Steel fibers can increase fail safe behavior significantly!**

# Micromechanical Simulation

# Micromechanical Simulation– Modelling

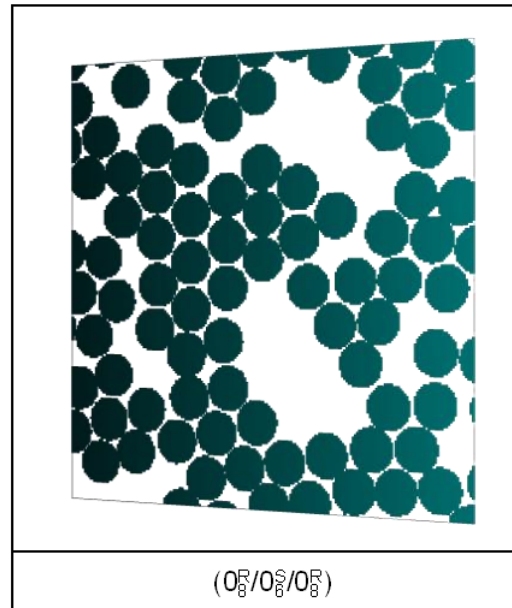
models of the different materials with 0.7  $\mu\text{m}$  resolution

CFRP UD



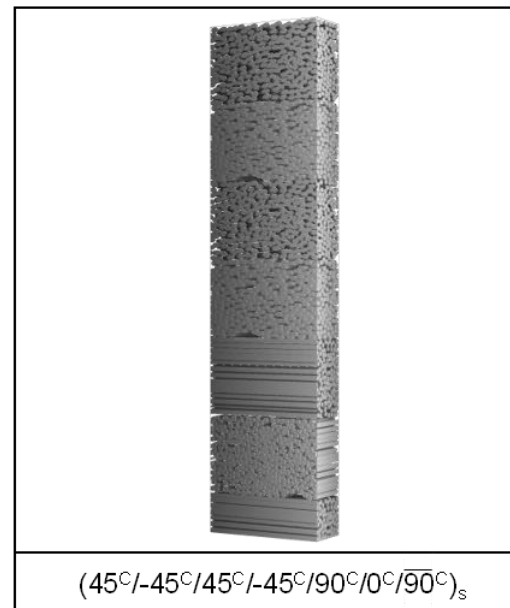
1x200x200  
(40,000 voxel)

SFRP UD



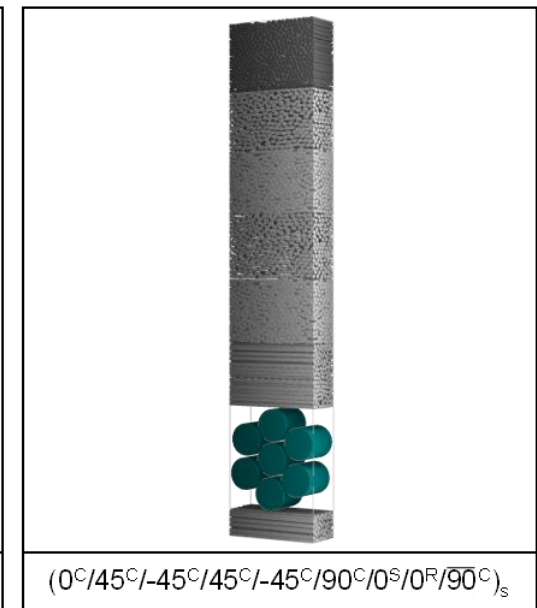
1x200x200  
(40,000 voxel)

CFRP MD



100x250x1141  
(28,525,000 voxel)

SCFRP 10i 0° MD



100x250x1320  
(33,000,000 voxel)

# Micromechanical Simulation– Material Models

## epoxy resin

- isotropic material with damage function:  $\Delta C = (T_1 \cdot \log(-T_2 \cdot \log(D)) + T_3) \cdot T_4$
- maximum strain failure criterion

## carbon fiber

- linear elastic transverse isotropic material
- maximum stress failure criterion

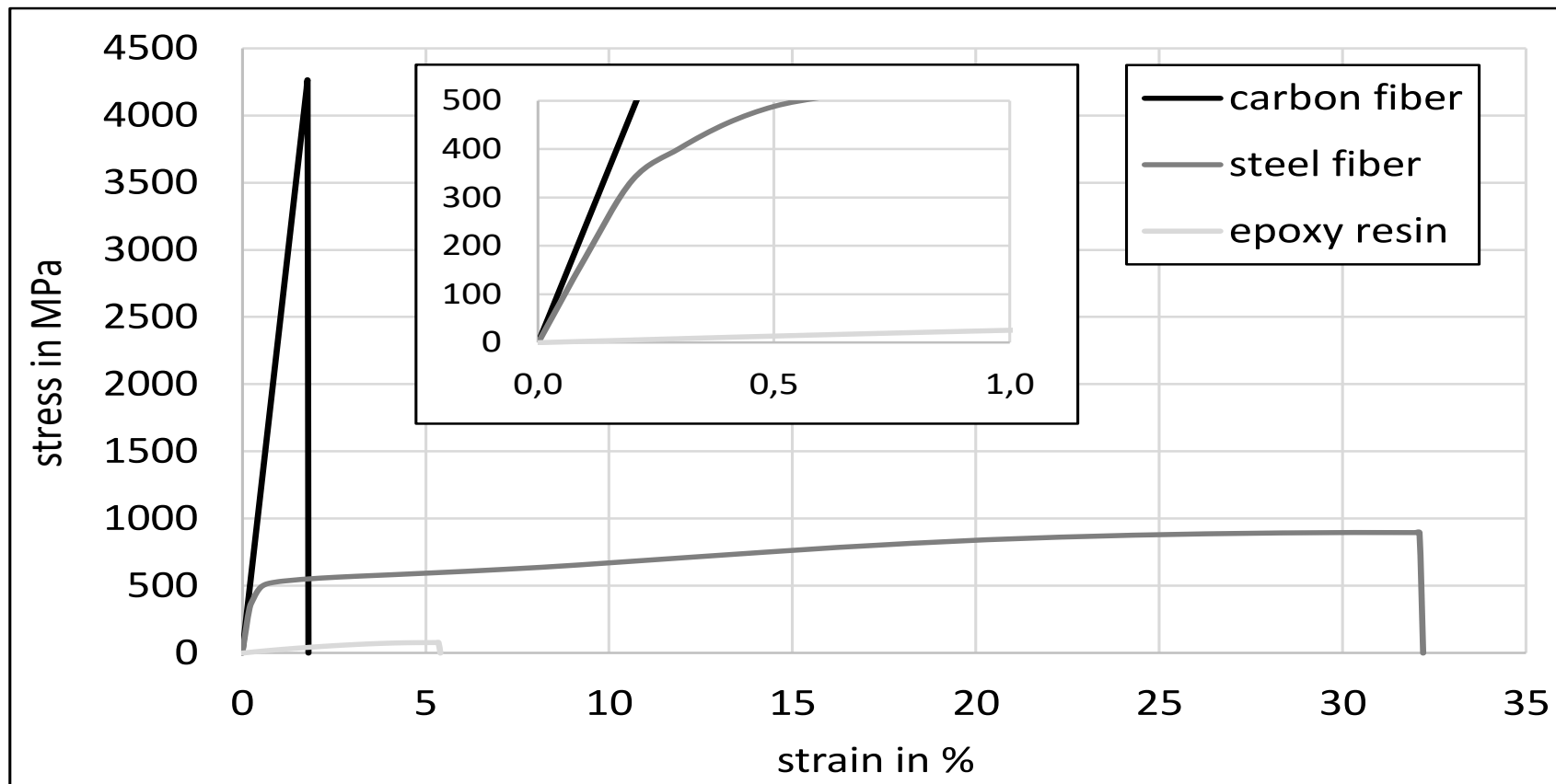
## steel fiber

- isotropic material with general von-Mises yield criterion

$$\sigma_v = \sqrt{\frac{1}{2} \cdot [(\sigma_{11} - \sigma_{22})^2 + (\sigma_{22} - \sigma_{33})^2 + (\sigma_{33} - \sigma_{11})^2 + 6 \cdot (\sigma_{12}^2 + \sigma_{23}^2 + \sigma_{31}^2)]}$$

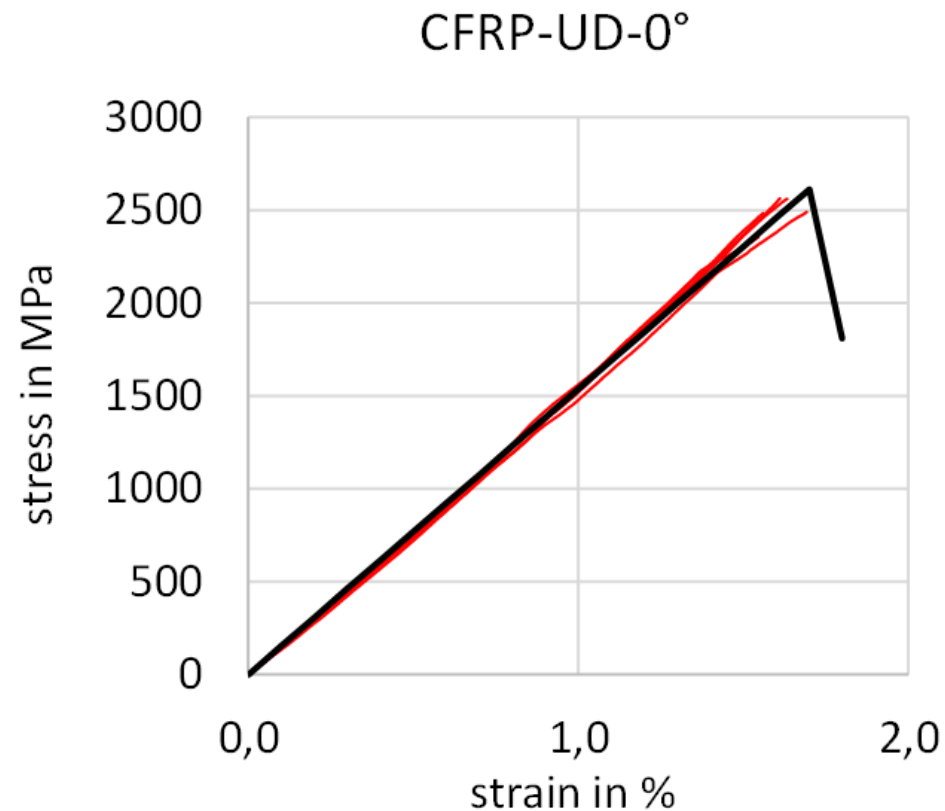
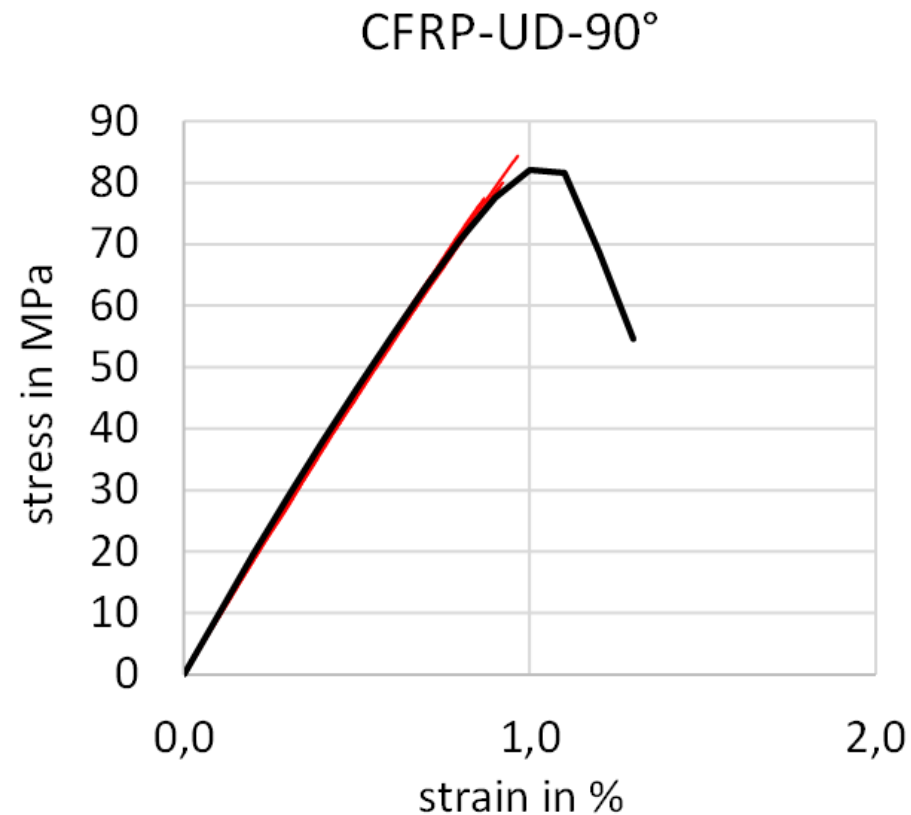
# Micromechanical Simulation- Material Models

stress-strain-curves of the constituent materials

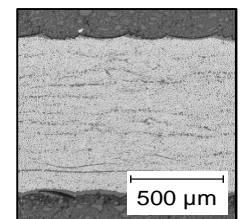


# Micromechanical Simulation- Results

unidirectional CFRP

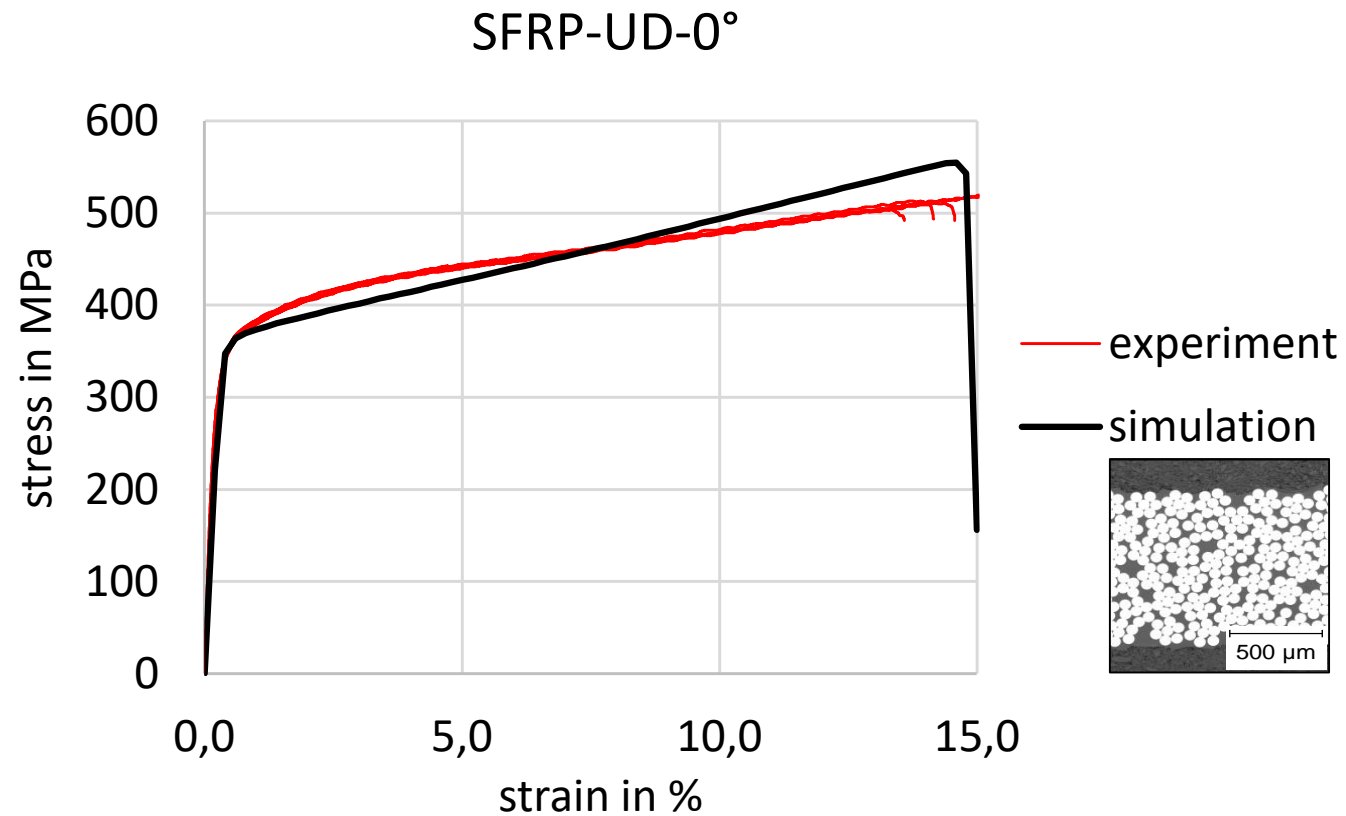


— experiment  
— simulation



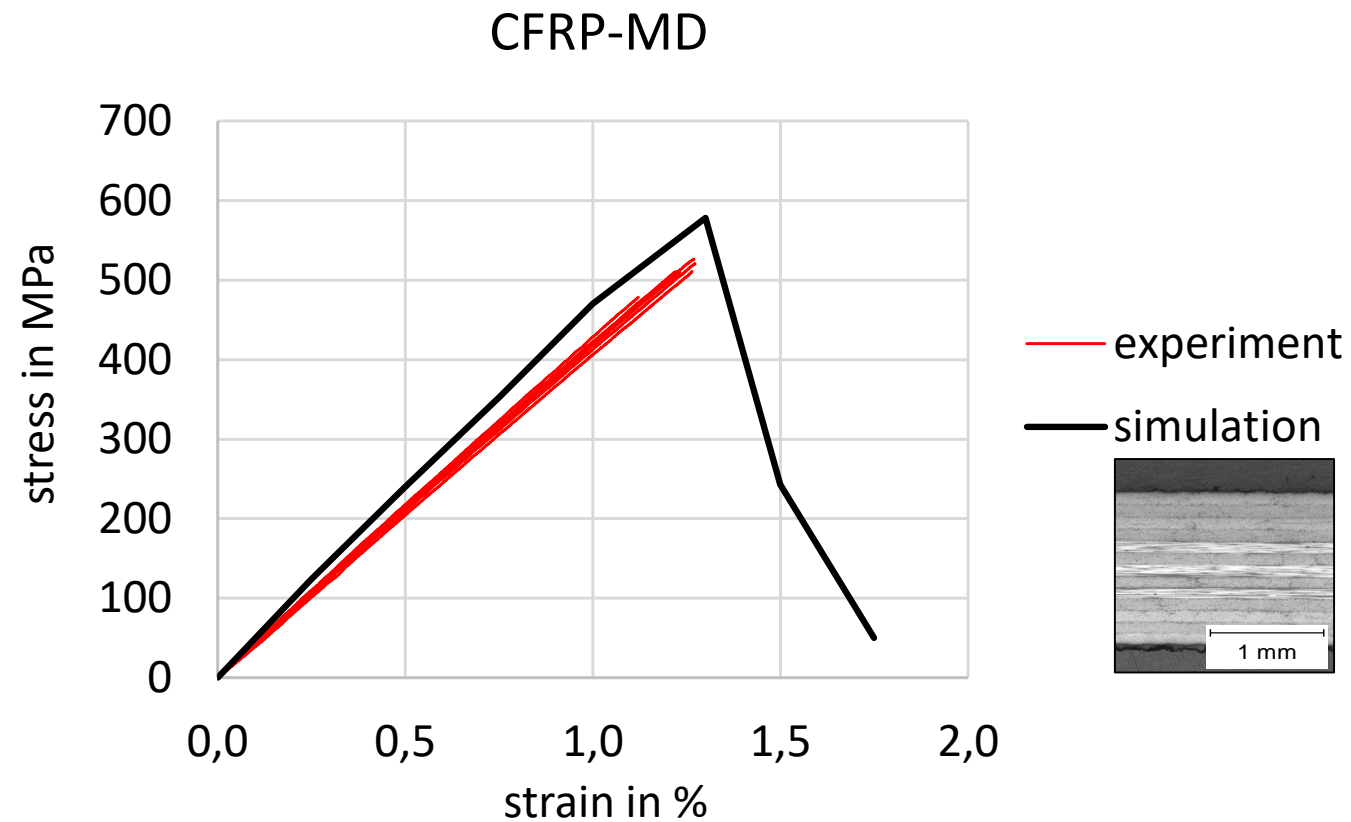
# Micromechanical Simulation- Results

unidirectional SFRP



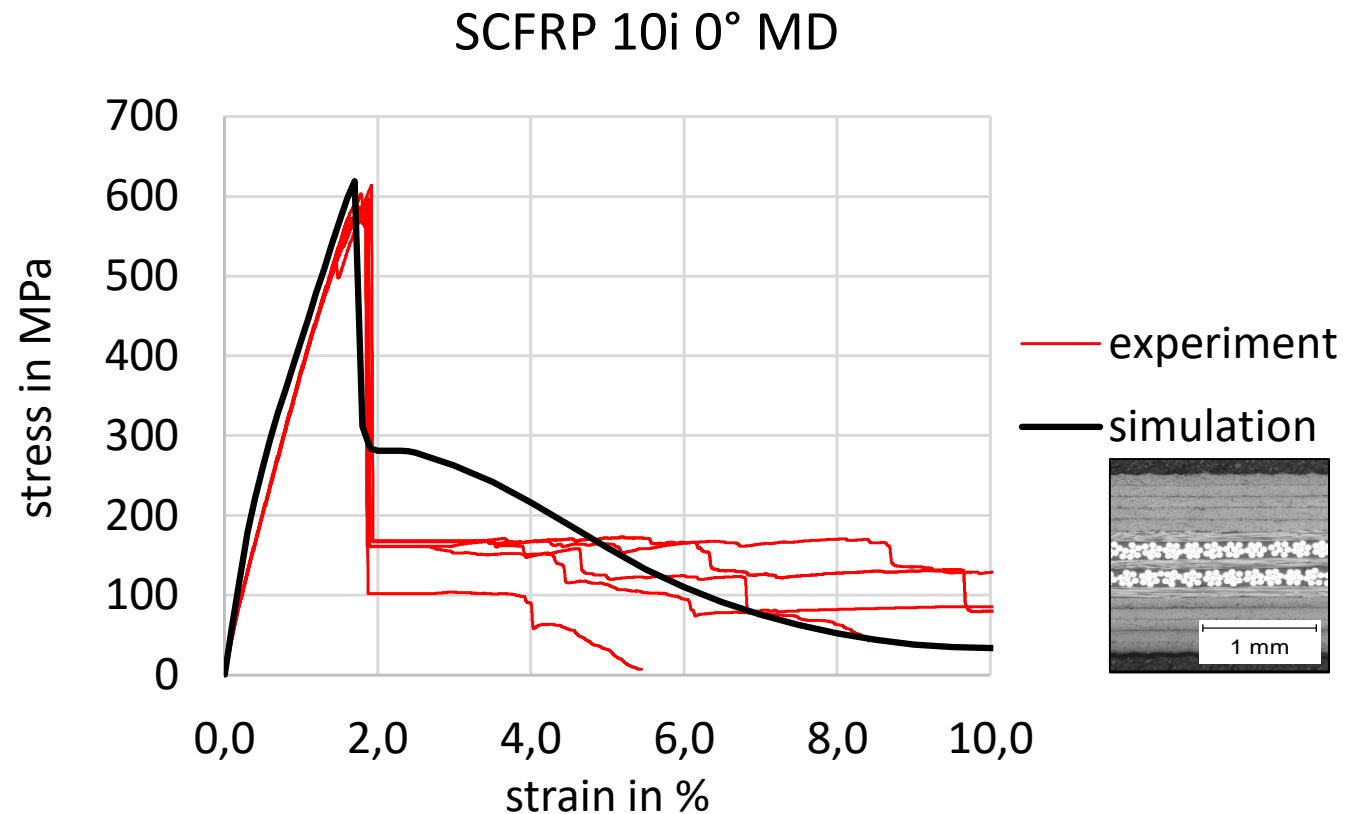
# Micromechanical Simulation- Results

multidirectional CFRP

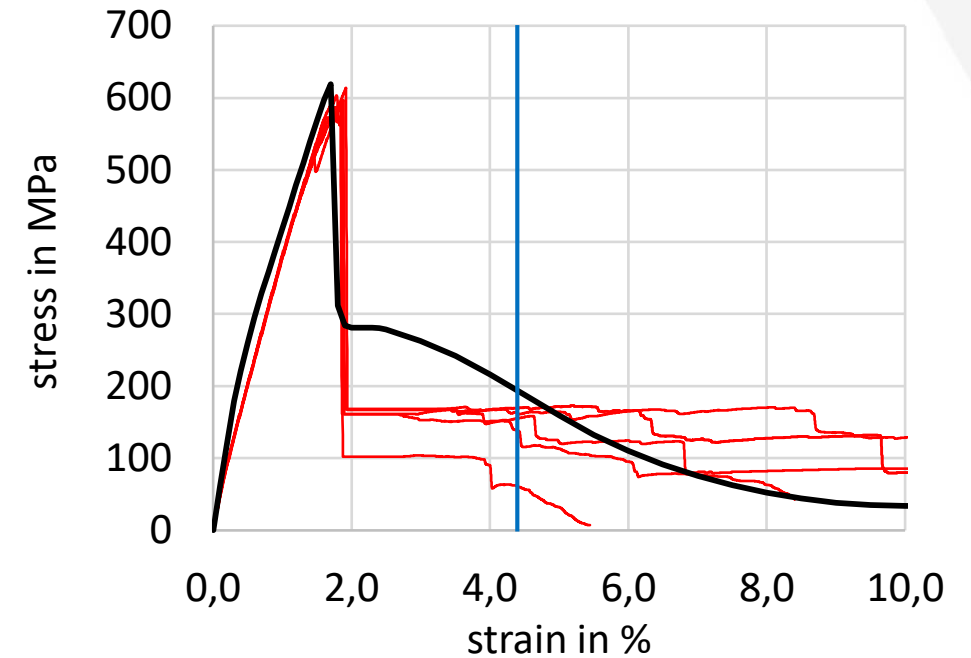
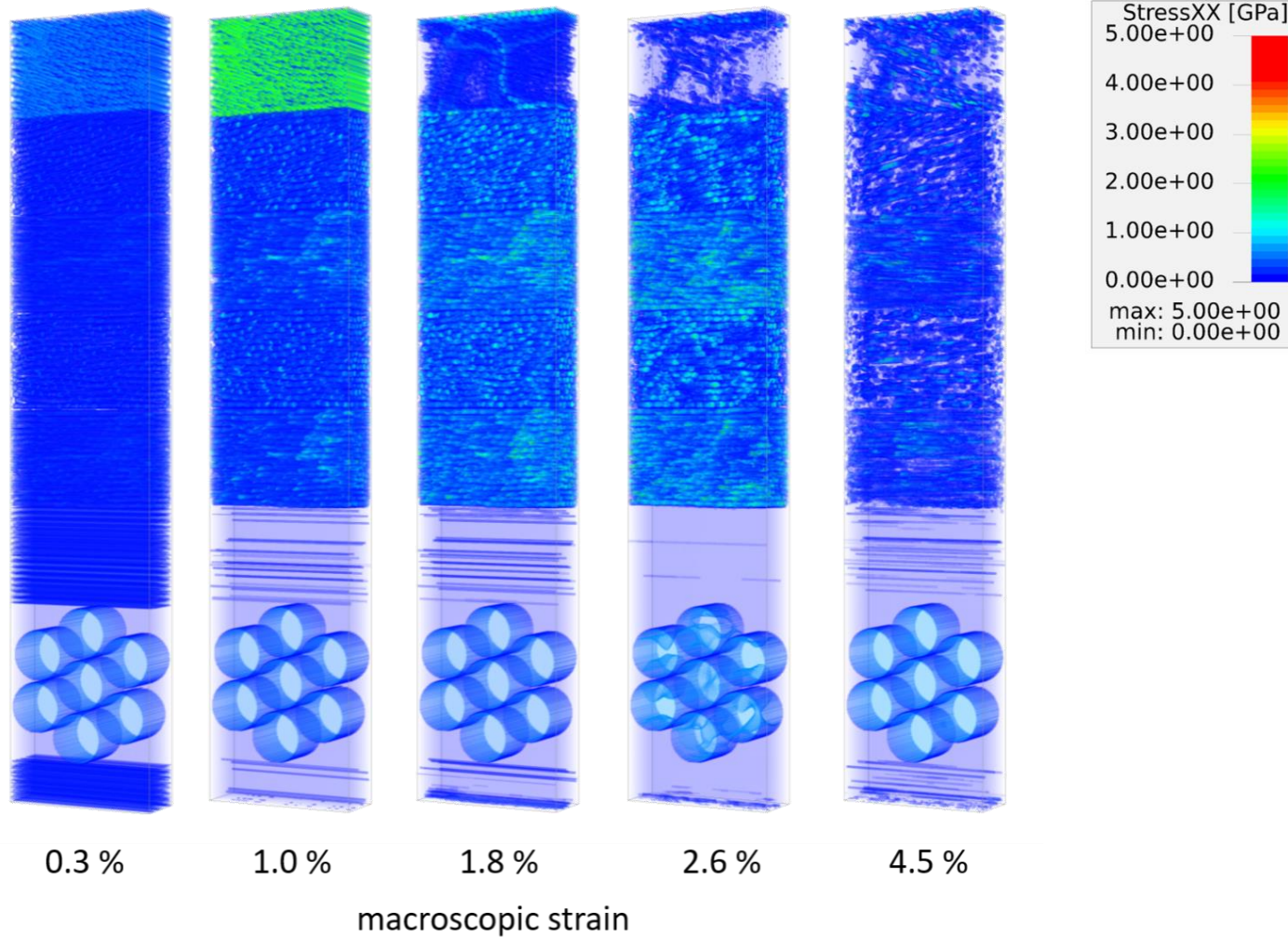


# Micromechanical Simulation— Results

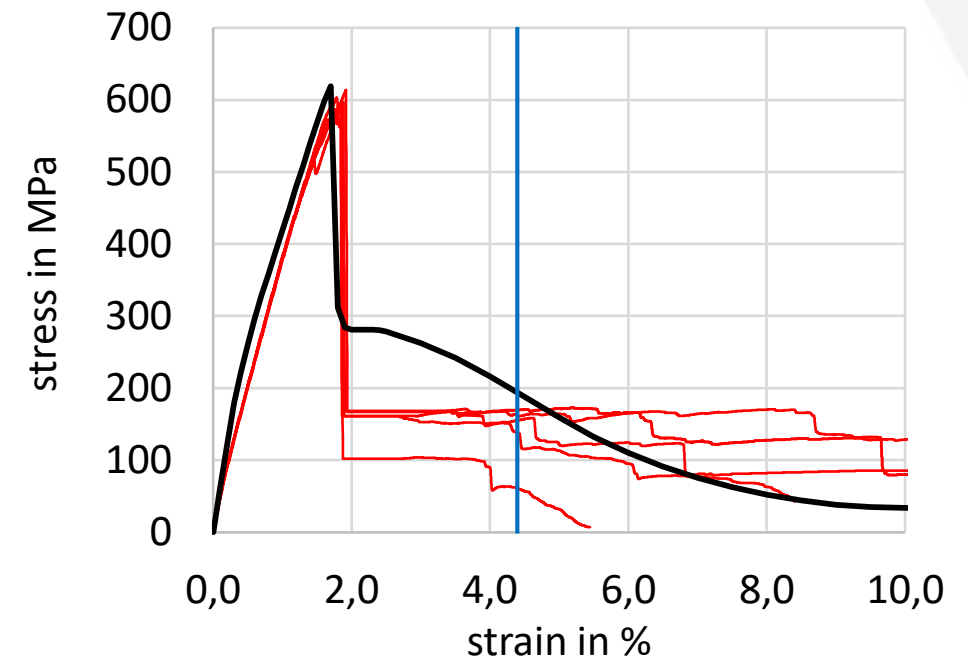
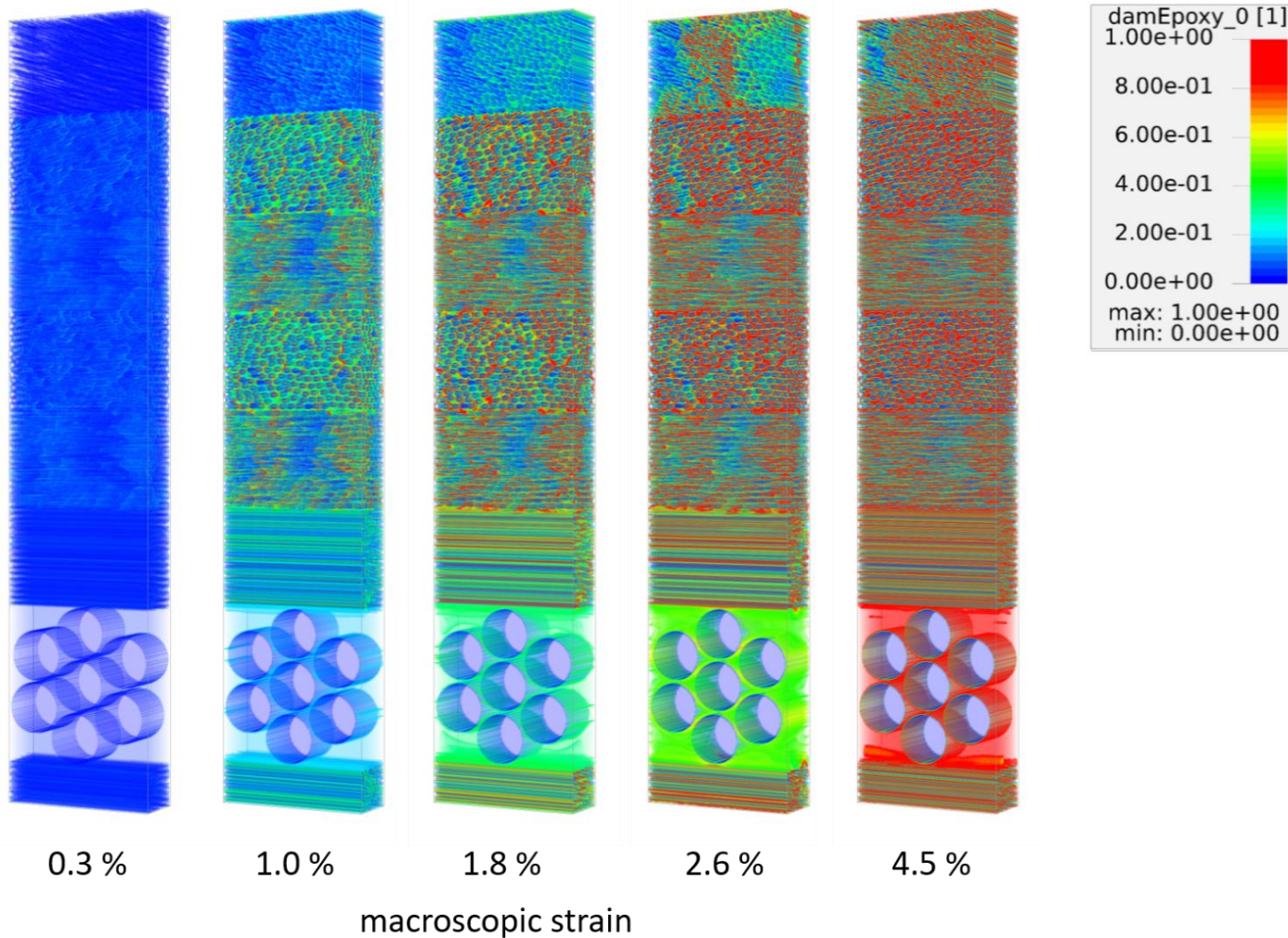
multidirectional SCFRP



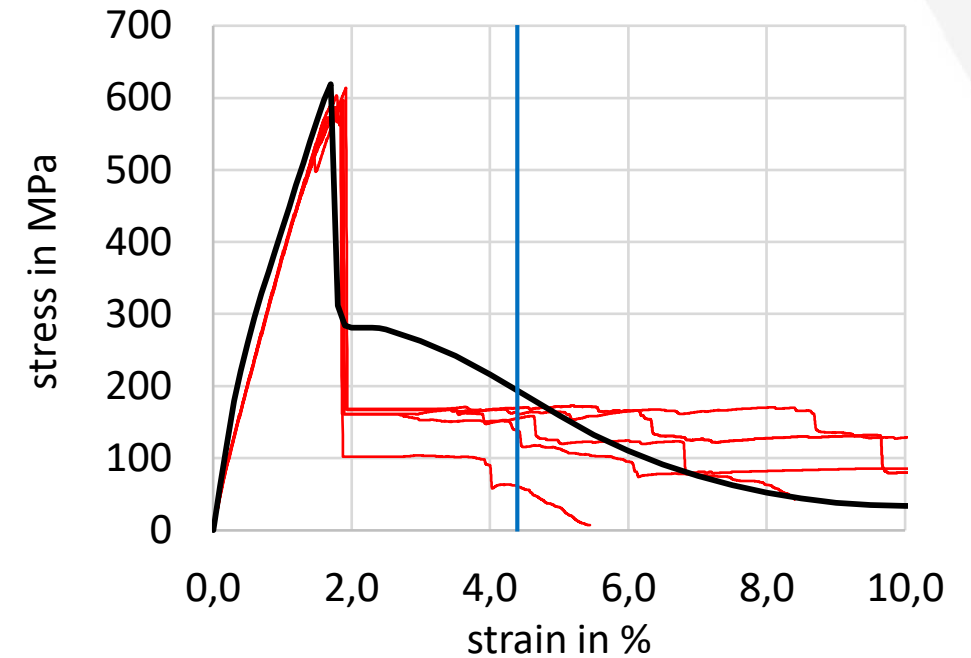
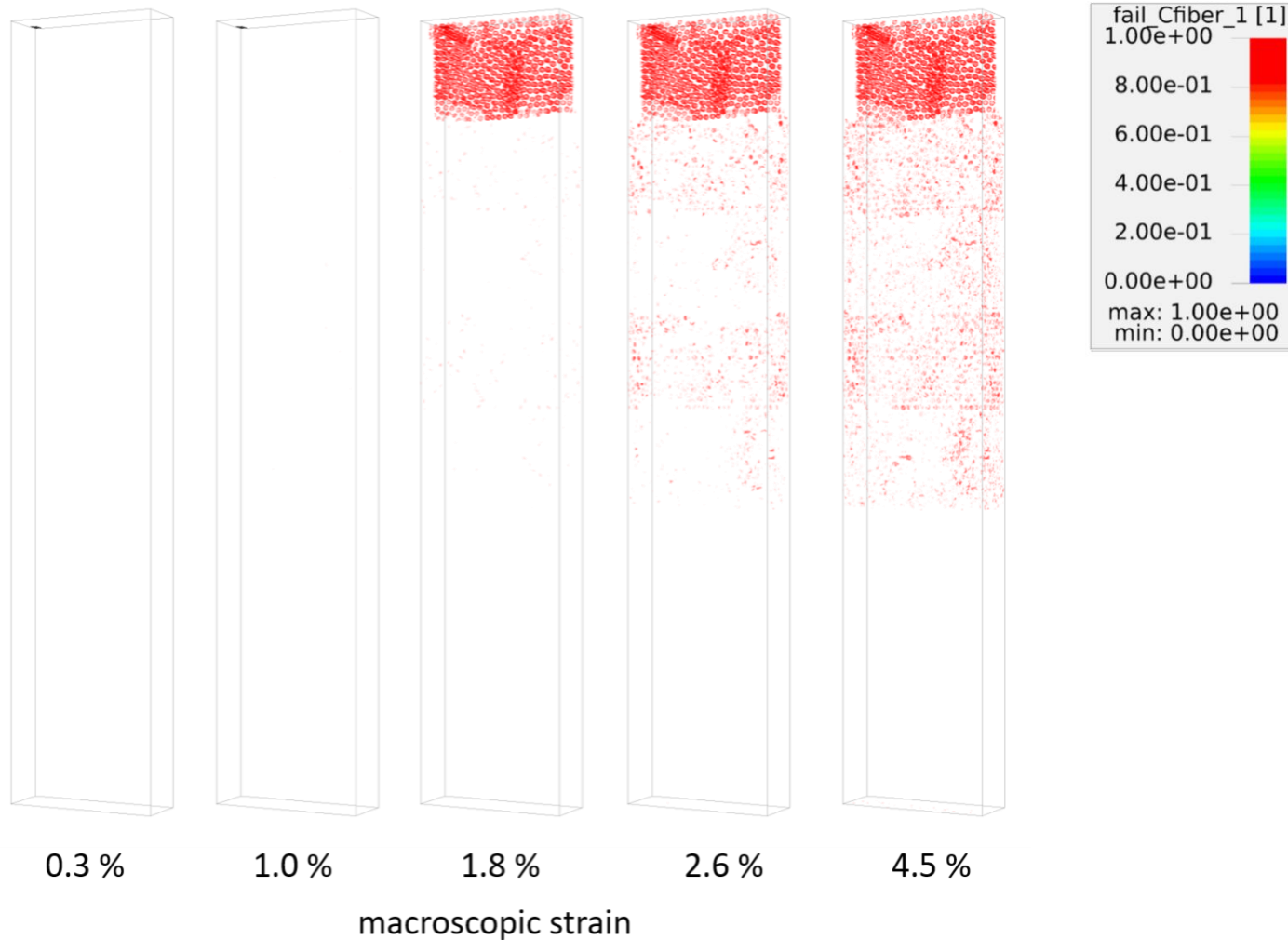
# Micromechanical Simulation- visualization stressXX



# Micromechanical Simulation– visualization damage epoxy resin



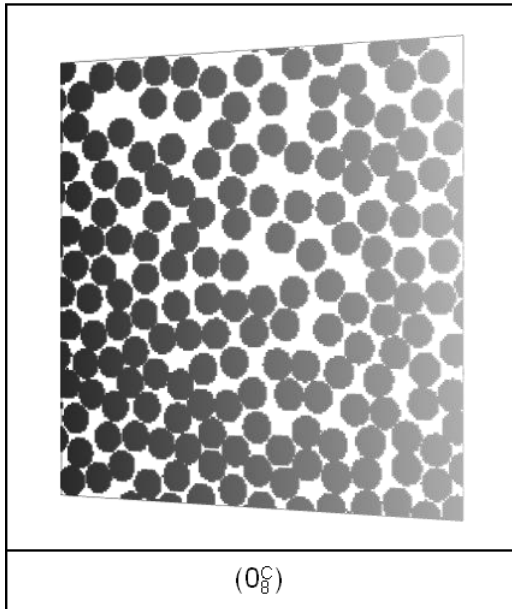
# Micromechanical Simulation– visualization failure carbon fiber



# Micromechanical Simulation— computation time and memory usage

16 threads of a 2x10-Core Intel E5-2690v2 @ 3.00 GHz

CFRP UD

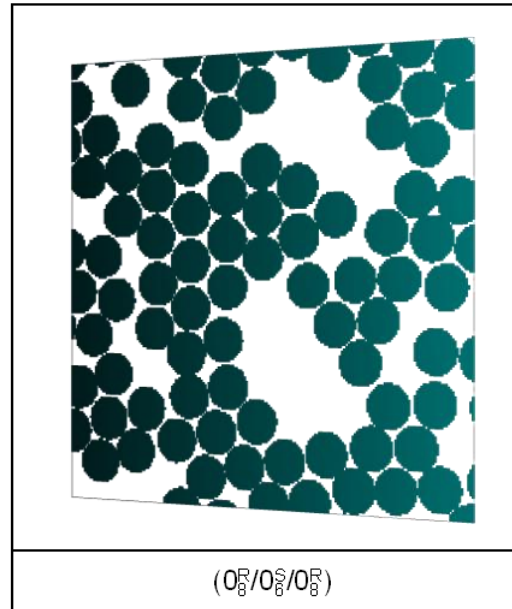


$(0^{\circ})$

40,000 elements

51 s  
0.03 GB RAM

SFRP UD

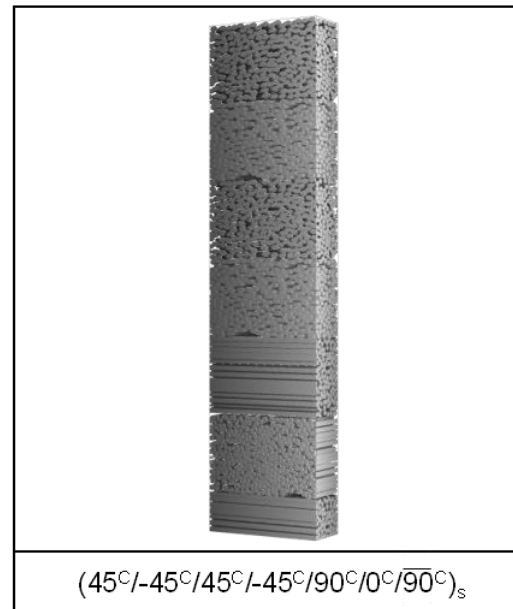


$(0^{\circ}/0^{\circ}/0^{\circ})$

40,000 elements

260 s  
0.03 GB RAM

CFRP MD

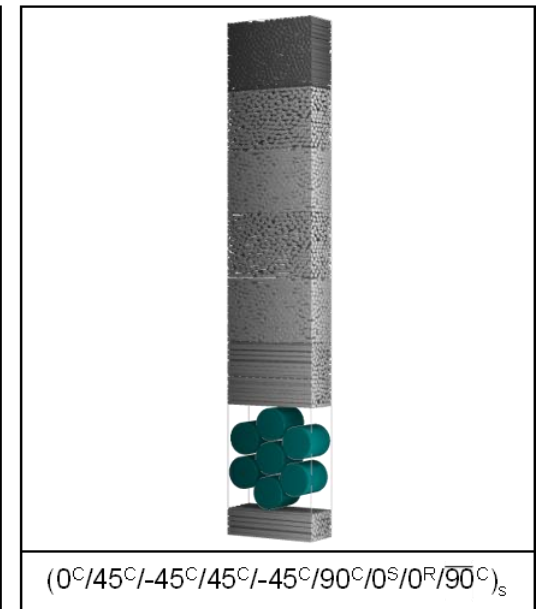


$(45^{\circ}/-45^{\circ}/45^{\circ}/-45^{\circ}/90^{\circ}/0^{\circ}/90^{\circ})_s$

28,525,000 elements

20 h  
5.5 GB RAM

SCFRP 10i 0° MD



$(0^{\circ}/45^{\circ}/-45^{\circ}/45^{\circ}/-45^{\circ}/90^{\circ}/0^{\circ}/0^{\circ}/90^{\circ})_s$

33,000,000 elements

16 h  
6.5 GB RAM

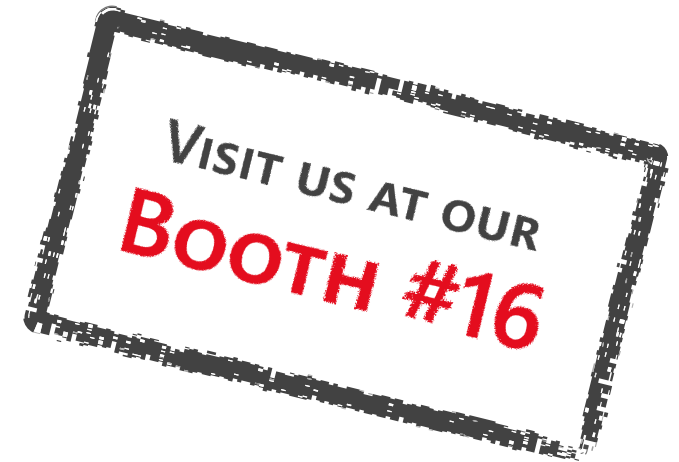
# CAASE18

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June 5 - 7, Cleveland, Ohio

Co-Hosted by  NAFEMS  DE  
Digital Engineering

## Thank You!



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[www.geodict.com](http://www.geodict.com)