Modeling and Characterization of Continuous-Discontinuous Long Fiber-Reinforced Polymer Structures

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14. Deutsches LS-DYNA Forum

Outline

- Introduction of GRK2078 CoDiCoFRP
  - Motivation and Objectives

- Research Topics
  - Preliminary Remarks on Short Fiber Reinforced Polymers
  - Microscale Characterization
  - Microscale Simulation and Homogenization
  - Macroscale Simulation and Characterization
  - Form Filling Micromechanical Modeling

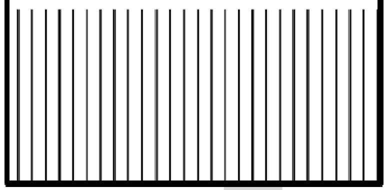
- Conclusions and Outlook

FRP Classes: Introduction and Application

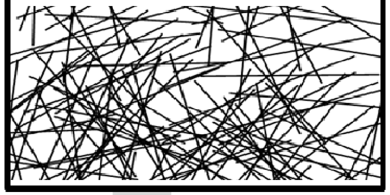
- High fiber volume content
- Controlled fibers alignment
- High stiffness and strength
- Restricted formability
- High cycle times
- High scrap rate
- Extensive trimming

Carbon cell

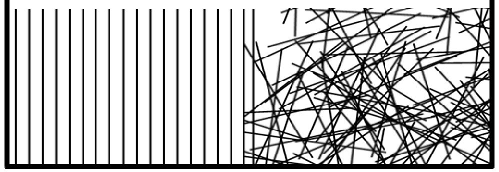
CoFRP
Continuous Fiber Reinforced Polymers



DiCoFRP
Discontinuous Fiber Reinforced Polymers

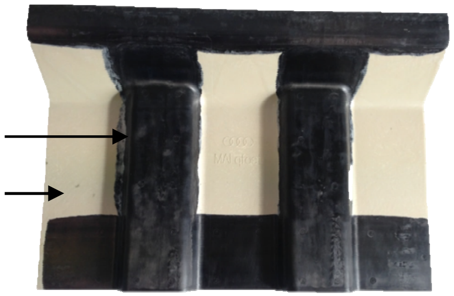


CoDiCoFRP
Discontinuous Fiber Reinforced Polymers with Continuous Fiber Reinforcement



- Good formability
- Function integration potential
- Low finishing demands
- Low cycle times
- Low stiffness and strength
- Process related complex microstructure

Frontend made of DiCoFRP



CoDiCoFRP component (front side)

CoDiCoFRP component (back side)

Challenges and Program Objectives

Challenges

Lack of **numerical** and **characterization methods**

Need for concepts for **manufacturing, automation** and **quality control**

Full optimization of the **processing chain** is required

Lack of **specifically qualified personel**

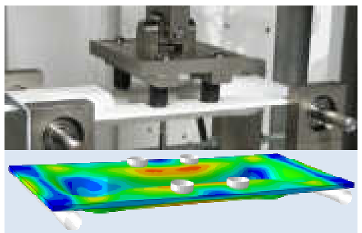
IRTG Objectives

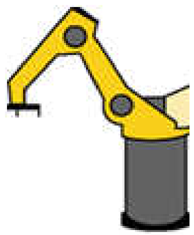
Research on **materials, simulation** and **design**

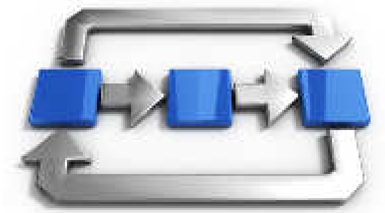
Develop **manufacturing** and **quality control** strategies

Develop **robust integrated engineering approach**

Train engineers and young **scientists**







GRK 2078 Twin Regions

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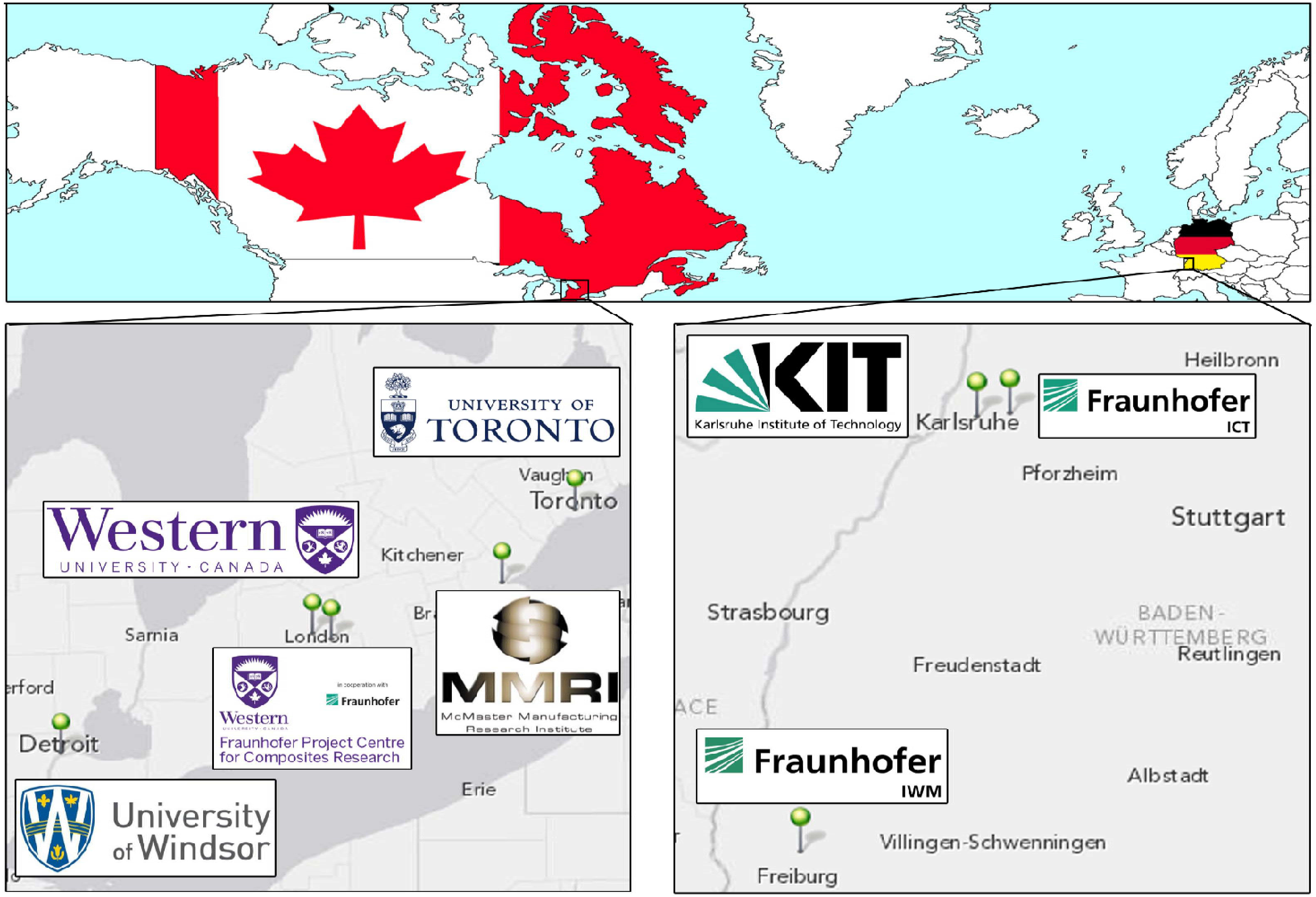
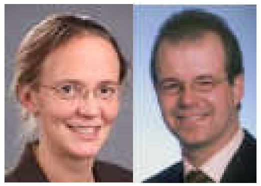


CoDiCo FRP

DFG GRK2078 Participating Institutes

Thomas Böhlke, Institute of Engineering Mechanics

Albert Albers, Institute of Product Engineering



Britta Nestler, Kay Weidenmann, Institute for Applied Materials

Gisela Lanza, Jürgen Fleischer, Volker Schulze,
Institute of Production Science

Peter Elsner, Frank Henning, Fraunhofer-ICT

Peter Gumbsch, Jörg Hohe, Fraunhofer-IWM

Luise Kärger, Institute for Vehicle Science

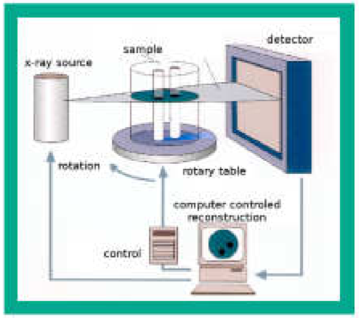
Thomas Seelig, Institute of Mechanics

Motivation: Homogenization of Elastic Properties of Short-Fiber Reinforced Composites

Contact: Viktor Müller

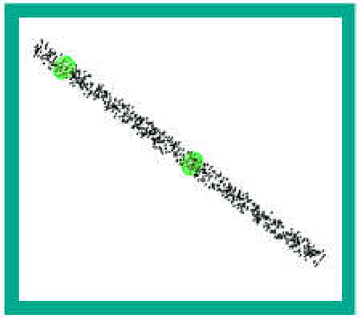
µCT Measurement and Fiber Segmentation

Müller et al. (JCM, 2015), cooperation with Dillenberger, Glöckner, Kolling

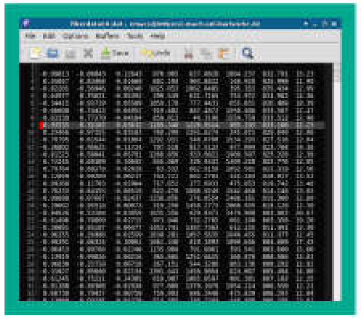


μCT measurement

image processing



percolation algorithm



resultant data

IDD scheme: continuous formulation

Zheng and Du (2001), Du and Zheng (2002), Wu (1997), Müller and TB (IJSS, 2015)

$$\mathbb{C}^{\mathsf{IDD}} = \mathbb{C}_{\mathsf{M}} + \left(\mathbb{I}^s - \sum_{\beta=1}^{N_{\mathsf{F}}} c_\beta \mathbb{M}_\beta \mathbb{P}^{\mathsf{D}}_\beta \right)^{-1} \sum_{\alpha=1}^{N_{\mathsf{F}}} c_\alpha \mathbb{M}_\alpha$$

with $\mathbb{M}_\gamma = (\mathbb{C}_\gamma - \mathbb{C}_{\mathsf{M}}) \left(\mathbb{I}^s + \mathbb{P}_\gamma (\mathbb{C}_\gamma - \mathbb{C}_{\mathsf{M}})\right)^{-1}$

Using averaged microstructure description

$$\mathbb{C}^{\mathsf{IDD}} = \mathbb{C}_{\mathsf{M}} + \left(\mathbb{I}^s - c_{\mathsf{F}} \int_S f(\boldsymbol{n}) \mathbb{M}(\boldsymbol{n}) \mathbb{P}^{\mathsf{D}}(\boldsymbol{n}) \, \mathrm{d}S \right)^{-1} c_{\mathsf{F}} \int_S f(\boldsymbol{n}) \mathbb{M}(\boldsymbol{n}) \, \mathrm{d}S$$

with $\mathbb{M}(\boldsymbol{n}) = (\mathbb{C}_{\mathsf{F}} - \mathbb{C}_{\mathsf{M}}) \left(\mathbb{I}^s + \mathbb{P}(\boldsymbol{n}) (\mathbb{C}_{\mathsf{F}} - \mathbb{C}_{\mathsf{M}})\right)^{-1}$

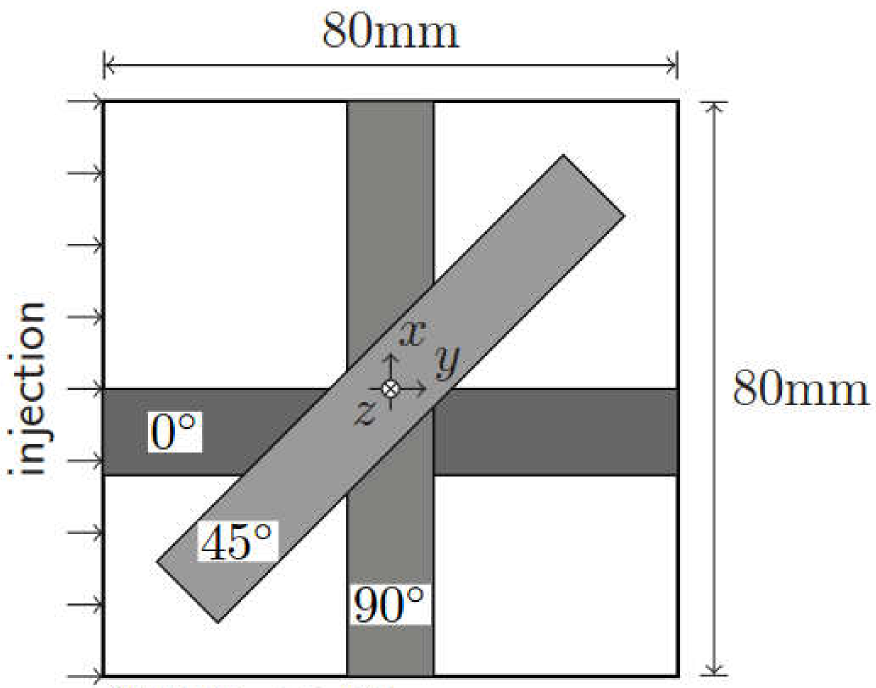
$c_{\mathsf{F}},\ f(\boldsymbol{n})$: total vol. frac. of fibers, FODF

$\mathbb{P}(\boldsymbol{n}) = \mathbb{P}\left(\mathbb{C}_{\mathsf{M}}, \mathbb{C}_{\mathsf{F}}, \boldsymbol{n}, \omega\right)$: Hill's pol. tensor of fiber with const. aspect ratio

$\mathbb{P}^{\mathsf{D}}(\boldsymbol{n}) = \mathbb{P}^{\mathsf{D}}\left(\mathbb{C}_{\mathsf{M}}, \mathbb{C}_{\mathsf{F}}, \boldsymbol{n}, \omega^{\mathsf{D}}\right)$: Hill's pol. tensor of cell with const. aspect ratio

Preparation of specimen

Müller et al. (JCM, 2015)



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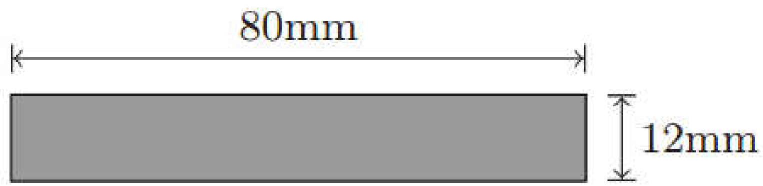
µCT specimen

Diameter: $d = 2\,\mathrm{mm}$ Height: $h = 2.5\,\mathrm{mm}$

Position: $P(0, 0)$

Geometry of specimen



Depth: $t = 2.5\mathrm{mm}$

Glass fibers

$E_\mathsf{F} = 73.0\mathrm{GPa}$, $\nu_\mathsf{F} = 0.22$

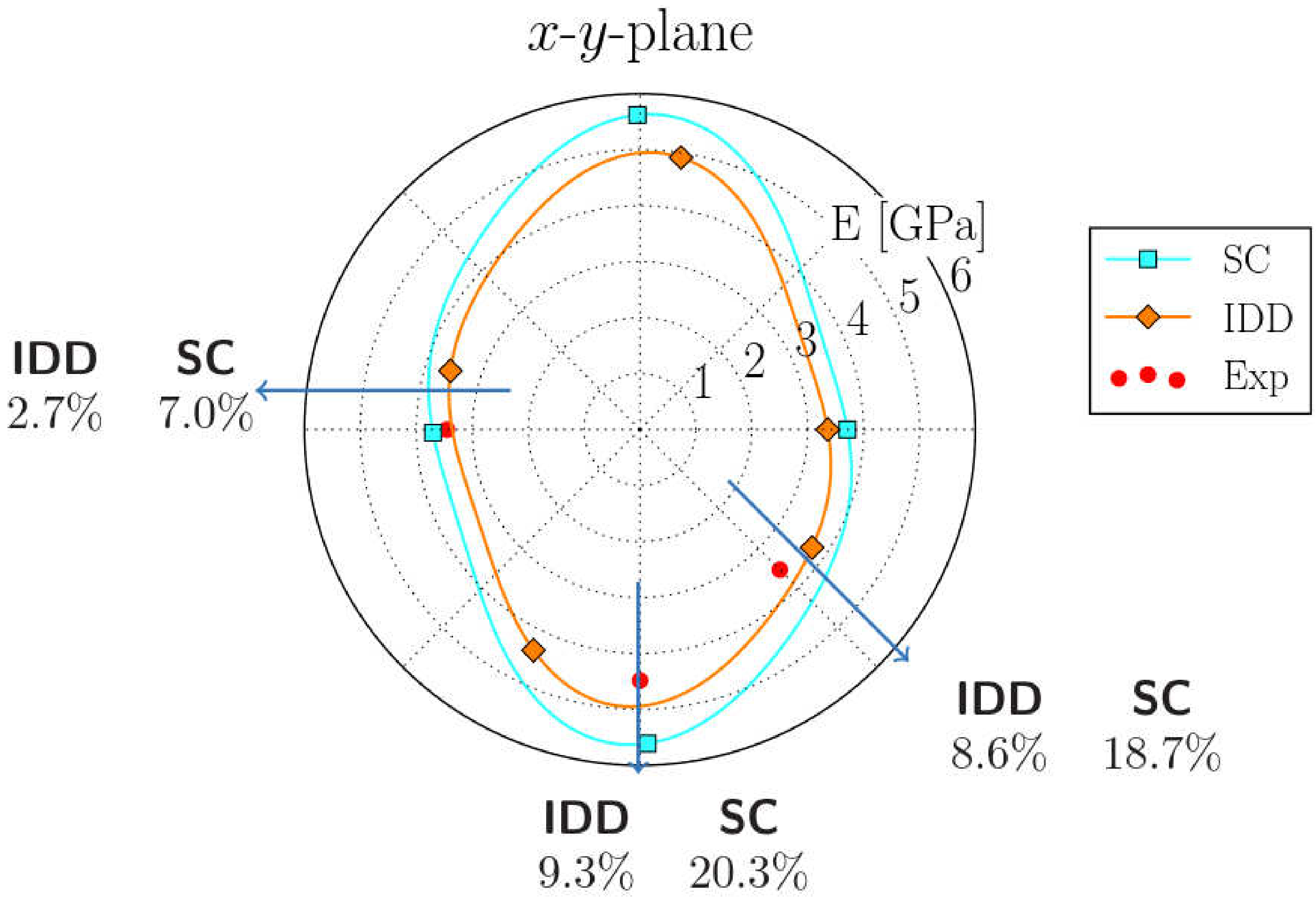
$c_\mathsf{F} = 30\mathrm{wt.}\text{-}\%$

Polypropylene matrix

$E_\mathsf{M} = 1.705\mathrm{GPa}$, $\nu_\mathsf{M} = 0.355$

Numerical vs experimental results

Müller et al. (JCM, 2015)



Maximum entropy principle (MEP)

Wu (1997), TB (2005), Müller and TB (CSTE, 2015)

First moment problem **Second moment problem**

$$\bar{S} := -\int_S \bar{f}(\boldsymbol{n}) \ln(\bar{f}(\boldsymbol{n}))\, \mathrm{d}S \to \max$$

$$\mathcal{C}_{<0>} := \int_S \bar{f}(\boldsymbol{n})\, \mathrm{d}S - 1 \overset{!}{=} 0$$

$$\mathcal{C}_{<2>} := \int_S \bar{f}(\boldsymbol{n})(\boldsymbol{n} \otimes \boldsymbol{n})' \, \mathrm{d}S - (\boldsymbol{N})' \overset{!}{=} 0$$

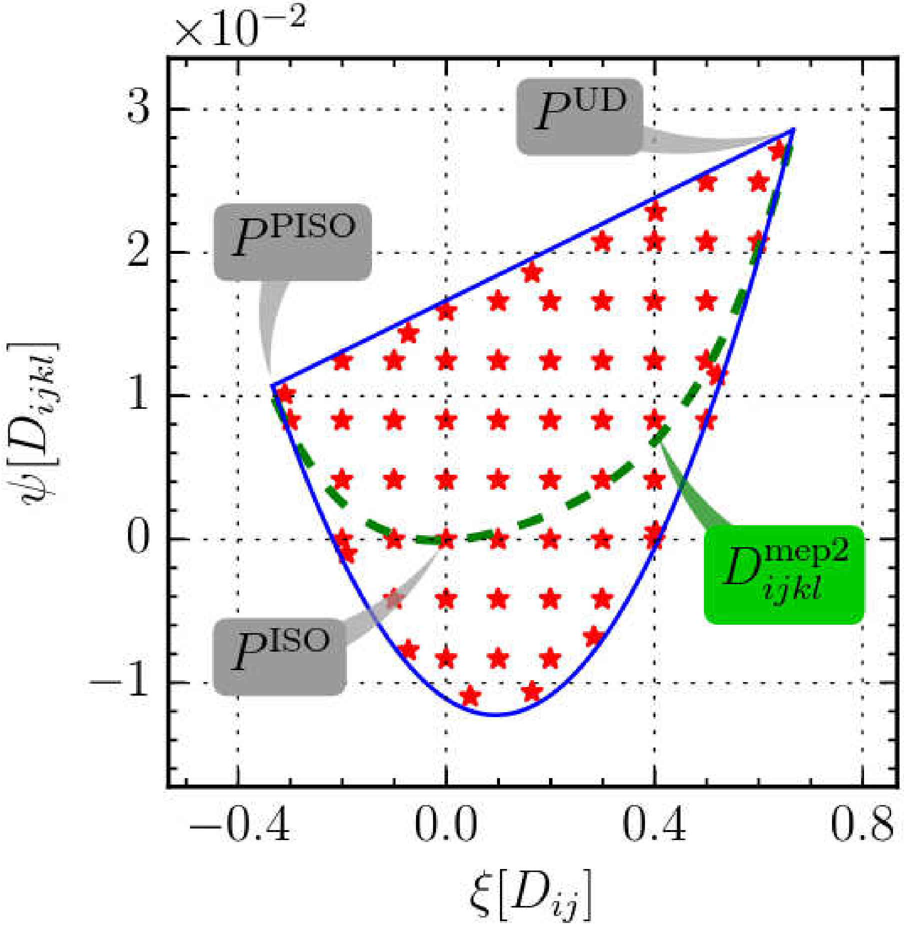
$$\mathcal{C}_{<4>} := \int_S \bar{f}(\boldsymbol{n})(\boldsymbol{n} \otimes \boldsymbol{n} \otimes \boldsymbol{n} \otimes \boldsymbol{n})' \, \mathrm{d}S - (\mathbb{N})' \overset{!}{=} 0$$

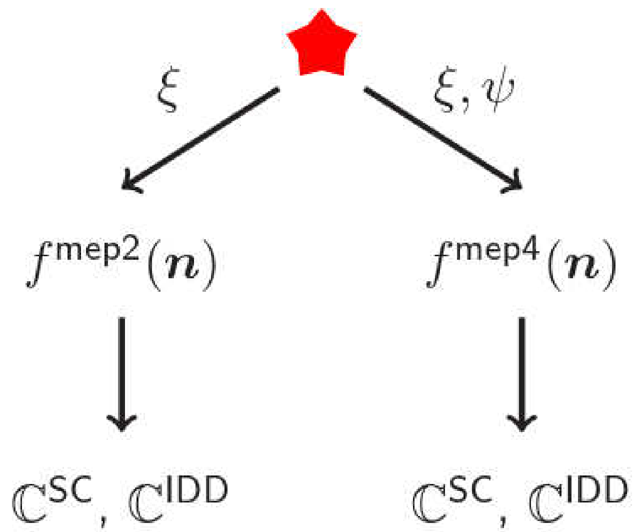
Optimization with Lagrange multipliers G, $\boldsymbol{G}$, $\mathbb{G}$

$$\mathcal{F} = \bar{S} - G \cdot \mathcal{C}_{<0>} - \boldsymbol{G} \cdot \mathcal{C}_{<2>} - \mathbb{G} \cdot \mathcal{C}_{<4>}$$

Parameter space for irreducible parameters

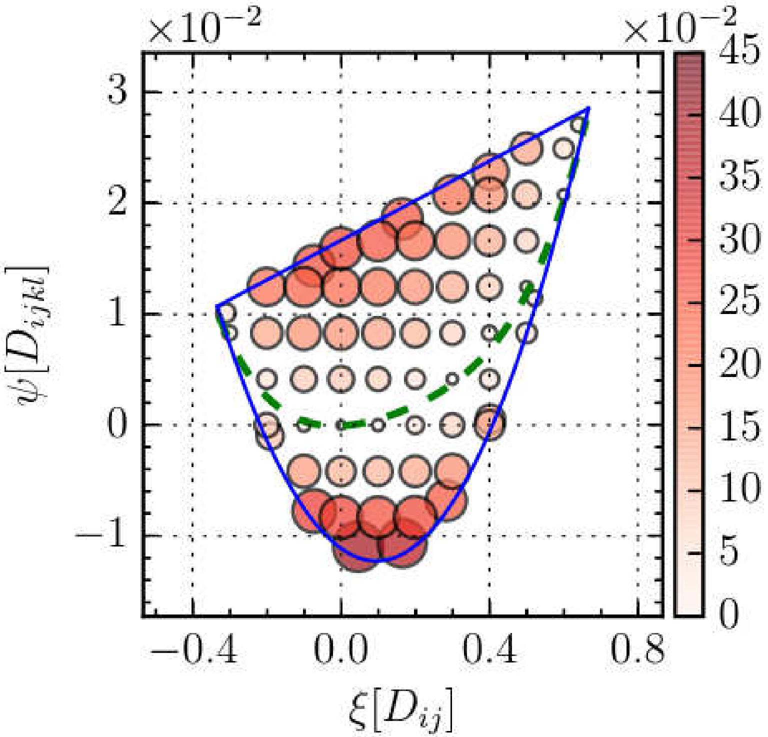
Müller and TB (IJSS, 2015)



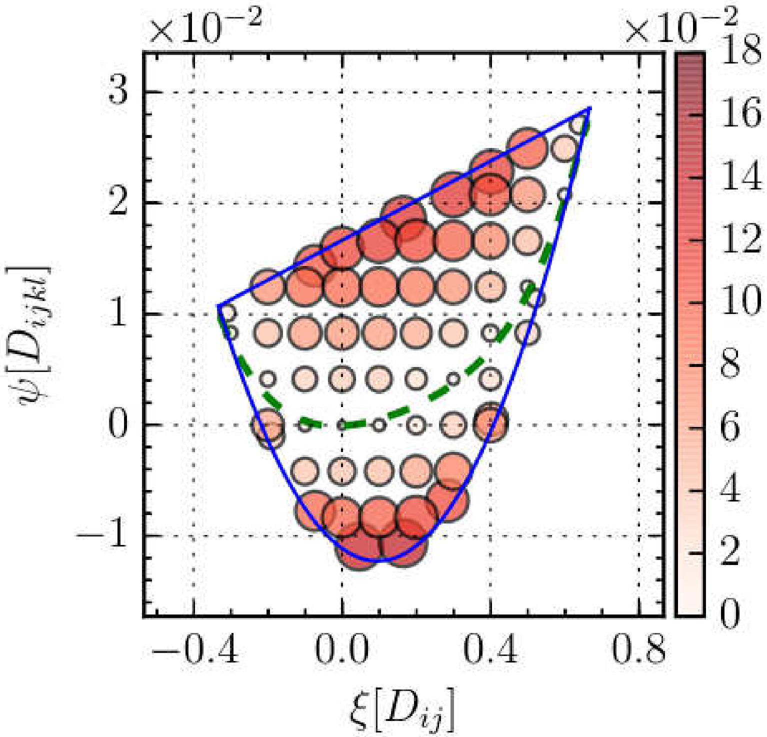


Deviation of Young's modulus (IDD)

Müller and TB (IJSS, 2015)



$$\frac{\|E_0^{\text{mep4}} - E_0^{\text{mep2}}\|}{\|E_0^{\text{mep4}}\|}$$



$$\frac{\|E_{90}^{\text{mep4}} - E_{90}^{\text{mep2}}\|}{\|E_{90}^{\text{mep4}}\|}$$

Mean Field vs Full-Field Modeling

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Material and microstructure parameter

Microstructure	Fiber vol. fraction		Material combination			
TP1	TP1/TP2	UD		$\eta = 44$	$\eta = 100$	$\eta = 1000$
TP2	13%	13%	E_F [GPa]	1.665	1	1
UD		17%	ν_F	0.36	0.36	0.36
		12%	E_M [GPa]	73	100	1000
			ν_M	0.36	0.36	0.36

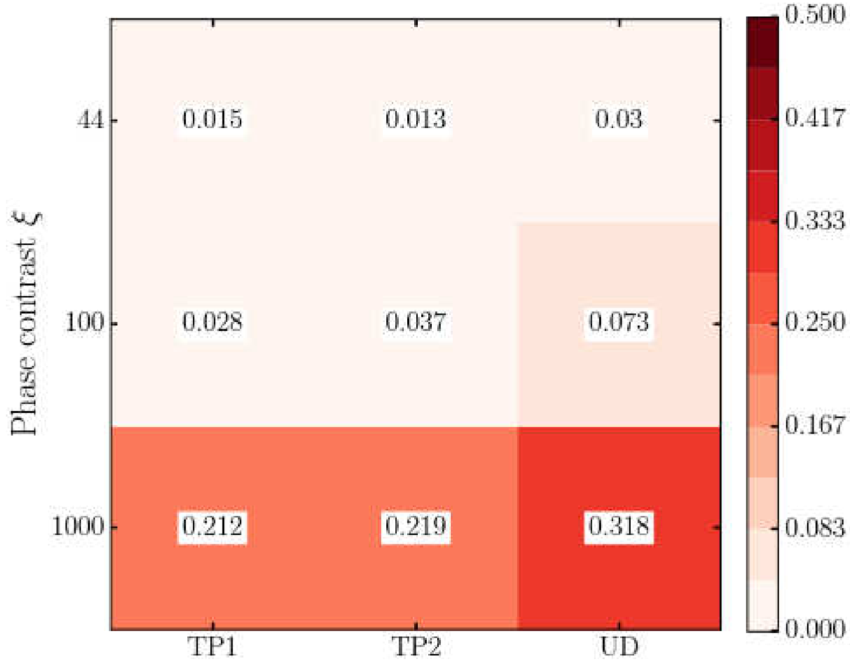
$$\boldsymbol{N}^{\mathrm{TP1}} = \begin{bmatrix} 0.61 & & \\ & 0.36 & \\ & & 0.03 \end{bmatrix} \quad \boldsymbol{N}^{\mathrm{TP2}} = \begin{bmatrix} 0.80 & & \\ & 0.18 & \\ & & 0.02 \end{bmatrix} \quad \boldsymbol{N}^{\mathrm{UD}} = \begin{bmatrix} 1.0 & & \\ & 0.0 & \\ & & 0.0 \end{bmatrix}$$

CoDiCo FRP

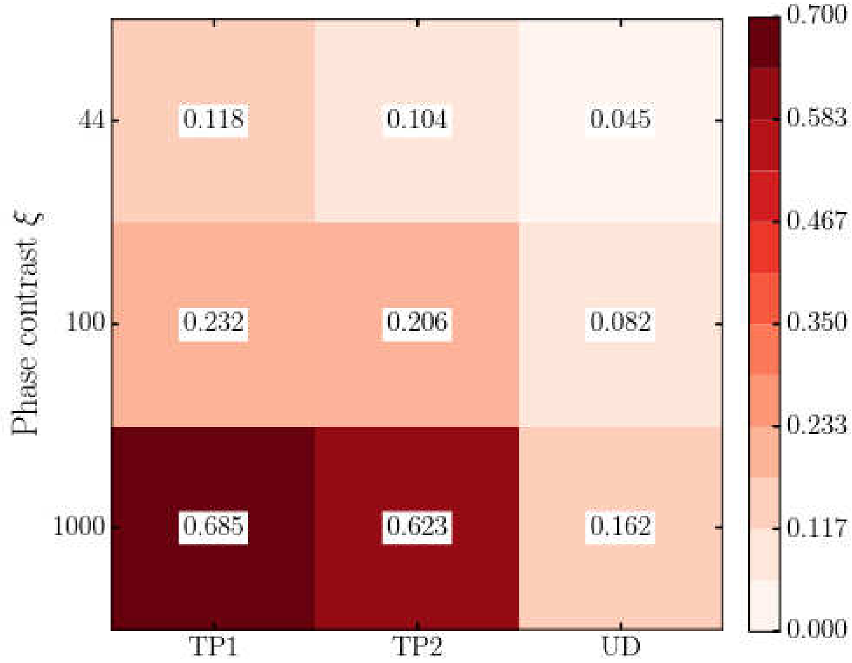
Influence of Phase Contast and Microstructure

Müller et al. (2015)

MF-IDD vs FFT-BS for $c_F = 13\%$



MF-SC vs FFT-BS for $c_F = 13\%$

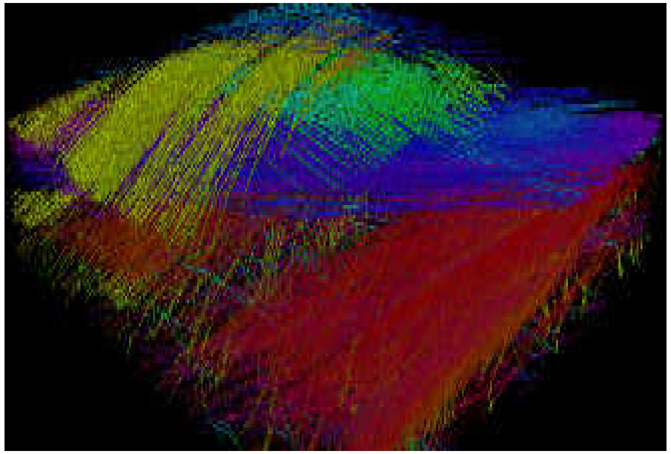


Microscale Characterization

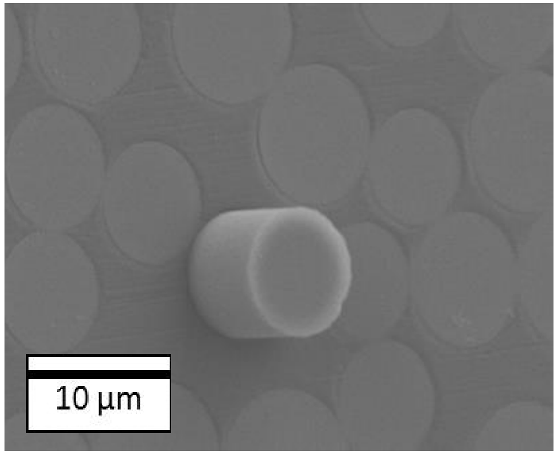
Contact: Pascal Pinter, pascal.pinter@kit.edu, KIT IAM-WK

Microscale Characterization

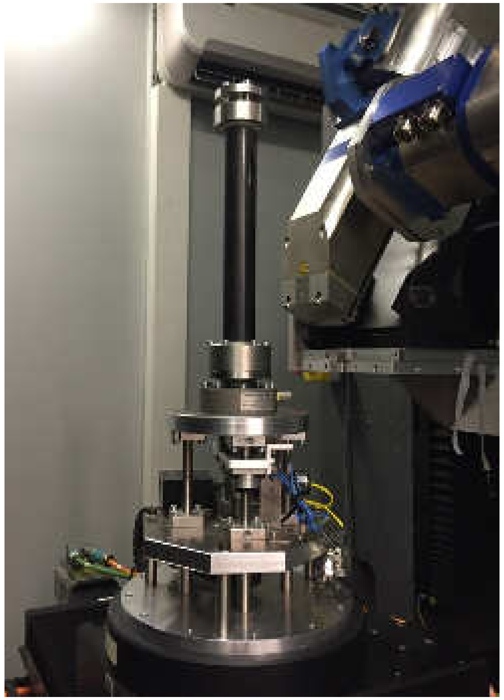
- Development and application of destructive and non-destructive testing methods:
  - Determination of 4th order orientation tensors directly from µCT-scans via in-house software “Composight”
  - Fiber length distributions from µCT-scans
  - Mechanical properties of fibers
  - Interfacial shear strength
  - In-Situ tensile tests for validation of models



Orientation analysis (SMC)



Push-Out-Test



In-Situ-Stage

[Contact: Pascal Pinter, pascal.pinter@kit.edu, KIT IAM-WK]

Microscale Characterization

- Developed methods during IRTG:
  - Fiber orientation distributions: Calculation of 4th order orientation tensors from µCT-Images
  - Fiber length distribution (FLD): Possible specimen size of D=4 mm with 81% correctly traced fibers

LFT20 Ø 4 mm specimen - independent fibers are illustrated in different colors

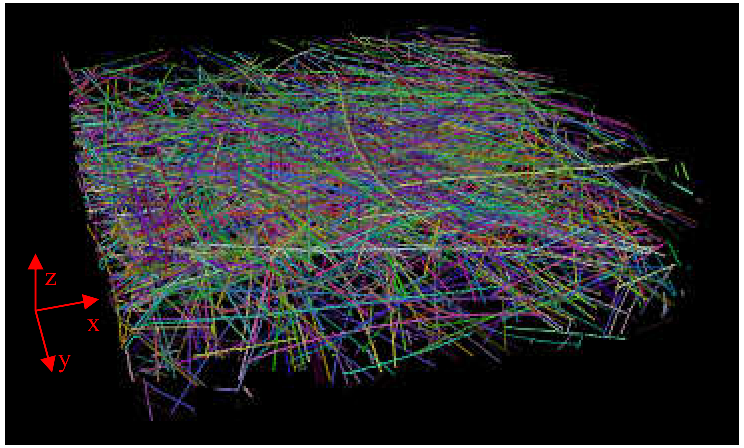
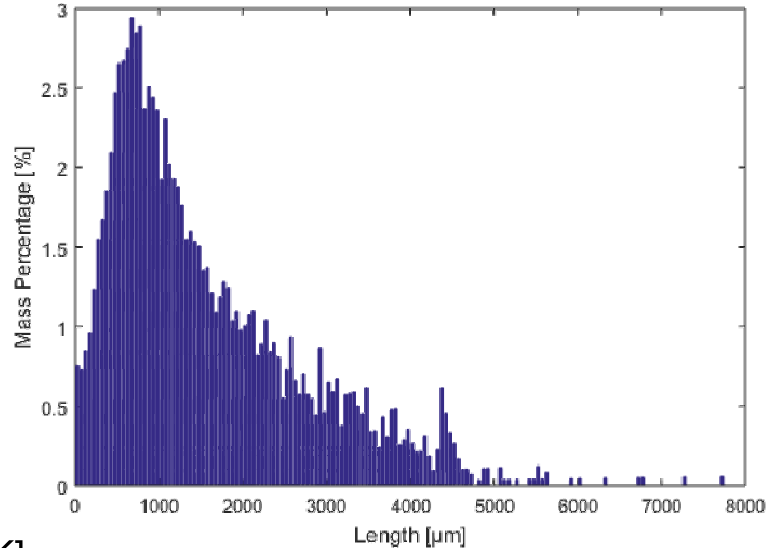


Image detail of same specimen 1.8x1.8x0.5 mm³



Fiber Length Distribution

[Contact: Pascal Pinter, pascal.pinter@kit.edu, KIT IAM-WK]

Microscale Simulation
and
Homogenization

Contact: Loredana Kehrer, loredana.Kehrer@kit.edu, KIT ITM

Characterization of mechanical properties by DMA

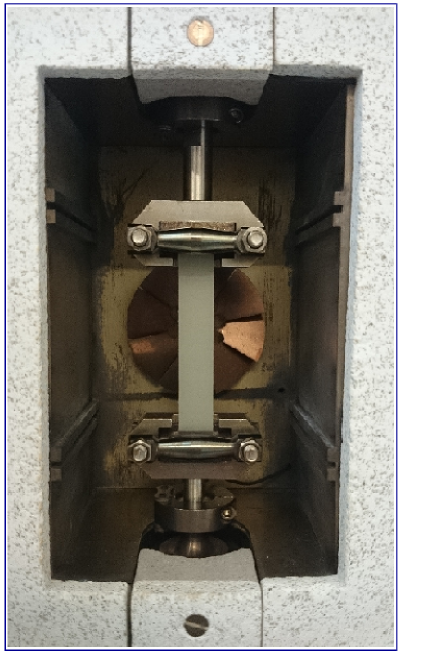
- Dynamic mechanical analysis (DMA) with GABO Eplexor 500 N
- Analysis of thermal and viscoelastic material properties
- Measured quantities $E^* = E' + iE''$

E^* : dynamic modulus,
E' : storage modulus,
E'' : loss modulus

- Specifications:

Static force	1500 N
Dynamic force	± 500 N
Temperature range	-150°C to 500°C
Frequency range	0.01 Hz to 100 Hz

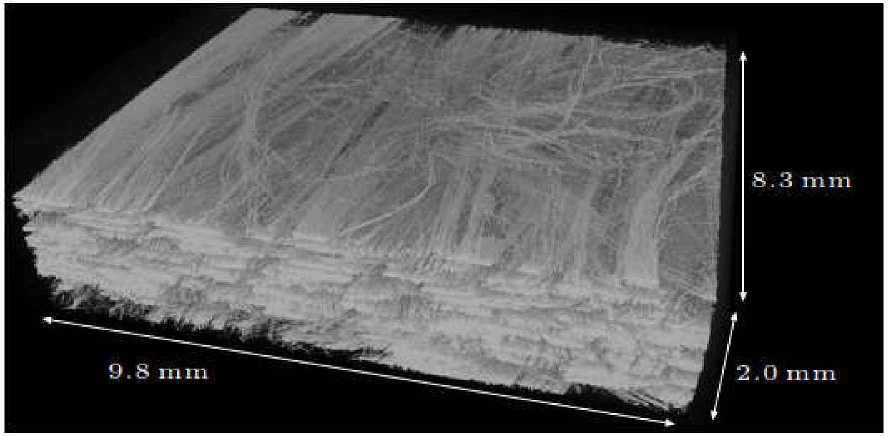
Quelle: GABO



Experimental results for tension mode under thermal load by DMA

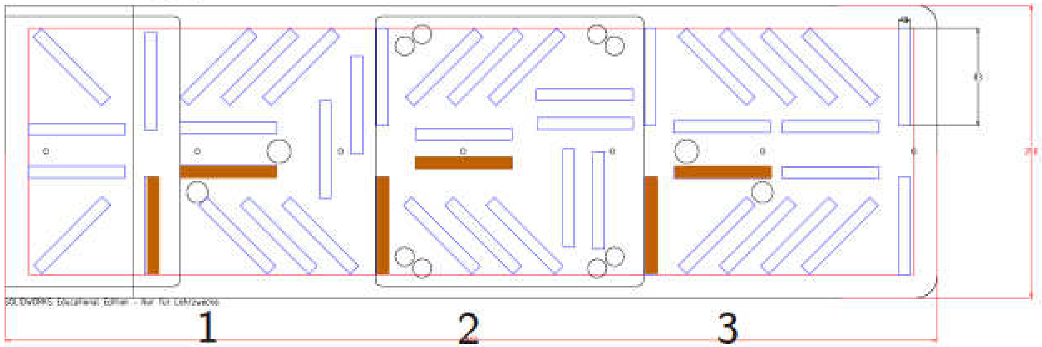
- GF DiCoFRTS

Resin system	VE resin
Fiber type	Glass
Fiber length	25 mm
Fiber content	41 wt.-%, 23 vol.-%



Source: P. Pinter (IAM-WK, KIT)

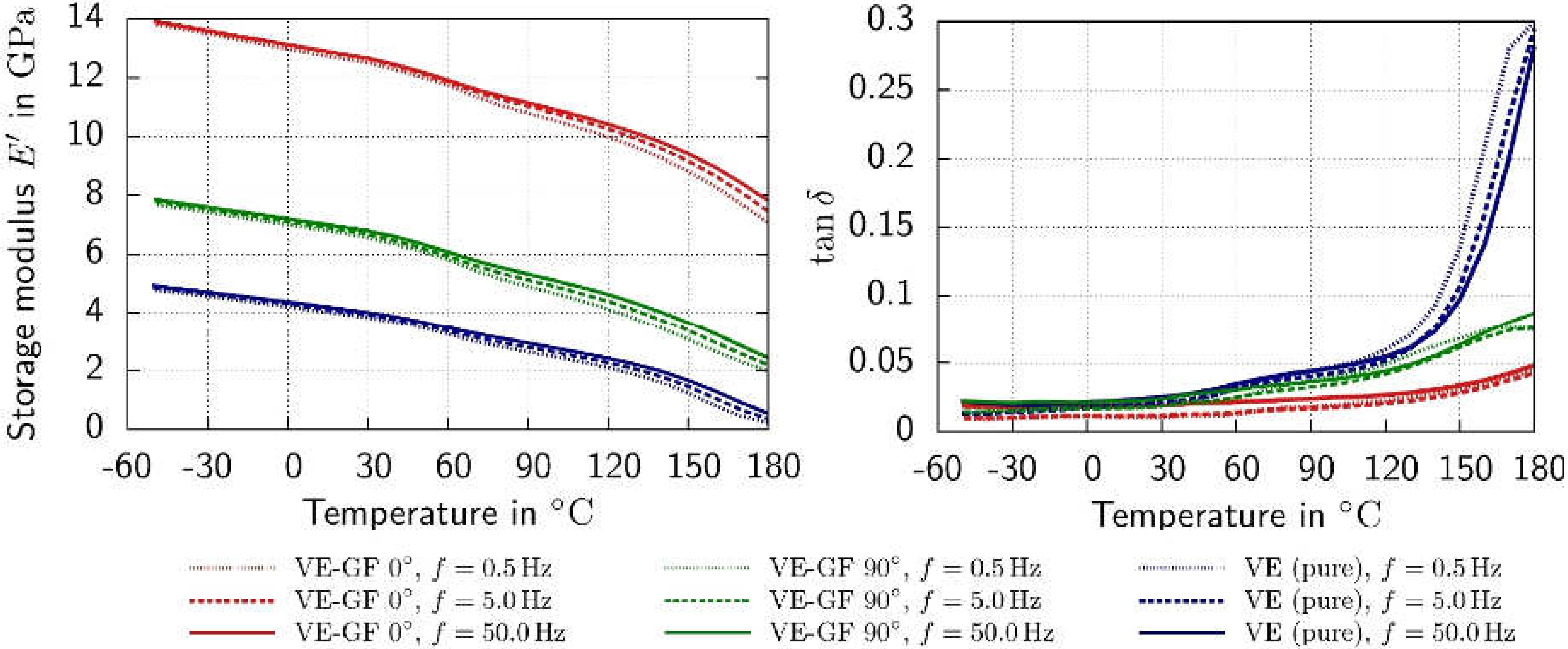
- Plate specifications:
  $800\,\mathrm{mm} \times 250\,\mathrm{mm} \times 2\,\mathrm{mm}$
- Filling of plate with resin at 33%, 50% and 100%
- Cutting plan



Mould charged with approx. 60% of semi-finished product

Experimental results for tension mode under thermal load by DMA

- Comparison of storage modulus for different temperature and frequency loads on VE-GF and pure VE



- Test parameters:

Static load ε_{stat} = 0.1%	Contact force F_c = 5 N
Dynamic load ε_{dyn} = 0.05%	Load cell capacity 500 N

Hashin-Shtrikman related two-step method

Walpole (9169), Willis (1977), Willis(1981), Müller (2015)

- Based on generalized formulation with eigenstrains
  - First step

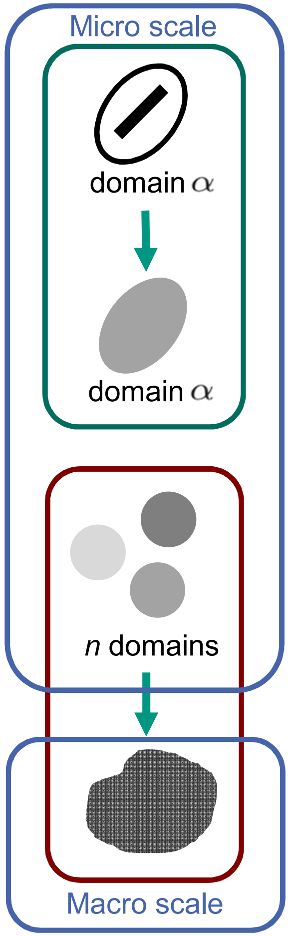
$$\bar{\mathbb{C}}_\alpha^{\mathrm{UD}+} = \mathbb{C}_\alpha + c_\mathrm{M}(\mathbb{C}_\mathrm{M} - \mathbb{C}_\alpha)\Big(\mathbb{I}^\mathrm{S} + c_\alpha \mathbb{P}_\alpha^\mathrm{UD}(\mathbb{C}_\mathrm{M} - \mathbb{C}_\alpha)\Big)^{-1}$$

$$\bar{\mathbb{C}}_\alpha^{\mathrm{UD}-} = \mathbb{C}_\mathrm{M} + c_\alpha(\mathbb{C}_\alpha - \mathbb{C}_\mathrm{M})\Big(\mathbb{I}^\mathrm{S} + c_\mathrm{M} \mathbb{P}_\alpha^\mathrm{UD}(\mathbb{C}_\alpha - \mathbb{C}_\mathrm{M})\Big)^{-1}$$

  - Second step

$$\bar{\mathbb{C}}^{\mathrm{HS}\pm} = \sum_{\alpha=1}^{n} \frac{c_\alpha}{c_\mathrm{F}} \bar{\mathbb{C}}_\alpha^{\mathrm{UD}\pm} \mathbb{A}_\alpha^\mathrm{HS} = \sum_{\alpha=1}^{n} \frac{c_\alpha}{c_\mathrm{F}} \bar{\mathbb{C}}_\alpha^{\mathrm{UD}\pm} \mathbb{M}_\alpha \langle \mathbb{M} \rangle^{-1}$$

$$\mathbb{M}_\alpha = \Big(\mathbb{I}^\mathrm{S} + \mathbb{P}_0(\bar{\mathbb{C}}_\alpha^{\mathrm{UD}\pm} - \mathbb{C}_0)\Big)^{-1} \quad \text{and} \quad \langle \mathbb{M} \rangle = \textstyle\sum_{\alpha=1}^{n} \frac{c_\alpha}{c_\mathrm{F}} \mathbb{M}_\alpha$$



- Two-step method for formulation with variable reference stiffness $\mathbb{C}_0$

$$\mathbb{C}_0 = (1-a)\mathbb{C}_\mathrm{M} + a\,\mathbb{C}_\mathrm{F} \qquad a \in [0,1]$$

Mean field and full field simulation

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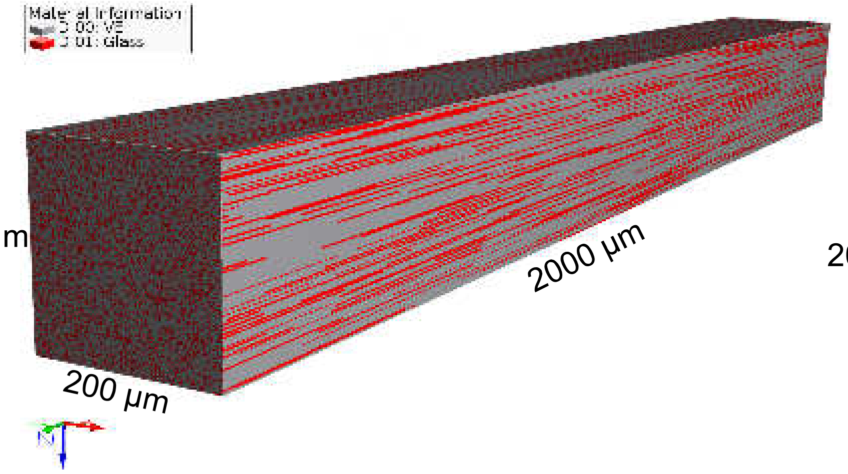
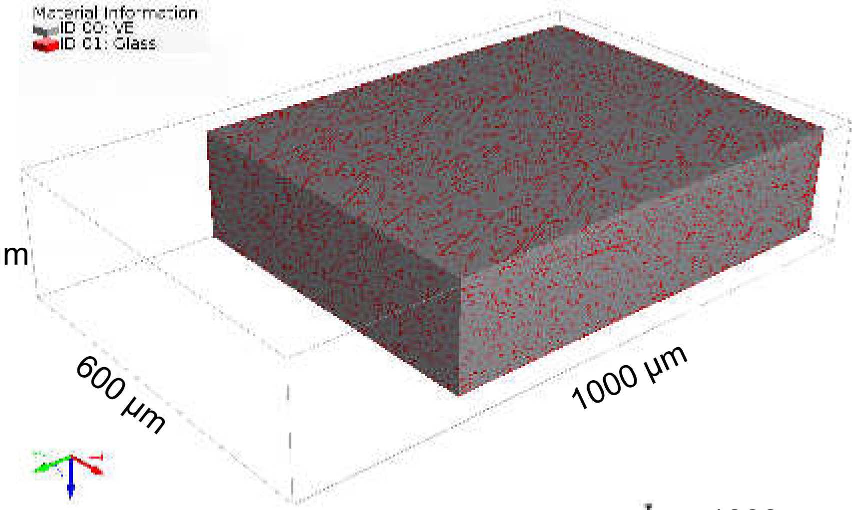
- Virtual microstructure generated with GeoDict®
  - Unidirectional long fibers
  - Randomly non-uniform distributed long fibers





l_F = 1500 µm

d_F = 10 µm

l_F = 1000 µm

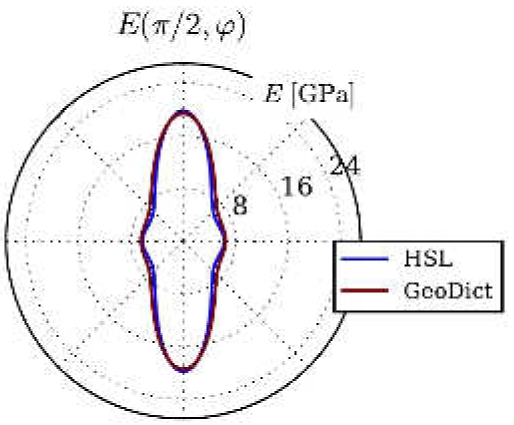
d_F = 10 µm

- Material parameters:

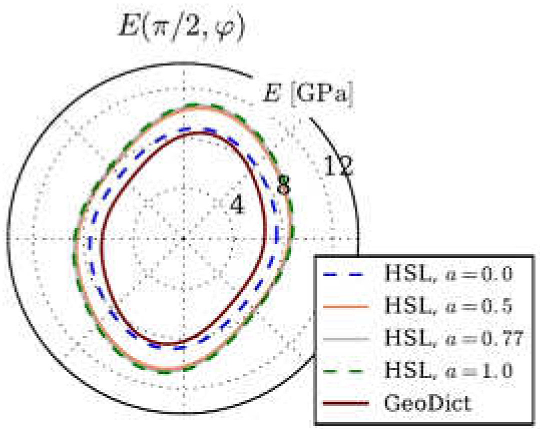
Matrix	Young's modulus E_M	4.0 MPa
	Poisson's ratio ν_M	0.35
Fiber	Young's modulus E_F	73.0 MPa
	Poisson's ratio ν_F	0.22
	Fiber volume fraction c_F	0.23

Comparison between full field and mean field homogenization

- Young‘s modulus for UD fibers in matrix material



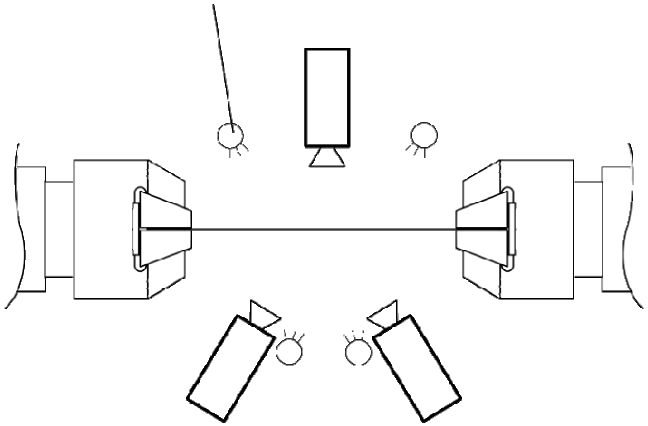
- Young‘s modulus for randomly non-uniform distributed fibers in matrix material



Macroscale Simulation
and
Characterization

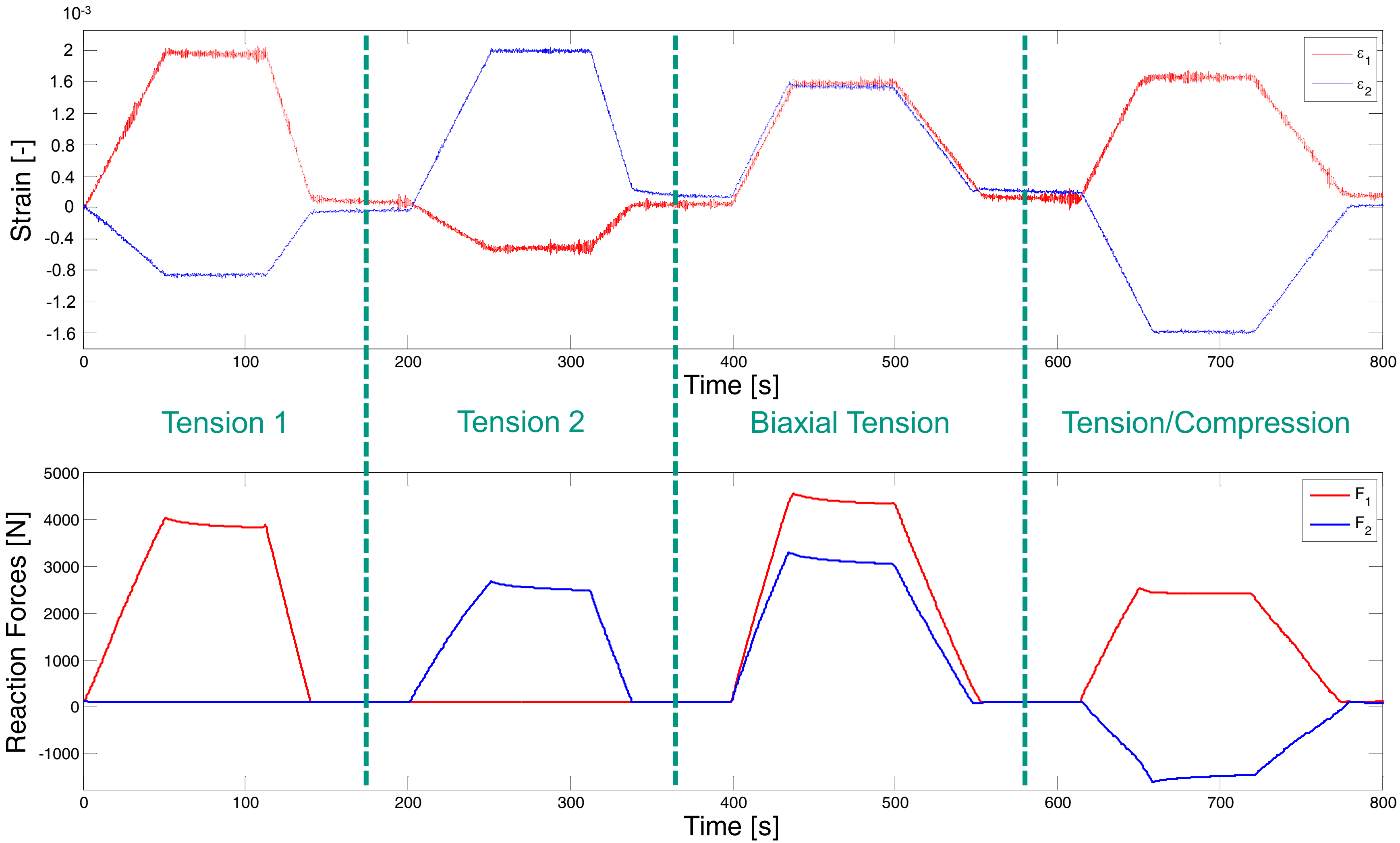
Contact:
Malte Schemmann, malte.schemmann@kit.edu, KIT ITM

Biaxial Tensile Machine (ITM)

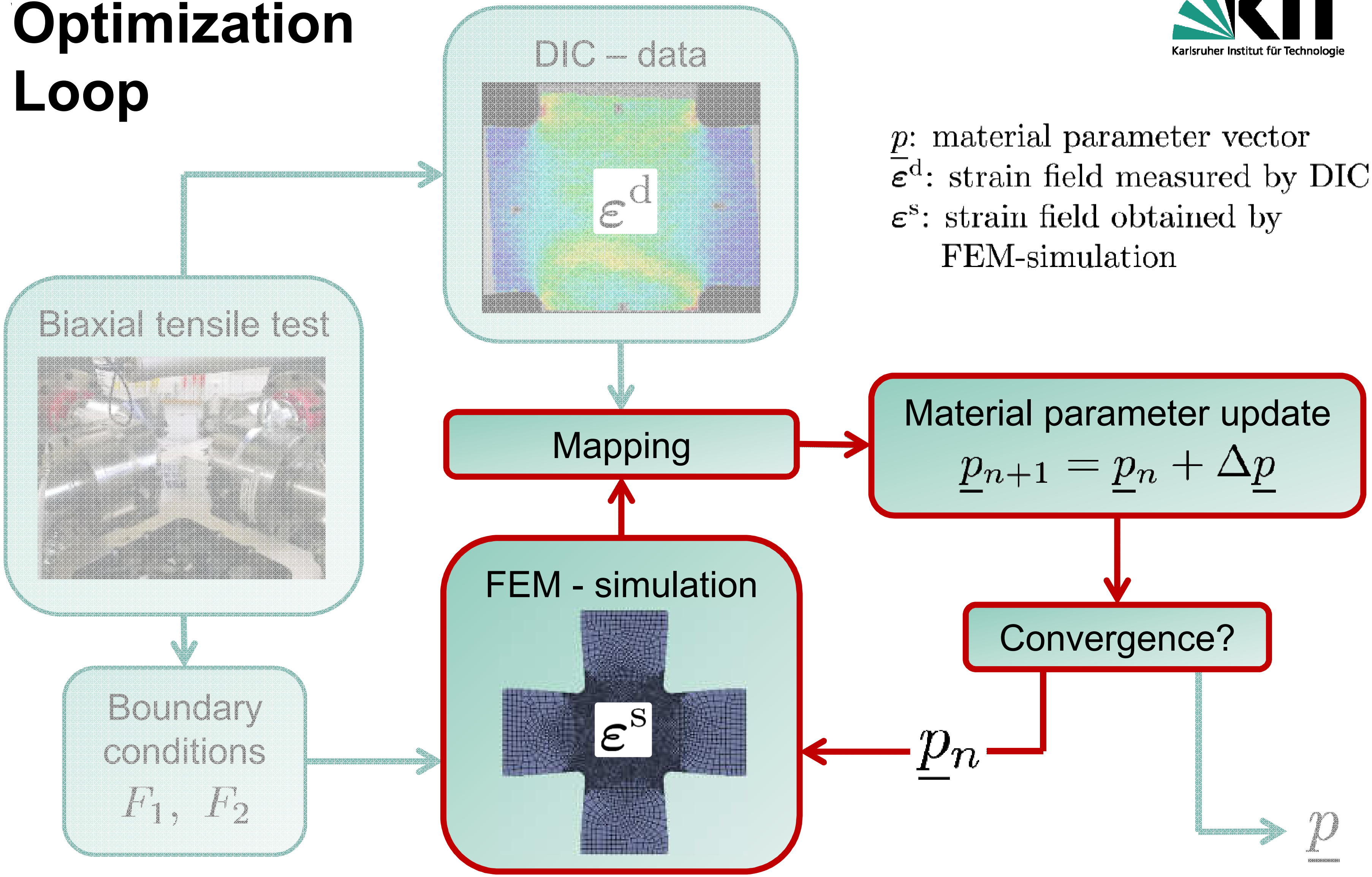


- Actors: four independent axes (maximum load: 150kN)
- Sensors:
  - Force measurement (on all four axes)
  - Integrated strain (Video XTens)
  - Full strain field via digital image correlation (GOM ARAMIS 4M)
- Active midpoint control

Viscoelastic Biaxial Tensile Tests: Prescribed Strain / Force Paths



Optimization Loop



$\underline{p}$: material parameter vector
$\bar{\varepsilon}^{d}$: strain field measured by DIC
ε^{s}: strain field obtained by FEM-simulation

Inverse Parameter Identification

- Problem: Find parameter $\underline{p}$ that minimizes the error Function $f(\underline{p})$

$$\underline{r}(\underline{p}) = \sum_{i=1}^{K}\sum_{j=1}^{N}\begin{pmatrix}\left|\varepsilon_{11,i,j}^{\text{sim}}(\underline{p}) - \varepsilon_{11,i,j}^{\text{exp}}\right| \\ \left|\varepsilon_{22,i,j}^{\text{sim}}(\underline{p}) - \varepsilon_{22,i,j}^{\text{exp}}\right| \\ \left|\gamma_{12,i,j}^{\text{sim}}(\underline{p}) - \gamma_{12,i,j}^{\text{exp}}\right|\end{pmatrix}$$

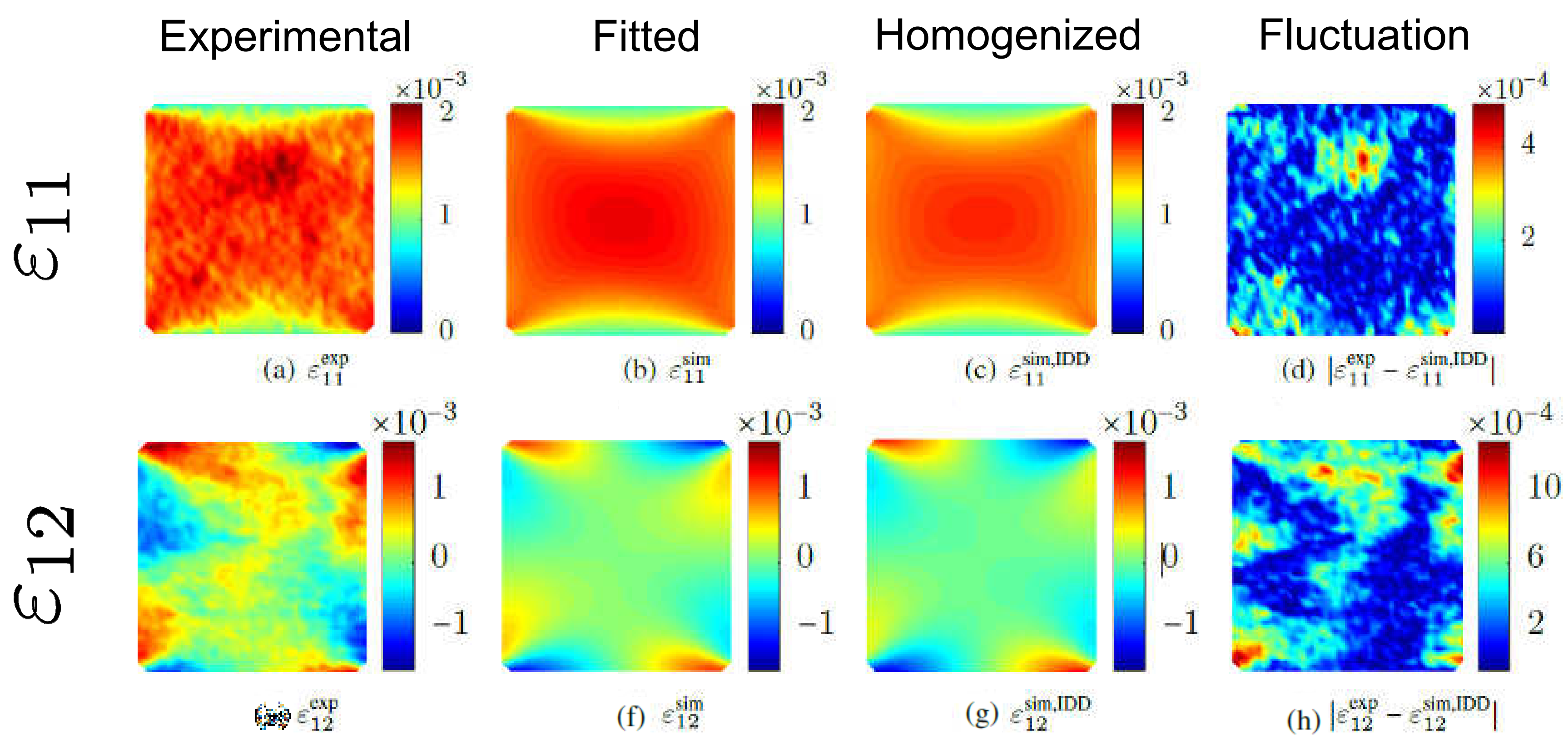
Louis (1989)
Mahnken et al. (1996)
Cooreman et al. (2007)

- Gauss-Newton procedure

$$f(\underline{p}) = ||\underline{r}(\underline{p})||_2^2 = \underline{r}(\underline{p})^{\mathsf{T}}\underline{r}(\underline{p}) \rightarrow \min_{\underline{p}\in\mathcal{P}}$$

$$\underline{p}^{k+1} = \underline{p}^k - \left[\underline{\underline{J}}(\underline{p}^k)^{\mathsf{T}}\underline{\underline{J}}(\underline{p}^k)\right]^{-1}\underline{\underline{J}}(\underline{p}^k)^{\mathsf{T}}\underline{r}(\underline{p}^k) \qquad J_{ij}(\underline{p}) = \frac{\partial\varepsilon_i^{\text{s}}(\underline{p})}{\partial p_j}$$

Validation Tension-Compression Loading



- The experimentally measured, fitted and homogenized strain field show a comparably good agreement
- SMC shows heterogeneities, possibly induced by varying fiber orientation or volume fraction

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Form Filling: Micromechanical Modeling

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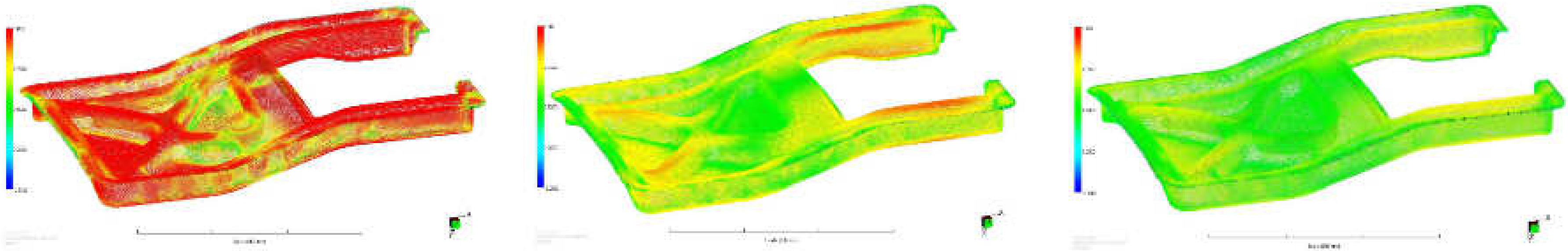
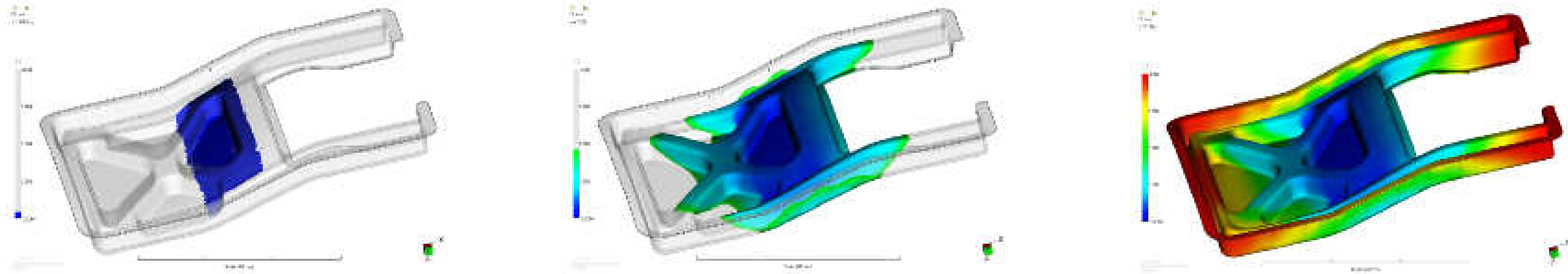
Form Filling Simulations – Motivation

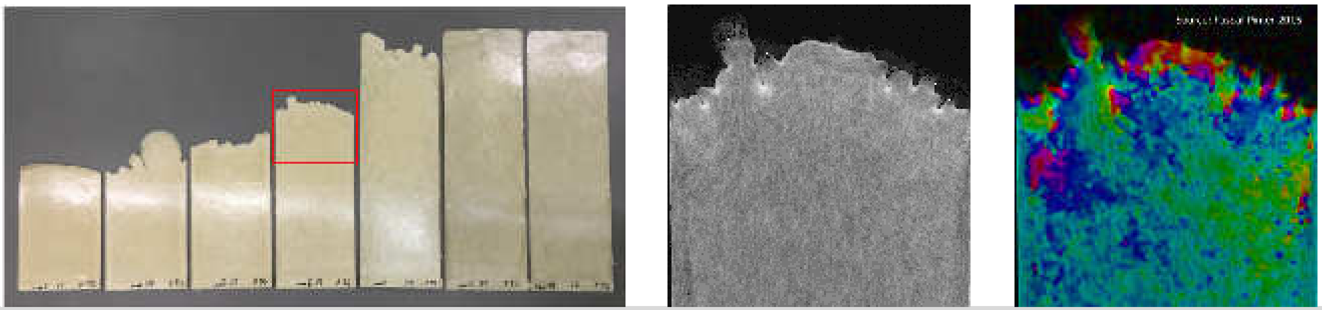
- Prediction of the **fiber orientation** of compression molded DiCoFRP (Buck2014)



- Prediction of the **flow front** evolution during compression molding (Buck2014)



- Development of the simulations through **comparison to experiments**



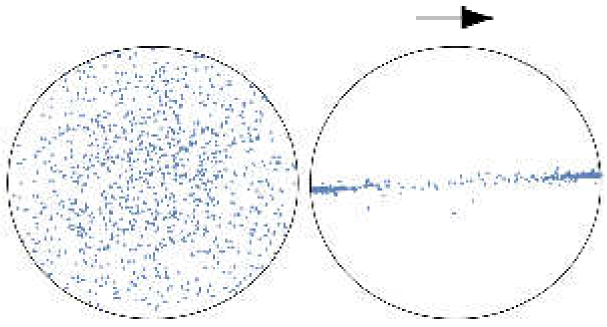
Evolution equations of Single Fiber and FOTs

- Change of single rigid-fiber orientation (Jeffery1922)

$$\dot{\boldsymbol{n}}_\alpha = \bar{\boldsymbol{W}}[\boldsymbol{n}_\alpha] + \bar{\xi}(\bar{\boldsymbol{D}}[\boldsymbol{n}_\alpha] - (\boldsymbol{n}_\alpha \otimes \boldsymbol{n}_\alpha \otimes \boldsymbol{n}_\alpha)[\bar{\boldsymbol{D}}])$$

where: $\bar{\boldsymbol{L}} = \mathrm{grad}(\bar{\boldsymbol{v}}) = \bar{\boldsymbol{D}} + \bar{\boldsymbol{W}}$ $\quad \bar{\boldsymbol{D}} = \frac{1}{2}(\bar{\boldsymbol{L}} + \bar{\boldsymbol{L}}^{\mathrm{T}})$

$\bar{\boldsymbol{W}} = \frac{1}{2}(\bar{\boldsymbol{L}} - \bar{\boldsymbol{L}}^{\mathrm{T}})$ $\quad \bar{\xi} = \frac{\bar{a}^2 - 1}{\bar{a}^2 + 1}$ $\quad \bar{a} = \bar{l}/\bar{d}$



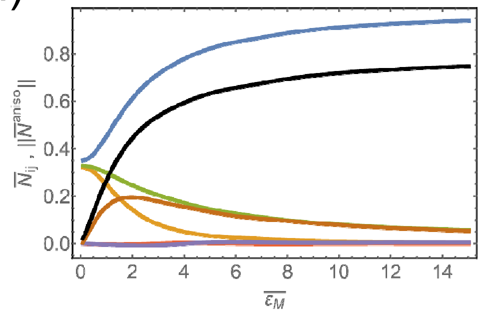
- Jeffery's equation for FOTs (including closure problem)

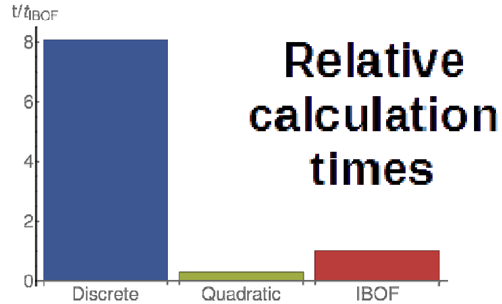
$$\dot{\bar{\boldsymbol{N}}} = \bar{\boldsymbol{W}}\bar{\boldsymbol{N}} - \bar{\boldsymbol{N}}\bar{\boldsymbol{W}} + \bar{\xi}(\bar{\boldsymbol{D}}\bar{\boldsymbol{N}} + \bar{\boldsymbol{N}}\bar{\boldsymbol{D}} - 2\bar{\mathbb{N}}^*[\bar{\boldsymbol{D}}])$$

where: $\bar{\mathbb{N}}^{\mathrm{Quad}} = \bar{\boldsymbol{N}} \otimes \bar{\boldsymbol{N}}$ (Doi1981)

(Chung2002)

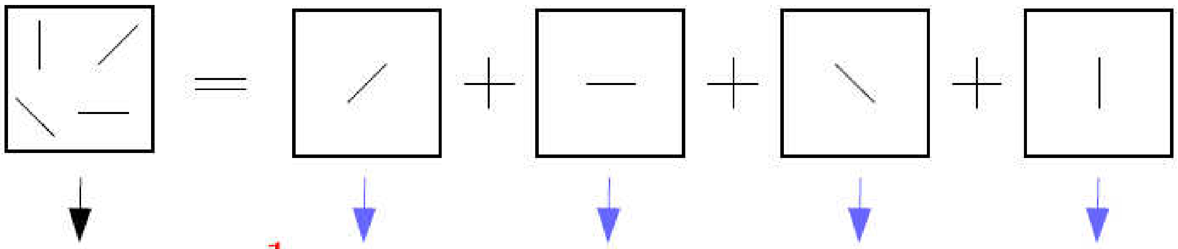
$$\begin{aligned}\bar{\mathbb{N}}^{\mathrm{IBOF}} = \; & \beta_1 \,\mathrm{sym}(\boldsymbol{1} \otimes \boldsymbol{1}) + \\ & \beta_2 \,\mathrm{sym}(\boldsymbol{1} \otimes \bar{\boldsymbol{N}}) + \\ & \beta_3 \,\mathrm{sym}(\bar{\boldsymbol{N}} \otimes \bar{\boldsymbol{N}}) + \\ & \beta_4 \,\mathrm{sym}(\boldsymbol{1} \otimes \bar{\boldsymbol{N}}\bar{\boldsymbol{N}}) + \\ & \beta_5 \,\mathrm{sym}(\bar{\boldsymbol{N}} \otimes \bar{\boldsymbol{N}}\bar{\boldsymbol{N}}) + \\ & \beta_6 \,\mathrm{sym}(\bar{\boldsymbol{N}}\bar{\boldsymbol{N}} \otimes \bar{\boldsymbol{N}}\bar{\boldsymbol{N}})\end{aligned}$$





DFG GRK 2078 – Böhlke, Henning, Kärger, Seelig, Weidenmann
14. Deutsches LS-DYNA Forum, Bamberg, 10-14.10.2016

Homogenization of the viscosity



macro scale $\bar{\mathbb{V}} = \frac{1}{4}(\bar{\mathbb{V}}_1^{\mathrm{ud}} + \bar{\mathbb{V}}_2^{\mathrm{ud}} + \bar{\mathbb{V}}_3^{\mathrm{ud}} + \bar{\mathbb{V}}_4^{\mathrm{ud}})$ 2. step

- 1. step: calculating the unidirectional effective viscosity(s) (Hasin-Strikman lower bound) (Walpole1969, Castaneda1998)
- 2. step: calculating the overall effective linear viscosity (orientation averaging, Voigt average, upper bound) (Advani1987)
- It is sufficient to calculate the unidirectional effective viscosity only once, and calculate the overall effective viscosity with the help of FOTs

$$\bar{\mathbb{V}}_\alpha^{\mathrm{ud}} = \mathbb{V}^{\mathrm{m}} + \frac{c_{\mathrm{f}}}{c_{\mathrm{m}}}\mathbb{P}_\alpha^{-1}$$

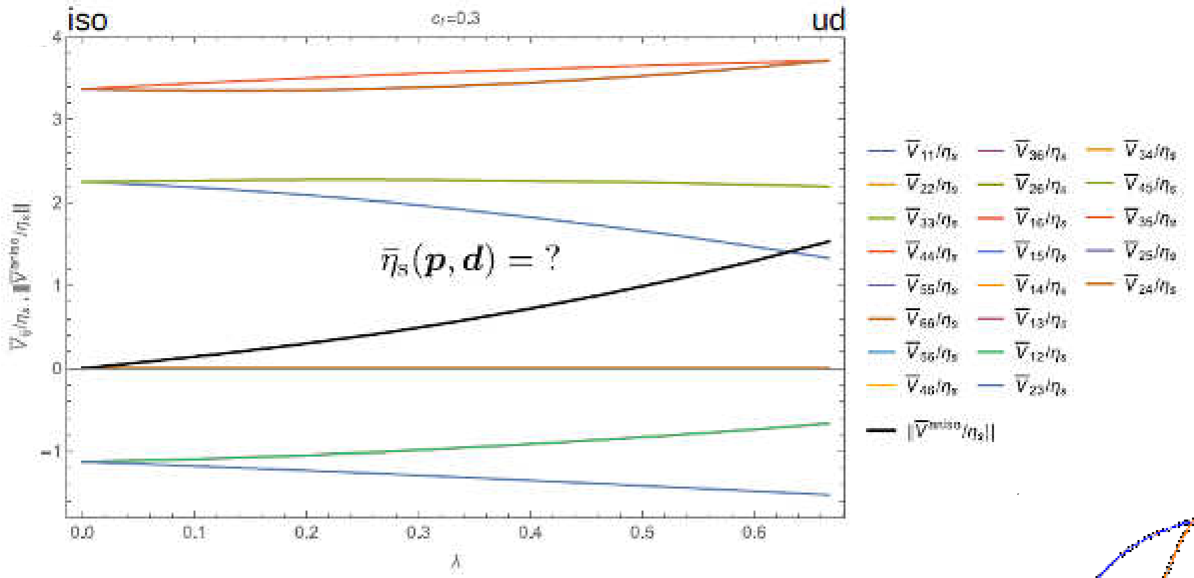
$$\bar{\mathbb{V}} = \frac{1}{N}\sum_{\alpha=1}^{N} \bar{\mathbb{V}}_\alpha^{\mathrm{ud}}$$

$$\bar{\mathbb{V}} = f(\bar{\mathbb{V}}_x^{\mathrm{ud}}, \bar{\boldsymbol{N}}, \bar{\mathbb{N}})$$

Homogenization of the viscosity

$$\bar{\boldsymbol{N}}^{\mathrm{iso}}(\lambda=0)=\begin{pmatrix}\frac{1}{3}&&\\&\frac{1}{3}&\\&&\frac{1}{3}\end{pmatrix}\quad \bar{\boldsymbol{N}}(\lambda)=\begin{pmatrix}\frac{1}{3}+\lambda&&\\&\frac{1}{3}+\frac{\lambda}{2}&\\&&\frac{1}{3}+\frac{\lambda}{2}\end{pmatrix}\quad \bar{\boldsymbol{N}}^{\mathrm{ud}}(\lambda=\frac{2}{3})=\begin{pmatrix}1&&\\&0&\\&&0\end{pmatrix}$$

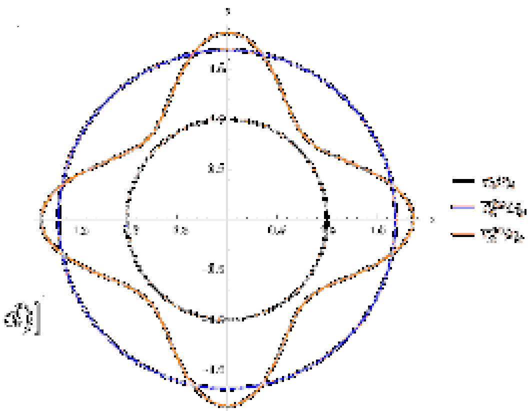
$$\Rightarrow \bar{\mathbb{V}}(\lambda):$$



- Sensitivity of the effective tensorial viscosity

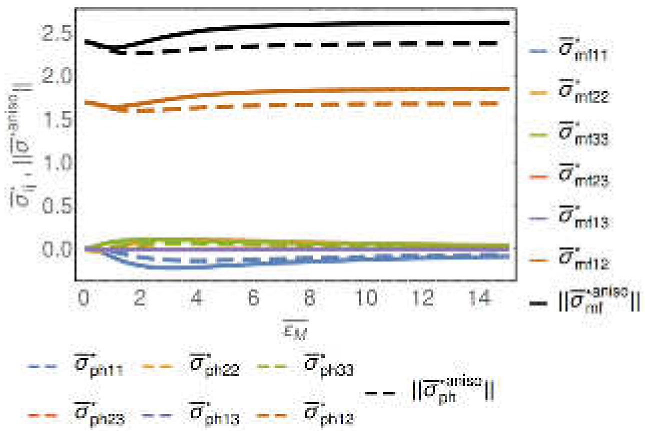
$$\bar{\eta}_s(p,d)=\frac{1}{2M(p,d)\cdot\bar{\mathbb{V}}^{-1}[M(p,d)]}$$

$$M(p,d)=\sqrt{2}(p\otimes d+d\otimes p)/2$$

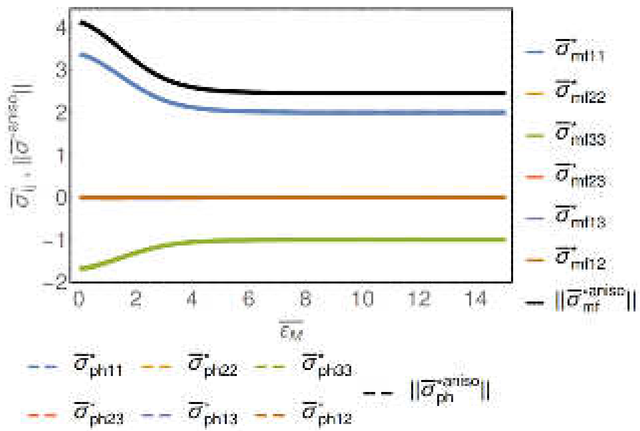


Test Cases – Stress tensor

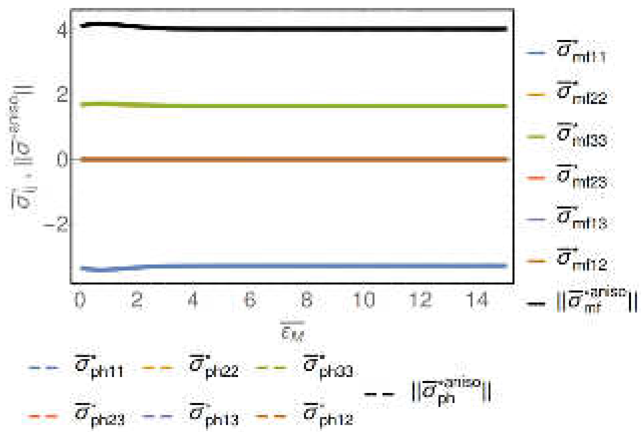
Simple shear flow



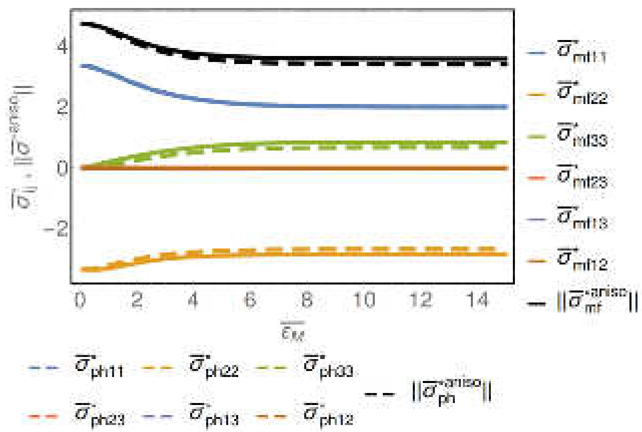
Isochoric elongation flow



Isochoric compression flow



Plain strain flow



Conclusions and Outlook

Karlsruher Institut für Technologie

- An **interdisciplinary and integrated engineering** approach is necessary for the application of CoDiCoFRP
- A virtual process chain is required for taking the highly process-dependent material properties into account
- Adaption and validation of a complex virtual process chain is only feasible with a **standardization data formats**
- Future work will extend the material range the thermoplastics
- A reference structure will be established by GRK 2078 in 2017 :
  - Incorporation of all technology projects within the process chain
  - Geometry is obtained by fully coupled design optimization, thereby considering modfilling and structural analysis including damage

Thank you for your attention.

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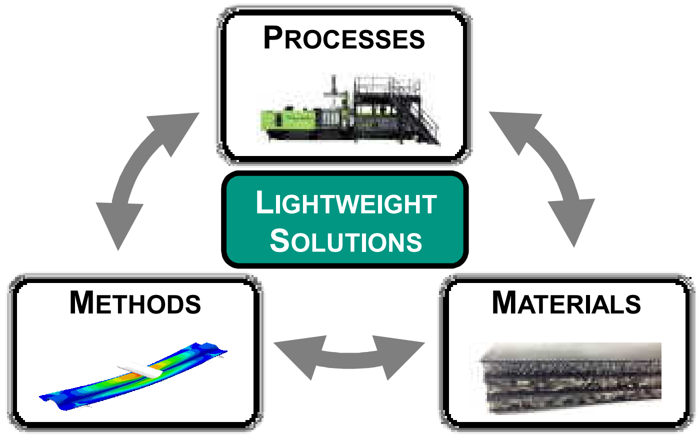
GRK 2078 CoDiCoFRP

www.grk2078.kit.edu

KIT - LIGHTWEIGHT DESIGN NETWORK



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