Integrated engineering of continuous-discontinuous long fiber reinforced polymer (CoDiCoFRP) structures in the framework of the International Research Training Group GRK 2078

Thomas Böhlke (KIT-ITM), Luise Kärger (KIT-FAST), Kay André Weidenmann (KIT-IAM-WK), Thomas Seelig (KIT-IFM), Frank Henning (KIT-FAST)

5. Fachkongress Composite Simulation, 25 February 2016

DFG GRK2078 Members

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Co-Speaker: Prof. Frank Henning

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Speaker: Prof. Kay Weidenmann

PhD cand.: Michael Schober, Pascal Pinter, Anna Trauth

Research Area Simulation

Speaker: Prof. Thomas Seelig

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Speaker: Prof. Frank Henning

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Research Area Design

Speaker: Dr.-Ing. Luise Kärger

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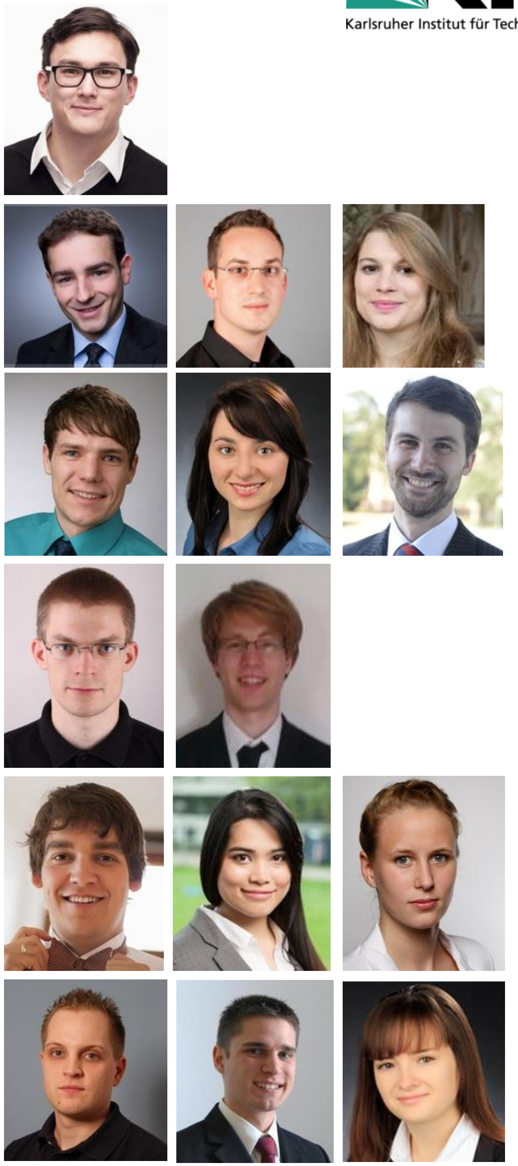


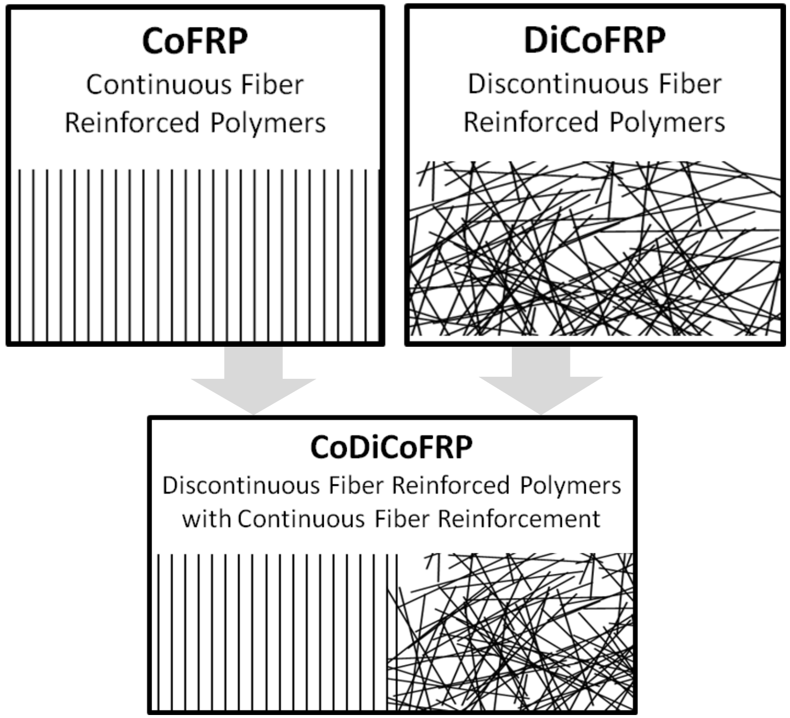
Outline

- Introduction of GRK2078 CoDiCoFRP
  - Motivation and Objectives
  - Product Development Process
  - Overview PhD Topics

- PhD Topics (Selection)
  - CoDiCoFRP Processing (RA Technology)
  - Rheological Measurement and Process Simulation (RA Charakt. und Simulation)
  - Characterization of the Micro Structure of DiCoFRP (RA Charakterisierung)
  - Biaxial Testing and Material Modelling of DiCoFRP (RA Simulation)
  - Patch Optimization (RA Design)

FRP Classes: Introduction and Application

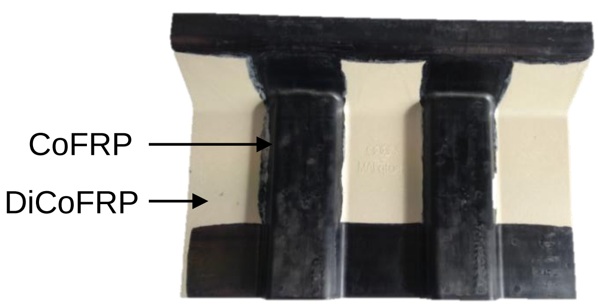
- ➕ High fiber volume content
- ➕ Controlled fibers alignment
- ➕ High stiffness and strength
- ➖ Restricted formability
- ➖ High cycle times
- ➖ High scrap rate
- ➖ Extensive trimming



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

Carbon cell

Frontend made of DiCoFRP



CoDiCoFRP component (front side)

CoDiCoFRP component (back side)

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5. Fachkongress Composite Simulation, Hamburg, 25.02.2016

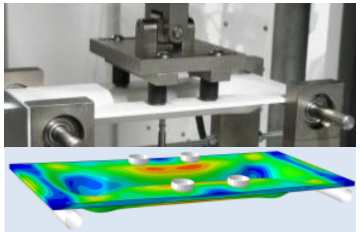
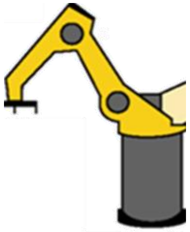
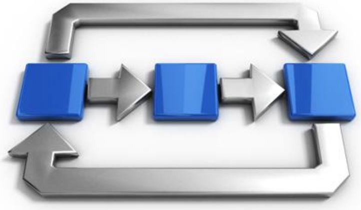
Challenges and Program Objectives

Challenges

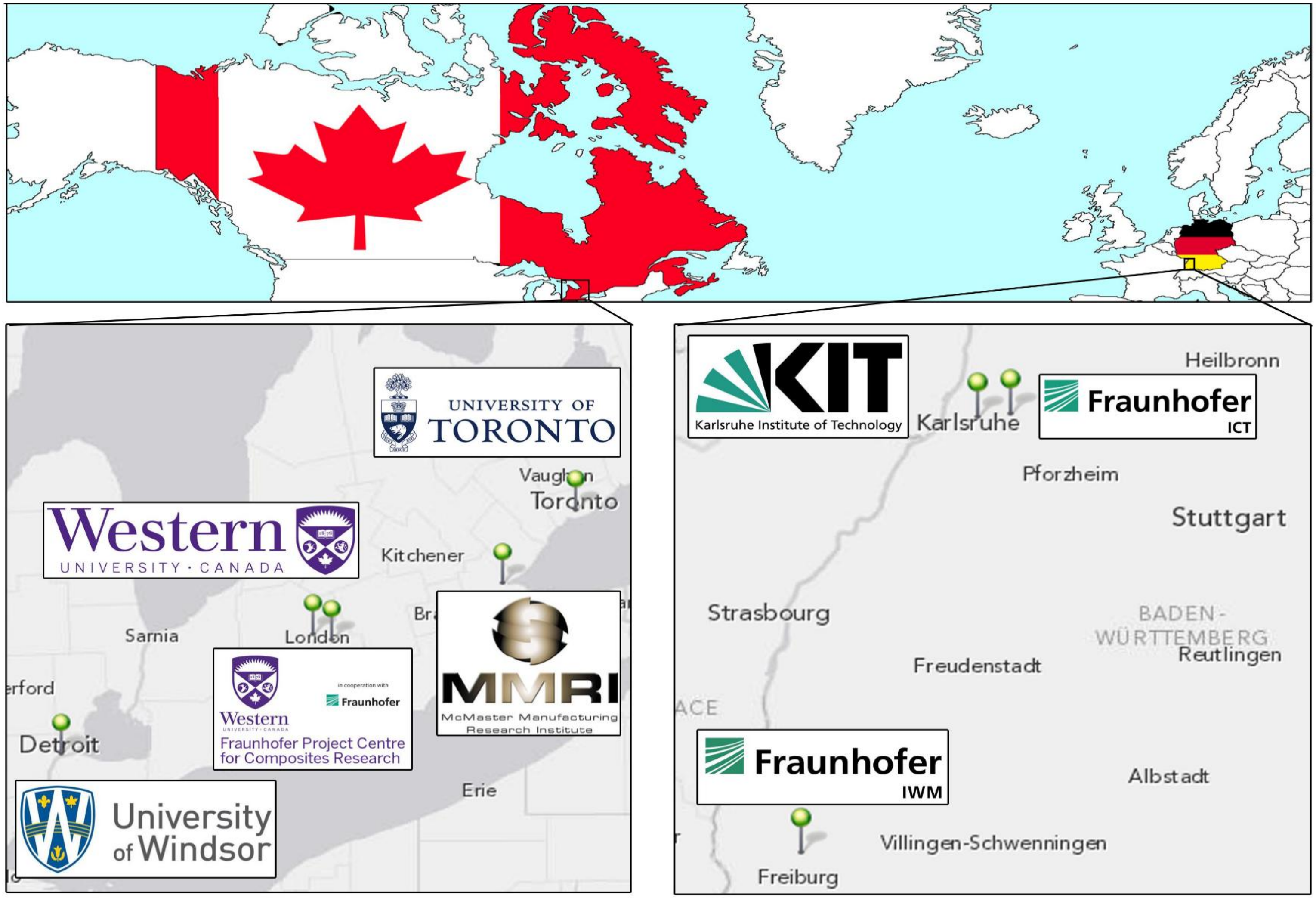
Lack of **numerical** and **characterization methods**	Need for concepts for **manufacturing, automation** and **quality control**	**Full optimization** of the **processing chain** is required	Lack of **specifically qualified personel**

IRTG Objectives

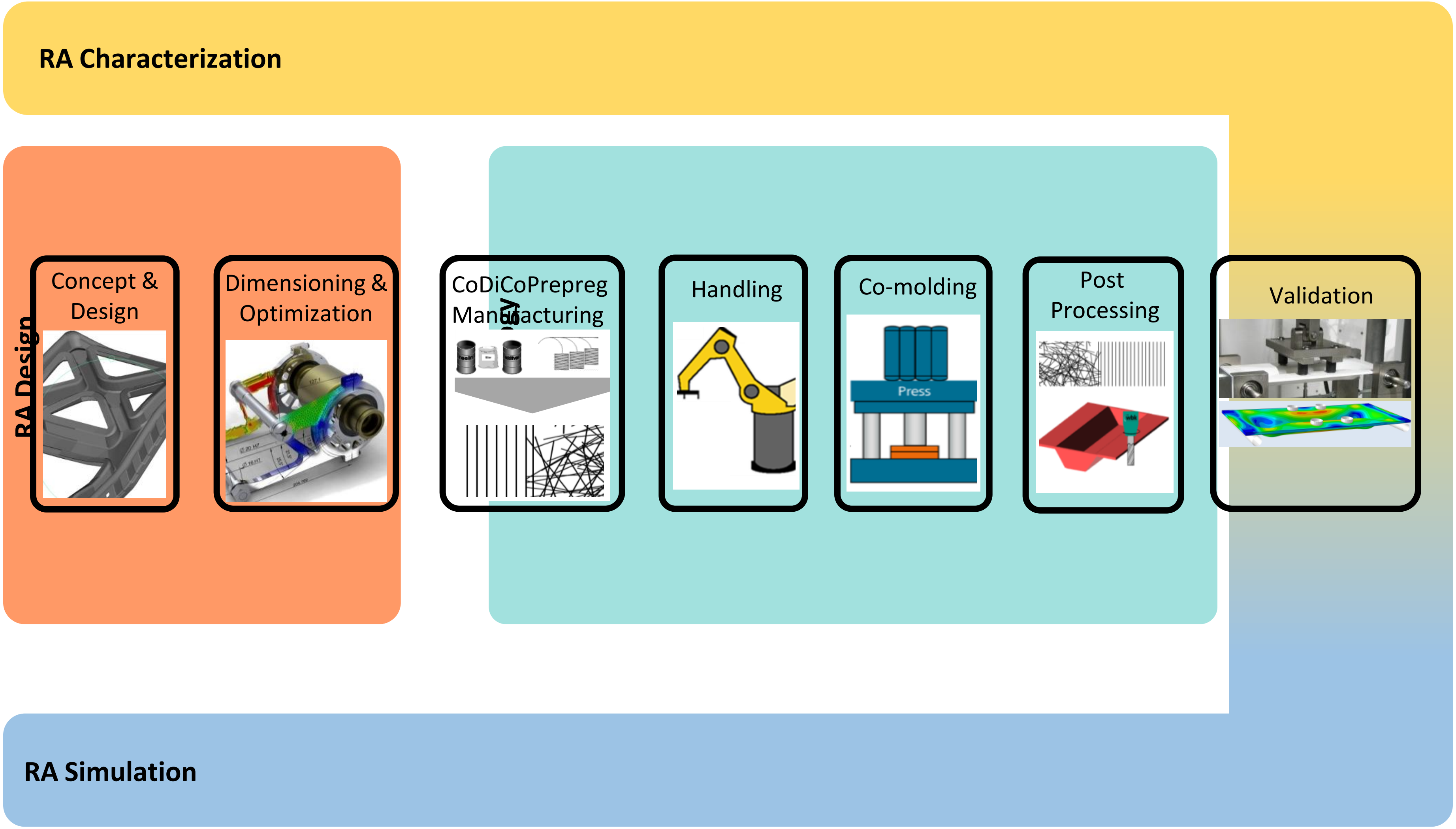
Research on **materials, simulation** and **design**	Develop **manufacturing** and **quality control** strategies	Develop **robust integrated engineering approach**	**Train engineers** and young **scientists**

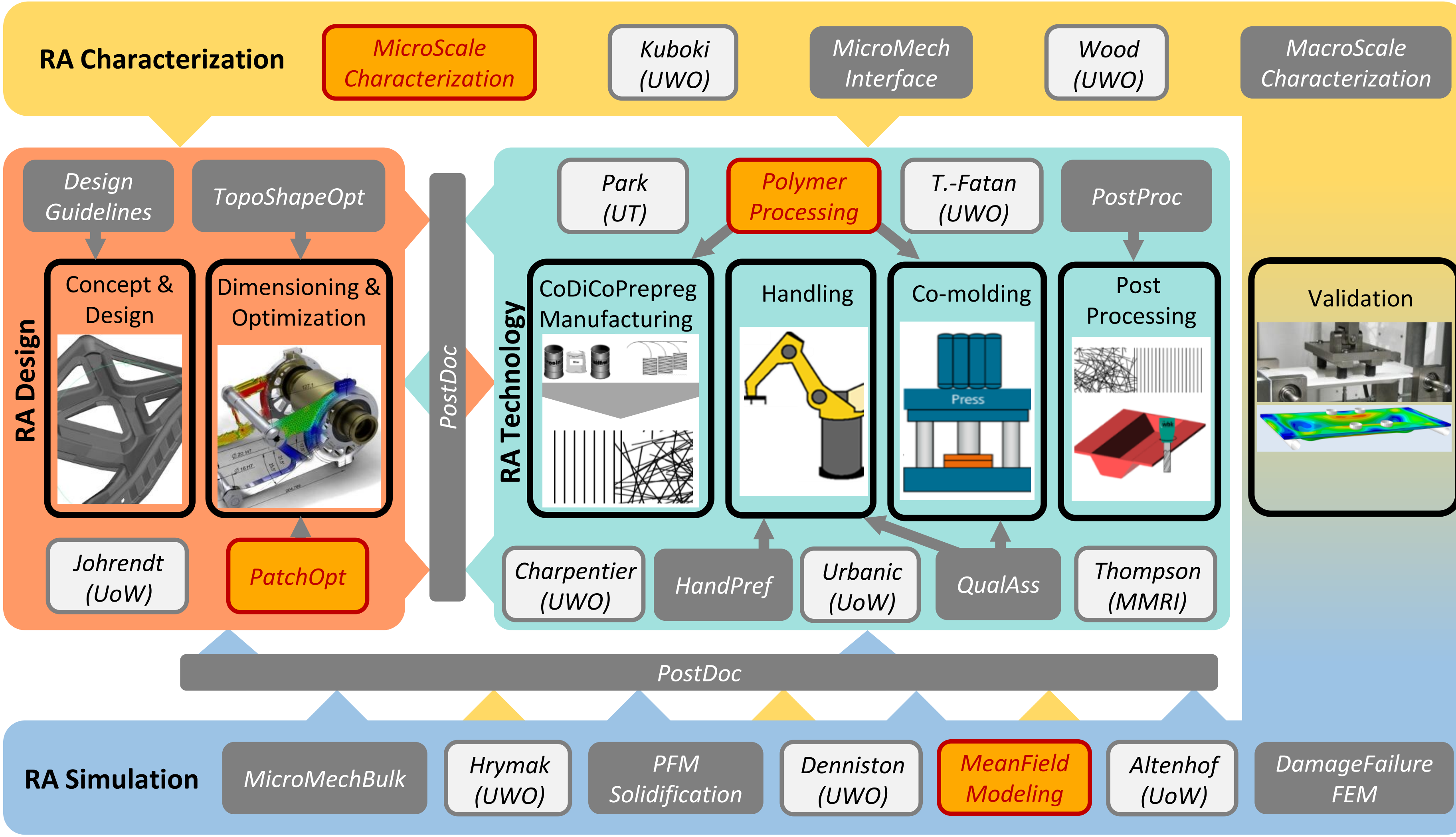

GRK 2078 Twin Regions



Product Development Process



GRK 2078 PhD Projects



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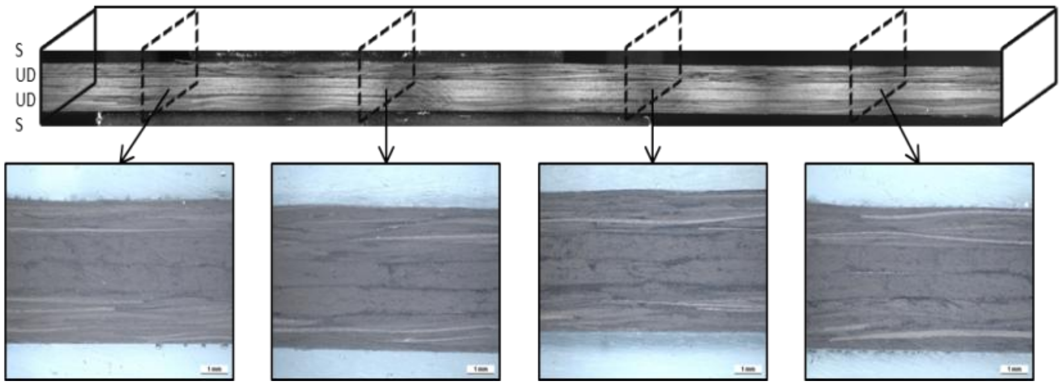
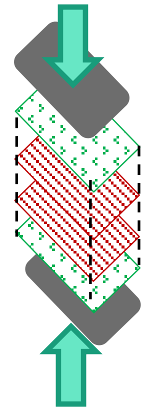
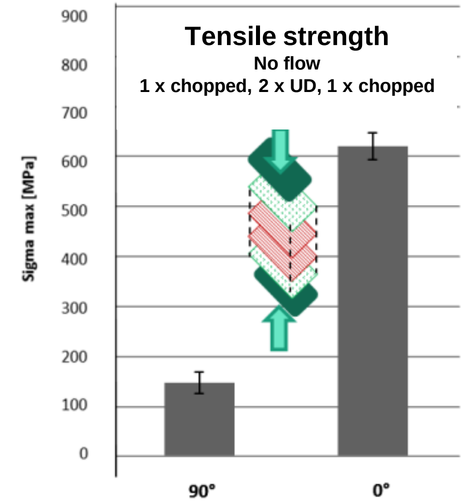
Carbon fiber reinforced SMC

Flow of material – High impact on UD alignment

- Cross section – no flow

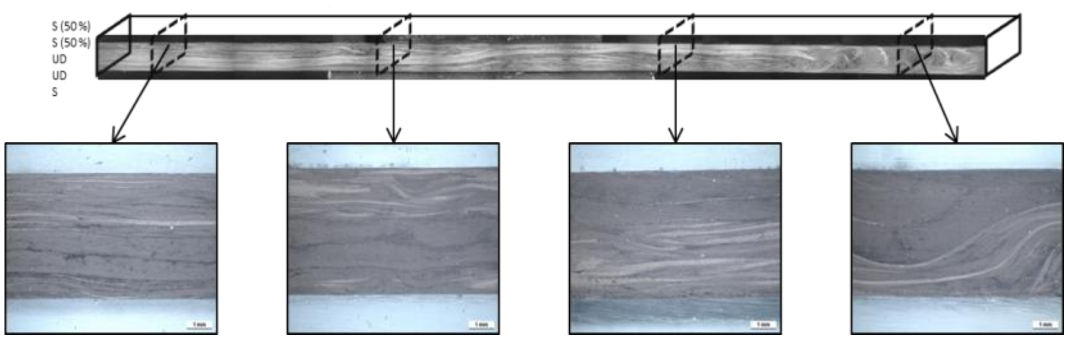


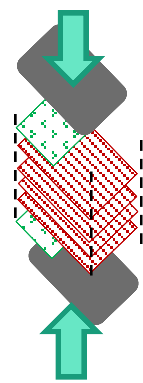


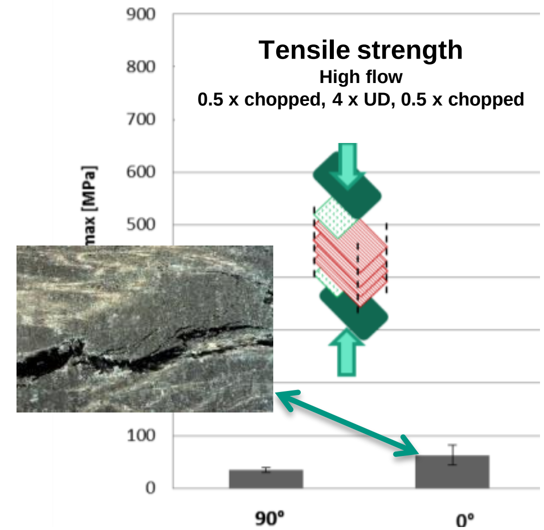


- Cross section – high flow

Direction of flow →







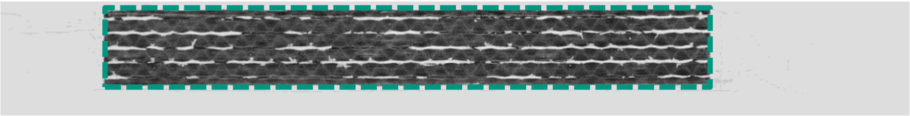
[Contact: David Bücheler, david.buecheler@kit.edu, KIT FAST, Fh ICT]

Carbon fiber reinforced SMC

Improvement of UD alignment

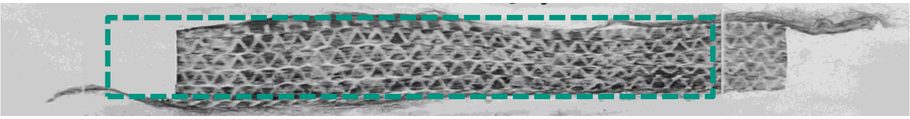
Functionalized resin system allows for:

- aligned UD fibers
- stiffer material while molding

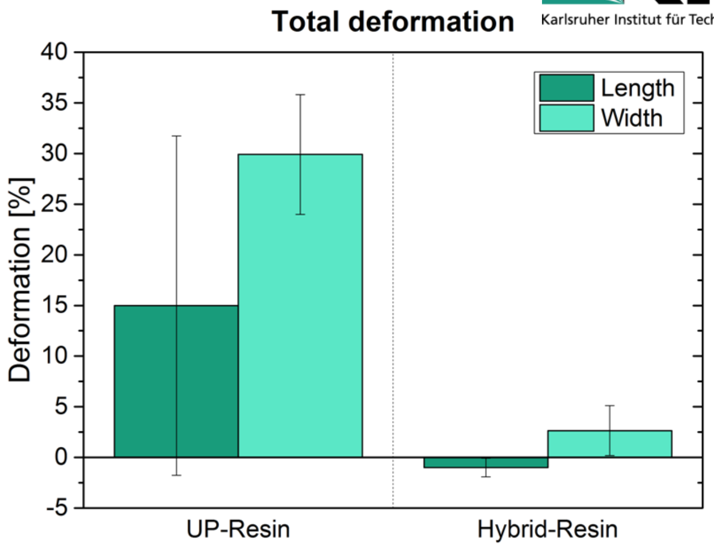


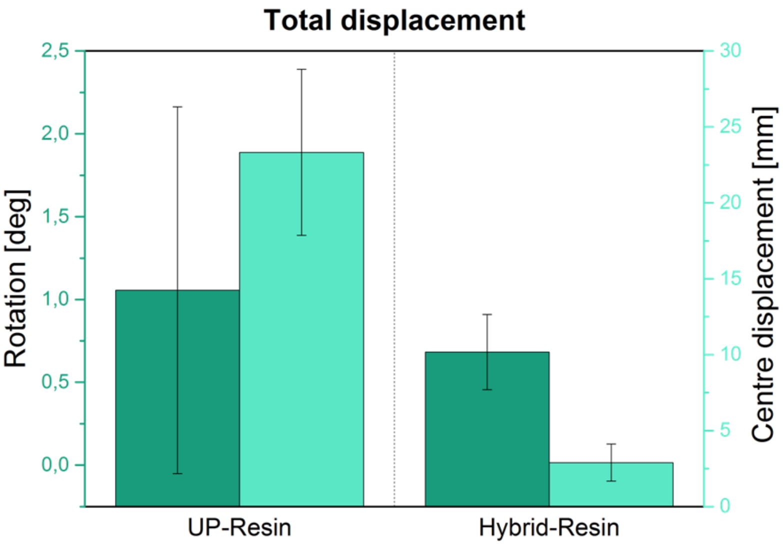
Hybrid-resin based alignment

Conventional resin system:



UP-resin based alignment





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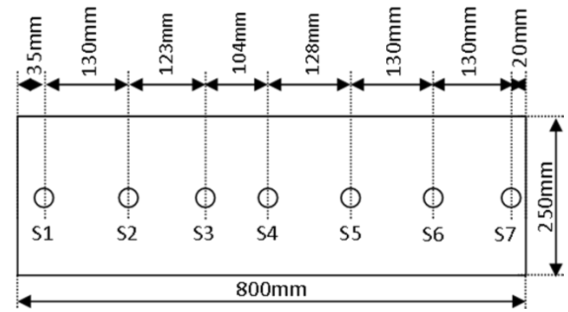
Rheological Measurement and Process Simulation - Motivation

Rheological Measurement:

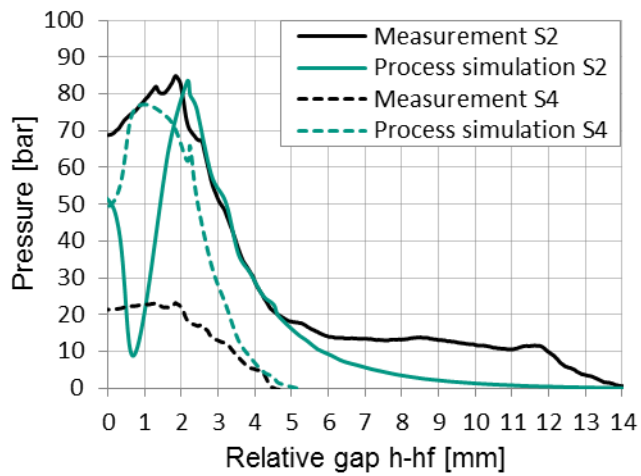
- No state of art method to measure the viscosity for long fiber reinforced suspensions
- Sample size of shear- or rotation rheometers is smaller than the fiber length (~25mm)

Process Simulation:

- Poor match between pressure measurements and commercial process simulation (best fitted parameter)
  - No SMC specific material model
- Due to the lubrication layer, extensional viscosity is dominant
  - Only shear based models available in commercial tools



Design of rheology tool with 7 pressure sensors



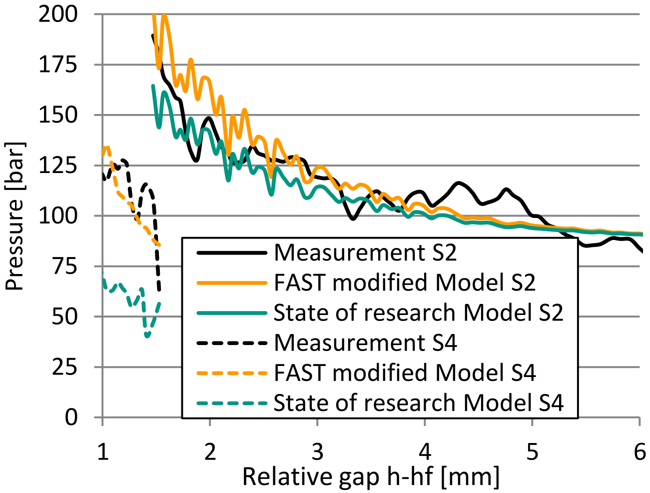
Pressure comparison between measurements and simulation for class A SMC

[Contact: Martin Hohberg, martin.hohberg@kit.edu, KIT FAST]

Rheological Measurement and Process Simulation - Results

Rheological Measurement:

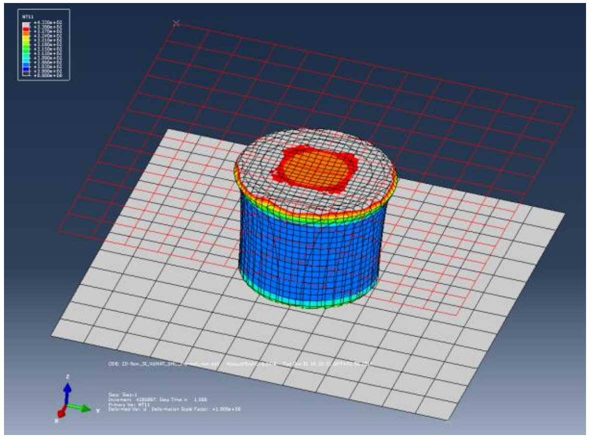
- Established a method to measure in-mold extensional viscosity
- Modification of state of research approaches to fit high performance SMC (compressible)



Pressure prediction by modified rheology model

Process Simulation:

- Implementation of state of art and state of research approaches for:
  - Material models
  - Fiber orientation models
- Ready to consider unidirectional tapes in the process simulation

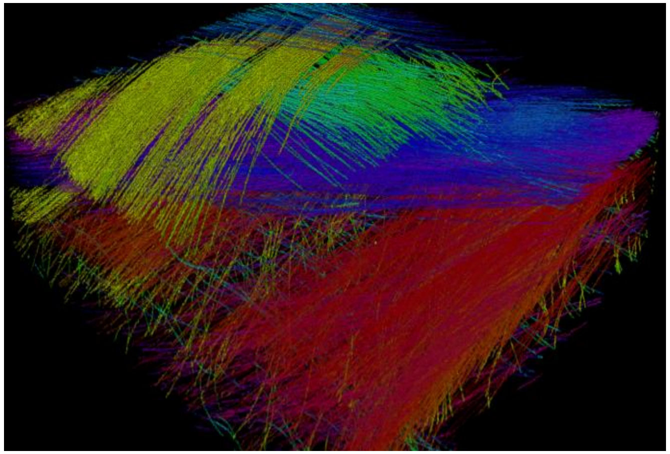


Cylindrical standard compression test

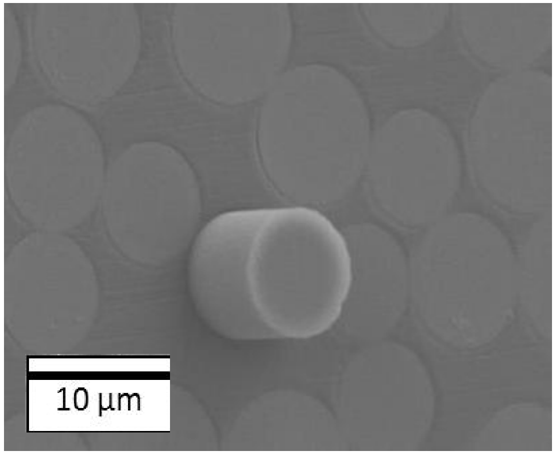
[Contact: Martin Hohberg, martin.hohberg@kit.edu, KIT FAST]

Microscale Characterization

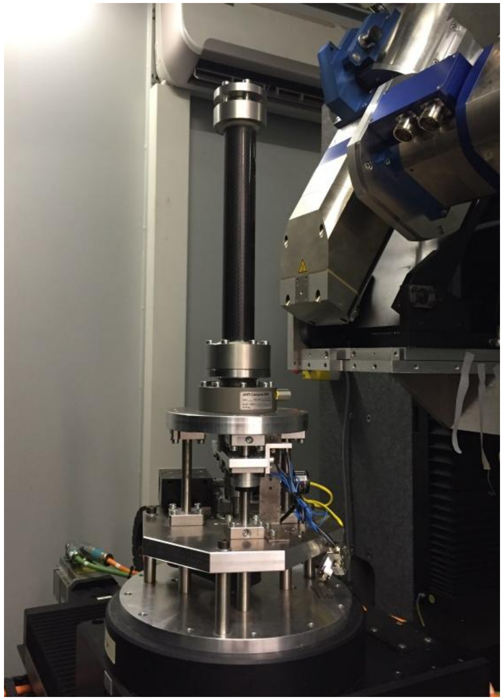
- Development and application of destructive and non-destructive testing methods:
  - Determination of 4th order orientation tensors directly from µCT-scans via in-house software “Composight”
  - Fiber length distributions from µCT-scans
  - Mechanical properties of fibers
  - Interfacial shear strength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



Orientation analysis (SMC)



Push-Out-Test

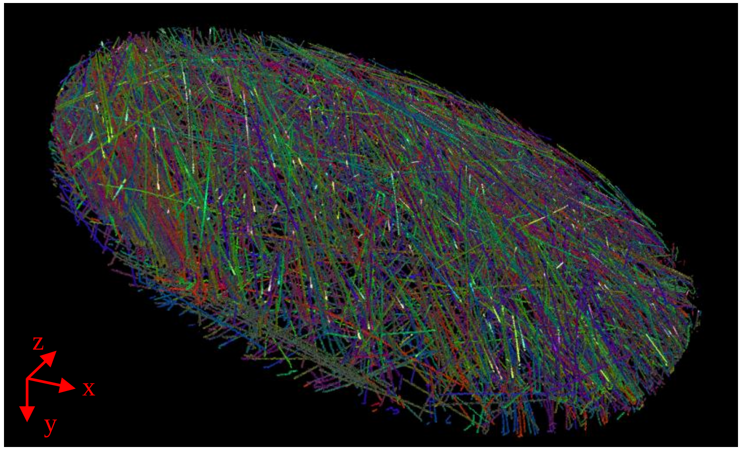


In-Situ-Stage

[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

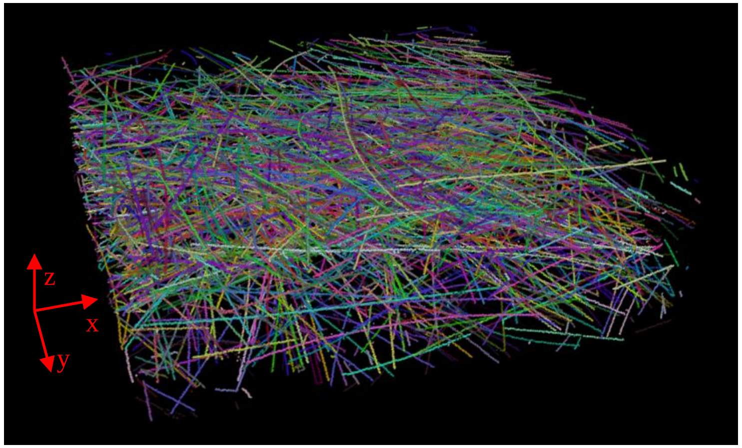
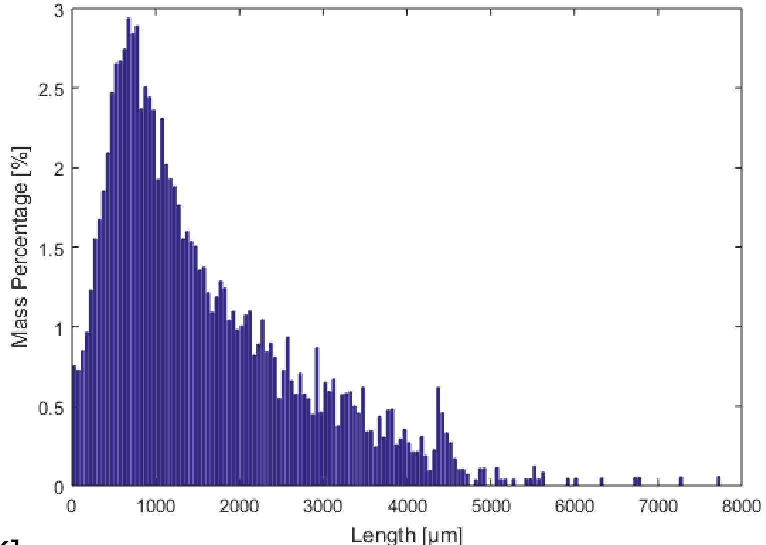


Image detail of same specimen 1.8x1.8x0.5 mm³



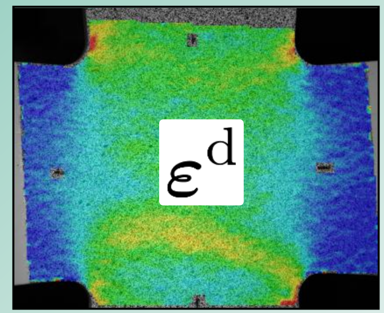
Fiber Length Distribution

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

Biaxial Testing and Material Modelling of DiCoFRP

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

DIC – data



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

Biaxial tensile test

Boundary conditions

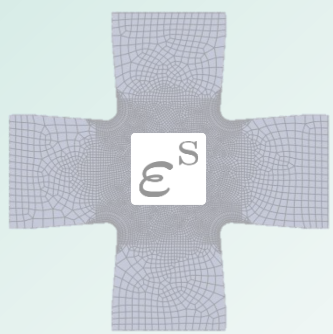
$F_1, \; F_2$

Mapping

Material parameter update

$$\underline{p}_{n+1} = \underline{p}_n + \Delta \underline{p}$$

FEM - simulation



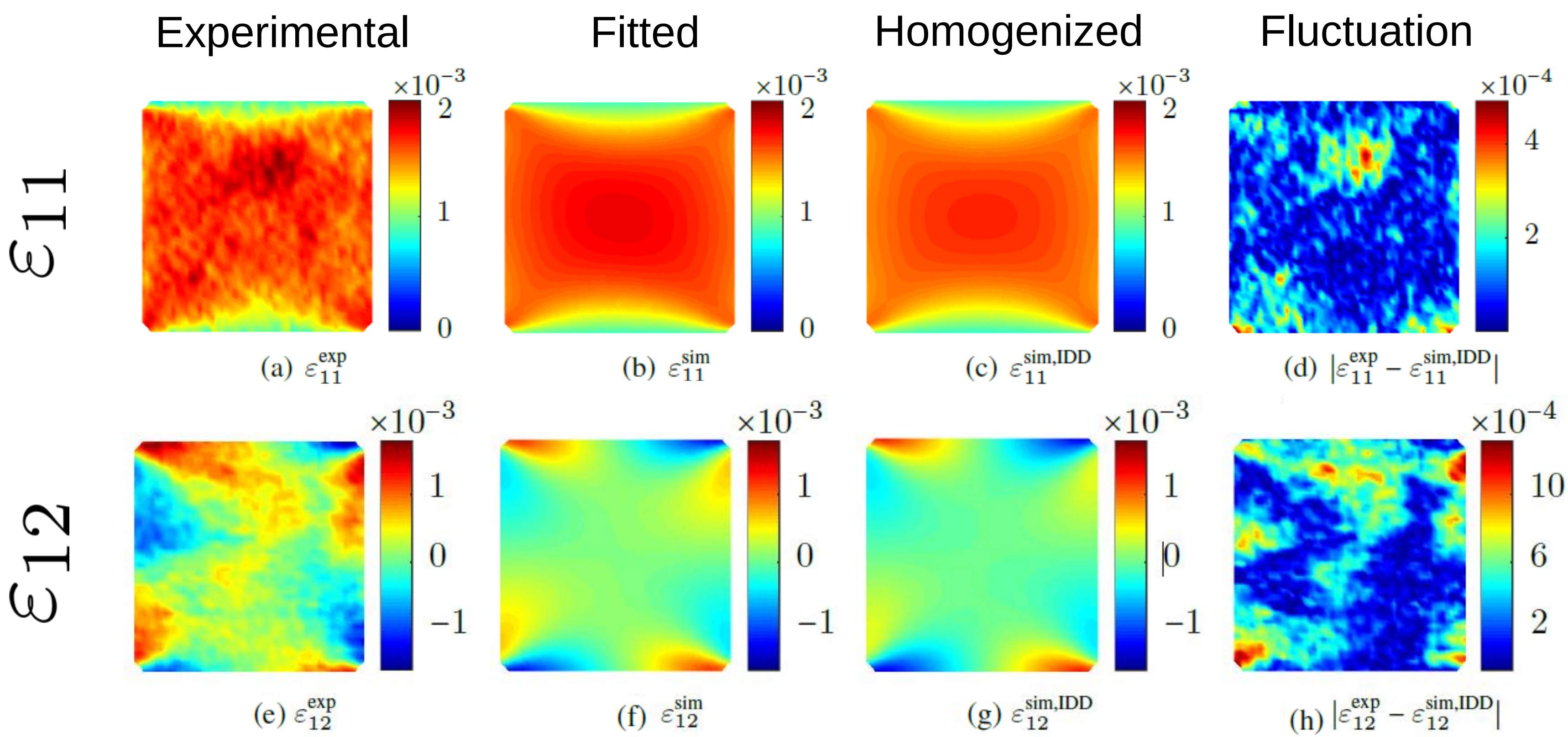
Convergence?

$\underline{p}_n$

$\underline{p}$

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

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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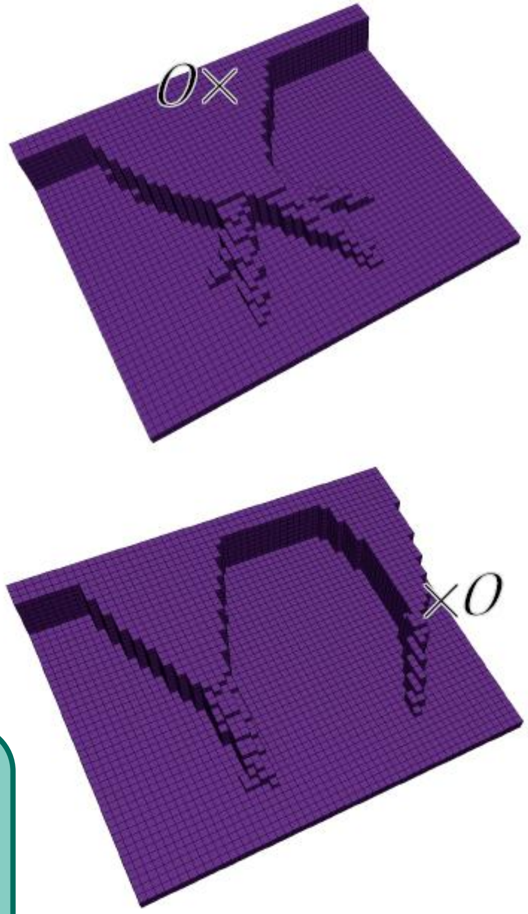
Patch Optimization

State of the Art:

- Topology optimization
  - methods available only for isotropic or determined anisotropic materials
  - tends to create lattice structures
  - for patch optimization coherent structures required
- Laminate optimization
  - available methods to optimize ply size, position and stacking sequence are based on topology optimization
- Manufacturing constraints are so far hardly implemented in optimization algorithms
  - e.g. mold opening direction for topology optimization

Objective: Integrated CoDiCo optimization, considering:
- continuous fiber patches and DiCo topology
- manufacturing constraints
- Forming and molding, curing and warpage

[Contact: Benedikt Fengler, benedikt.fengler@kit.edu, KIT FAST
& Markus Spadinger, markus.spadinger@kit.edu, KIT IPEK]

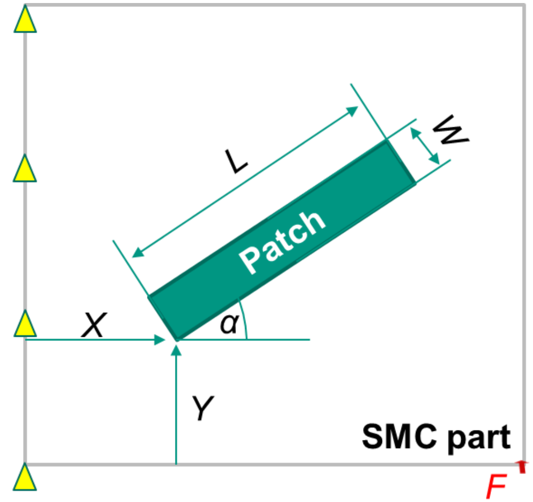


Results of topology rib optimization for different SMC sheet positions [Troll, KIT IPEK, 2015]

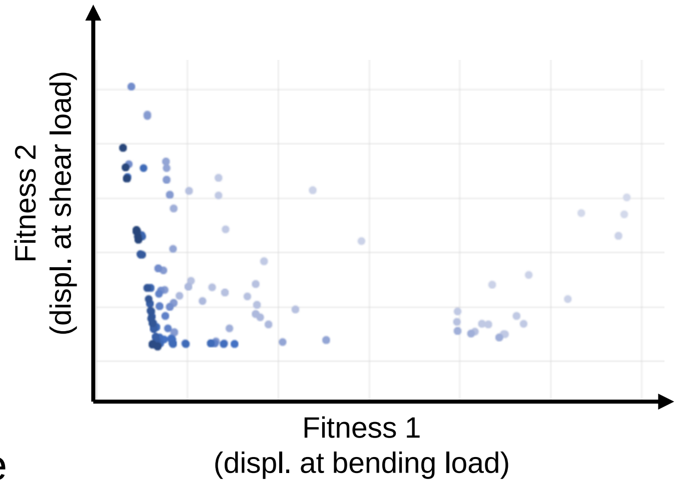
Patch Optimization

- Implementation of an Evolutionary Optimization Algorithm
  - independent parameters *X,Y,L,α,n*
  - recombination and mutation steps
  - selection method for population creation
- Coupling of the Optimization Algorithm with FE-Solver Abaqus
  - Automatic patch creation, based on optimization parameters
  - Calculation of fitness for parameter set (e.g. displacement at a reference point)
  - Multi-objective optimization
- Ongoing research:
  - Consideration of patch forming on curved geometries
  - Integration of curing and minimization of warpage

[Contact: Benedikt Fengler, benedikt.fengler@kit.edu, KIT FAST]

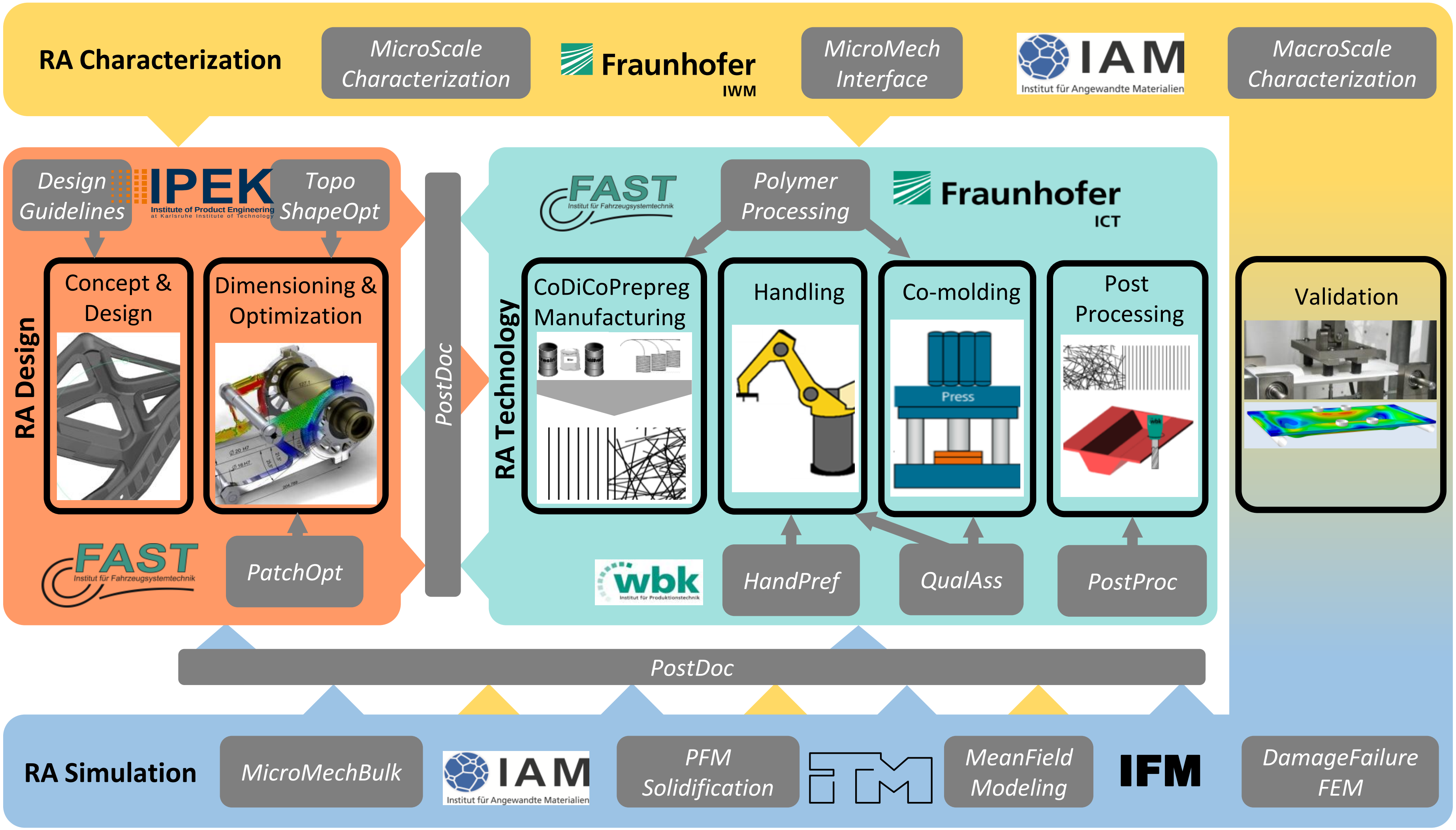


2D optimization problem definition



Optimization result: Pareto front per generation (bright = early generation; dark = late gener.)

GRK 2078 PhD Projects



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Thank you for your attention.

Karlsruher Institut für Technologie

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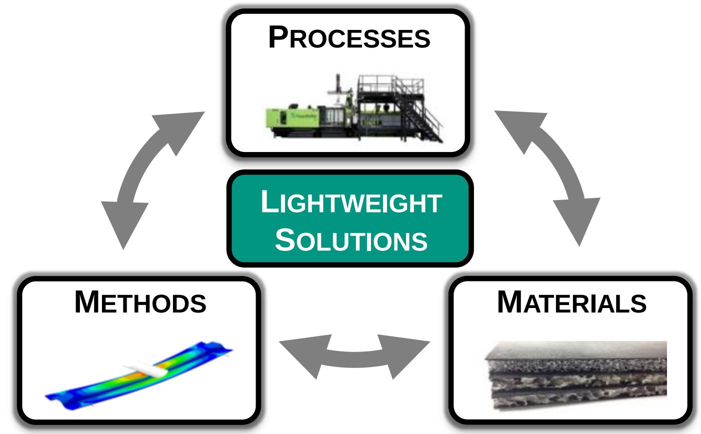
KIT - LIGHTWEIGHT DESIGN NETWORK



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GRK 2078 CoDiCoFRP

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