University of Stuttgart
Institute of Aircraft Design

IFB is famous for….

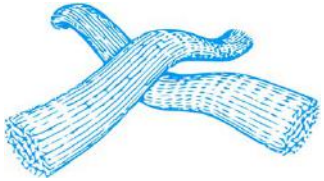
…. Own electric flying platforms, Composites, Wind Energy

IFB
Institut für Flugzeugbau

Institute of Aircraft Design

Research Areas

Aircraft Design
Prof. Strohmayer



Lightweight Design
Prof. Middendorf

Manufacturing Technologies
Prof. Middendorf

Wind Energy
Prof. Cheng

staff: 3 professors - 60 academics - 11 engineers - 5 administrators - ~80 students - 4 trainees
sales: 25% basic funding - 75% third-party-funds

accommodation: 2 buildings - 1000m^2 office - 250m^2 seminar rooms - 300m^2 laboratories - 1300m^2 workspace - 300m^2 storage

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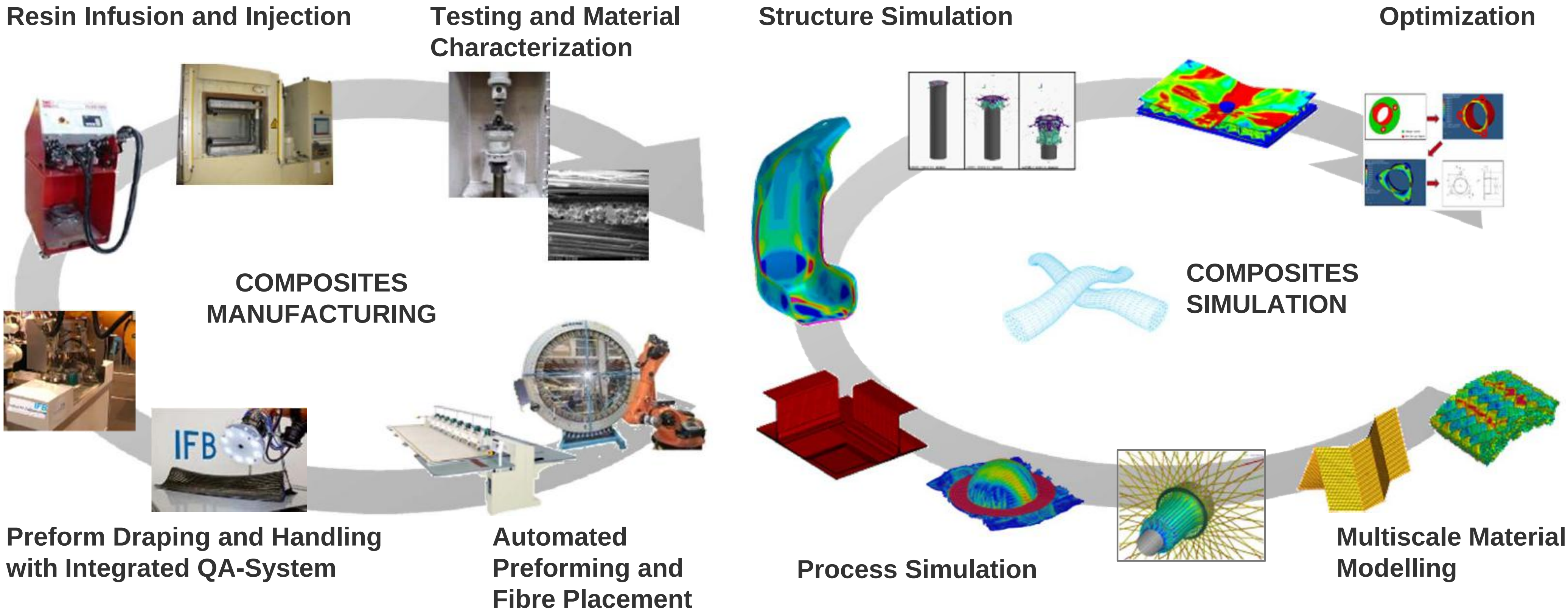
Composites

30 scientific engineers are dealing with composites



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More than Lectures

Industry Cooperation

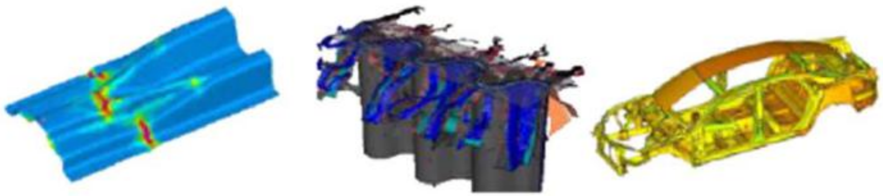
FKFS

Aldi

Zasche

Kögel (Kipperwand)

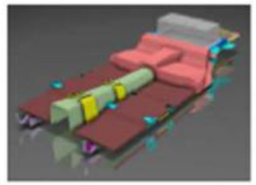
Audi HIN Kooperation



Public Funded Projects

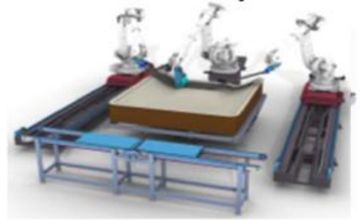
ALF

ARENA2036

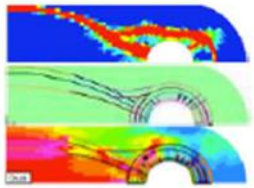


TC²

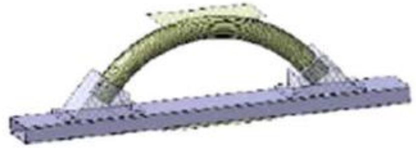
LowFlip



RecyComp



MAI-Design



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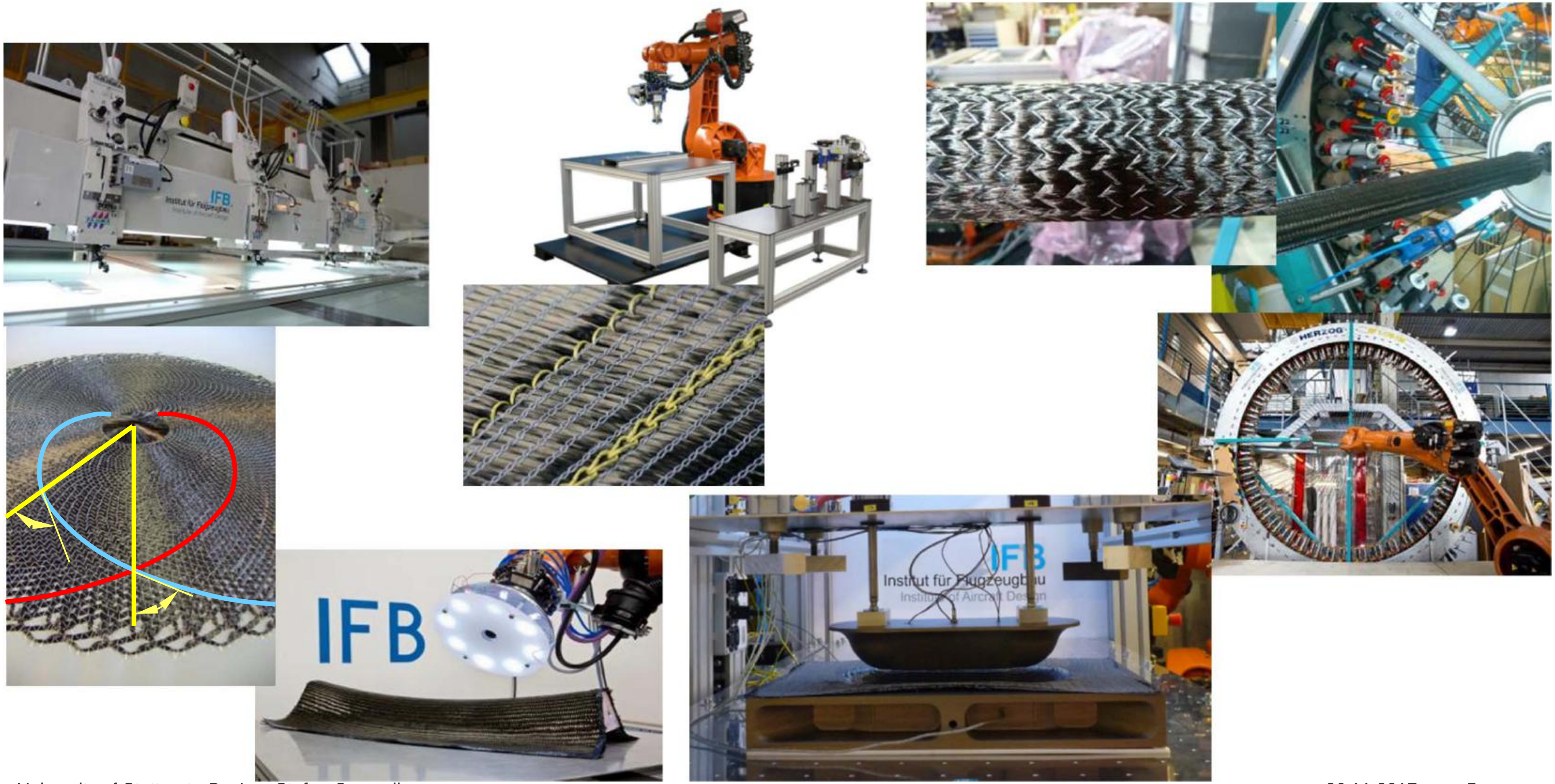
Experience in Preform Technologies Since 2005



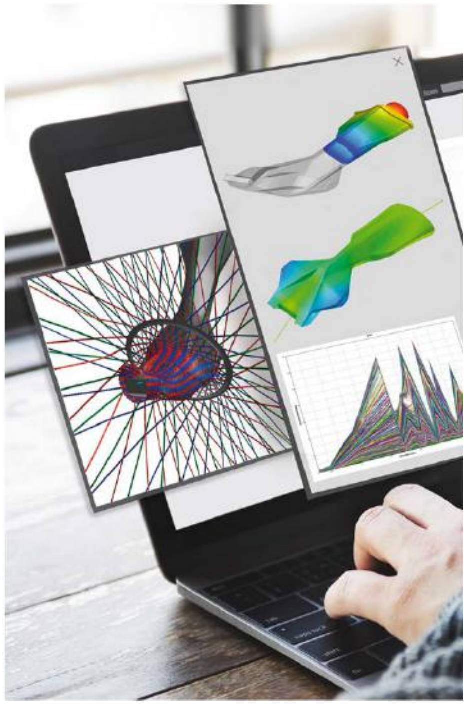
Braided Manipulator (ZASCHE handling)

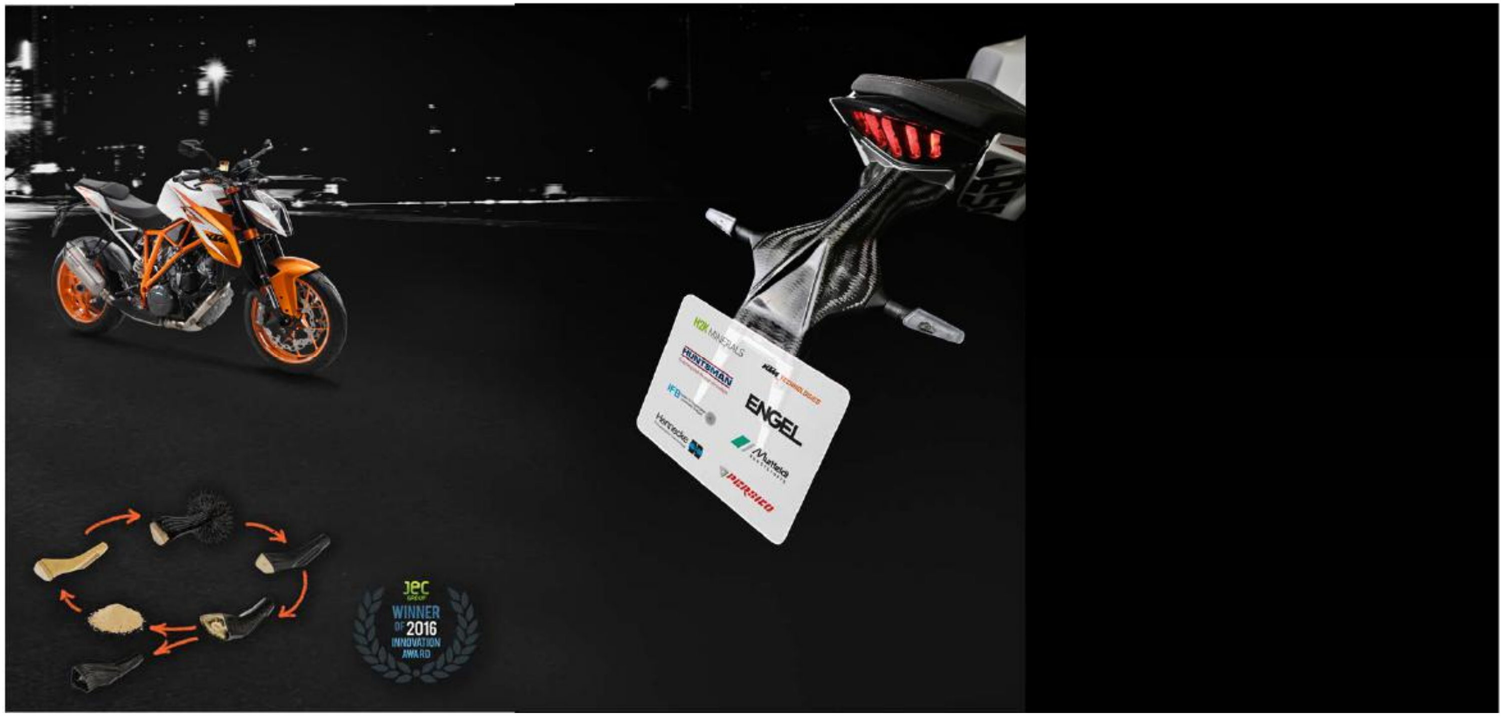
Development of a Carbon Manipulator using Braiding Technology

- **Low-weight carbon manipulator (70% less weight compared to steel)**
- **Radial braiding technology for efficient manufacturing**
- **High bending and torsional stiffness for easy manipulation**

4. Braiding technology

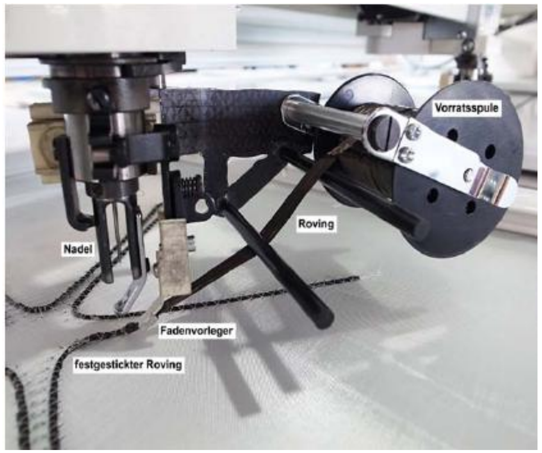
Example: R.A.C.E. Plate Holder

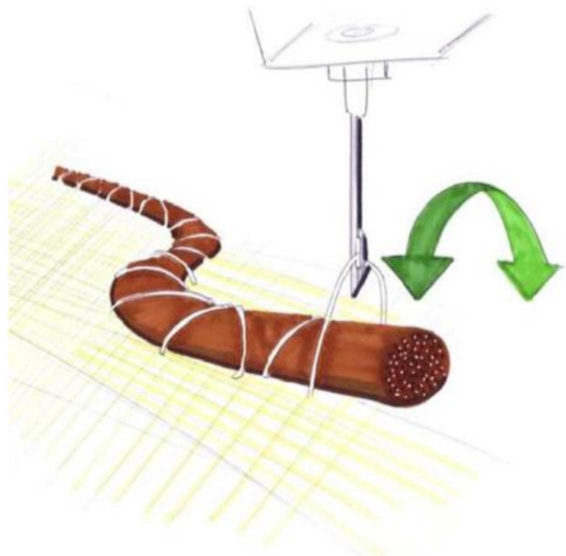


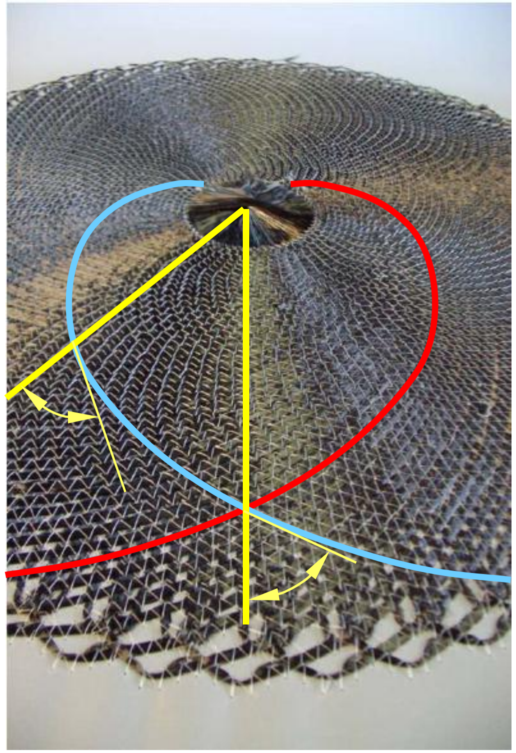


Tailored Fibre Placement

- Load path optimized lay-up
- Low cut-off (Near-Net-Shape)
- High volume production possible
- Multimaterial process
- High Design freedom







Tailored Fibre Placement - Introduction

ZIM: Innovative design and process chain for multifunctional parts made of continuous glass or carbon reinforced thermoplastics

- Machining of thermoplastic hybrid yarns by using the TFP technology
- Development of a pressing/grouting process for the TFP preforms
- Integration of functions of the consolidated preforms by
- Materials: Carbon fiber/PA6 und glass fiber/PA66
- Analysis of characteristic material values
- Part design using the example of a torque support

In Cooperation with:

Production Steps of a TFP Process

TFP Preform

Die-cutting

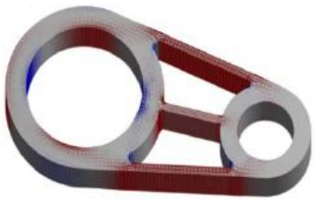
Consolidation

Machining

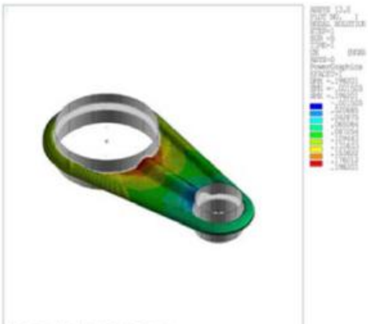
Overmolding

Final Part

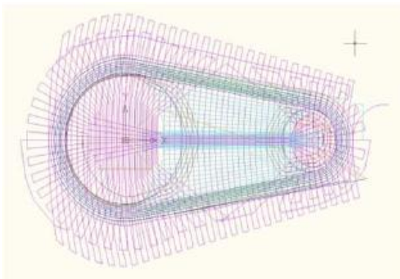
Designchain of a TFP Process



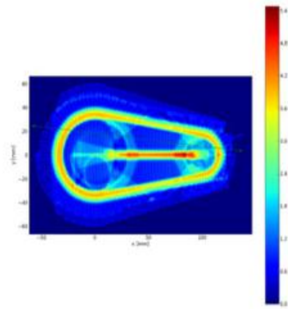
Demonstrator part
Torque support



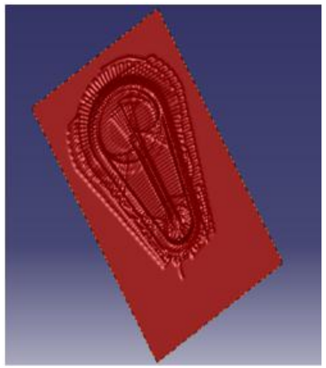
FEM analysis
AOPS



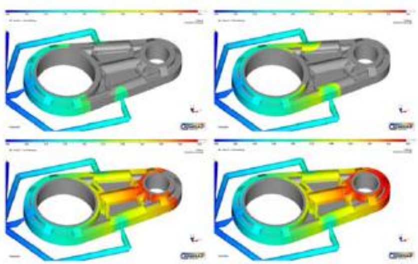
Design of
TFP pattern



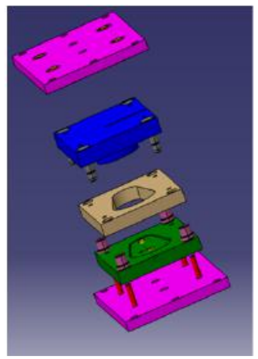
Preform topography
analysis EDOPath



Topography extraction
EDOPath



MoldFlow CFD Analysis
overmolding paramter



CAD tool design for
grouting/overmolding

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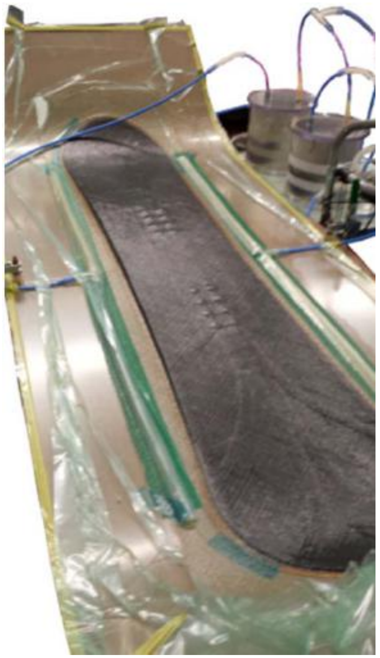
Resin Infusion Process: Vacuum Assited Infusion

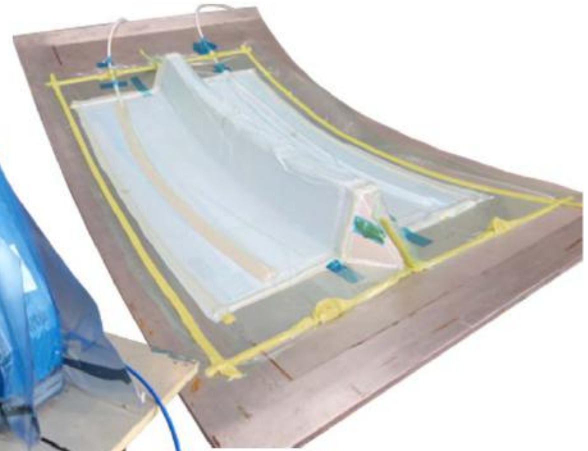
VARI - Vacuum Assisted Resin Infusion



Standard set-up in single sided mould with line injection

Set-up in oven or in a closed mould with cascade injection

VAP - Vacuum Assisted Process



To get a higher consolidation the process can be done within an autoclave.

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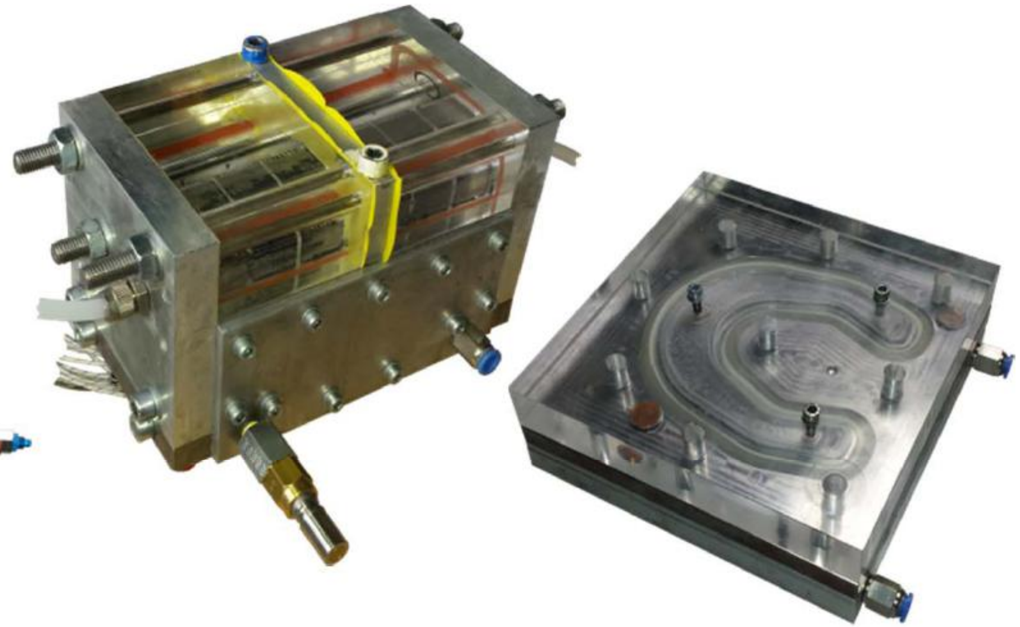
Resin Infusion Process: Resin Transfer Moulding (RTM)

RTM with press control and injection machine

Monitoring und control of temperature and pressure in the mould, at the inlet point,…

Field of application:
Basic research and development, prototyping, process optimization and small series production

RTM with transparent mould



Teaching application:
Visualizing the effects of vacuum, injection pressure, temperature, flow front speed, heating and cooling rates on the mould filling behaviour and laminate quality

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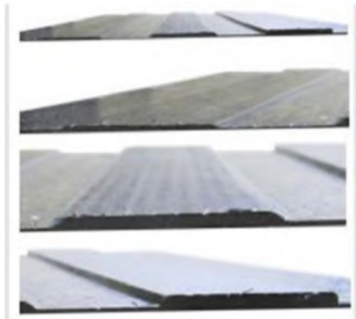
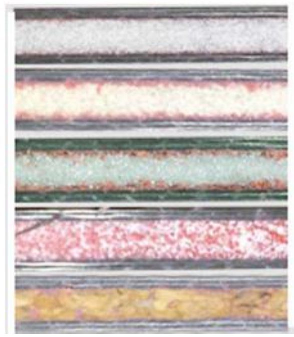
Out of Autoclave Processes, Wet Pressing

Wet pressing with press control

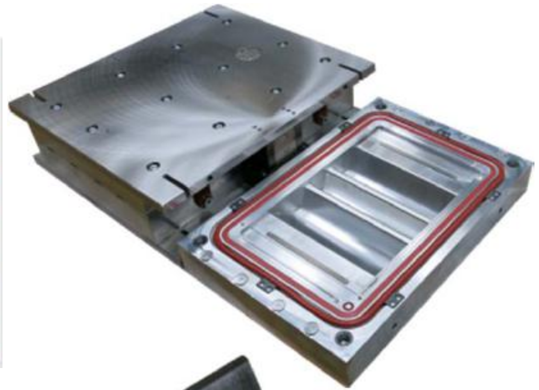
Monitoring und control of temperature and pressure in the mould,

Wet pressing with local reinforcement and one shot sandwich structures





3D application



Field of application:
Basic research and development, prototyping, process optimization and small series production

Process figures:
30 sec.- 1 min. curing, part to part < 2min., 58%-60% FV, < 1% void content

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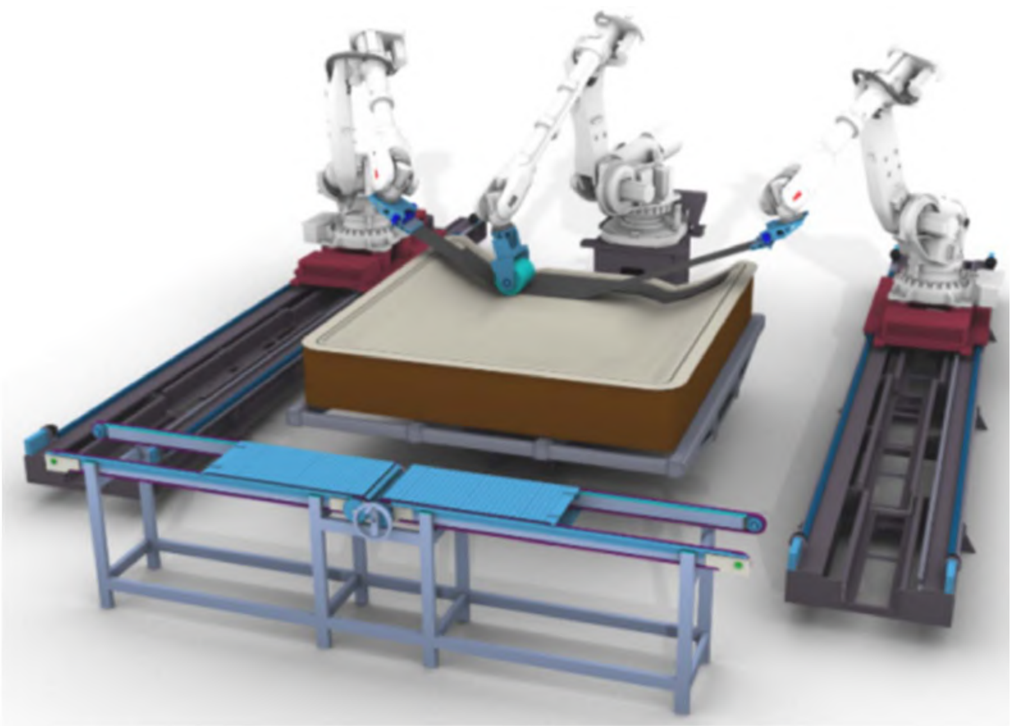
New APP Concept wit OoA Curing material @IFB



www.lowflip.eu

- Novel out of autoclave manufacturing process
- 3D placement technology for plies and tapes
- Wrinkle free placement of double curved surfaces
- Energy efficient and fast heating tools

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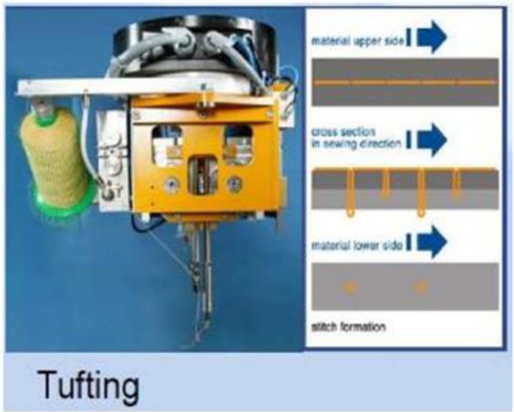
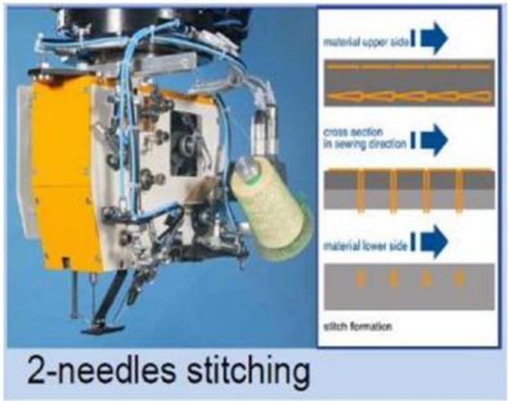
New APP Concept wit OoA Curing @IFB

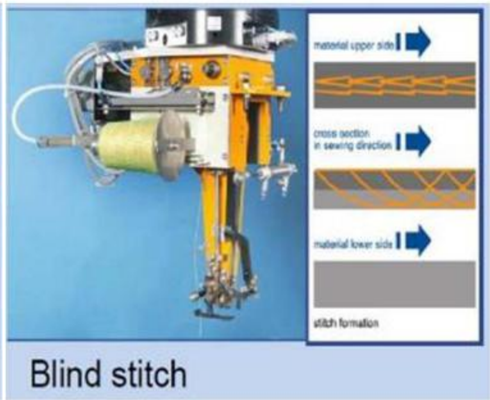
3D Stitching: Equipment and Competences



Tufting

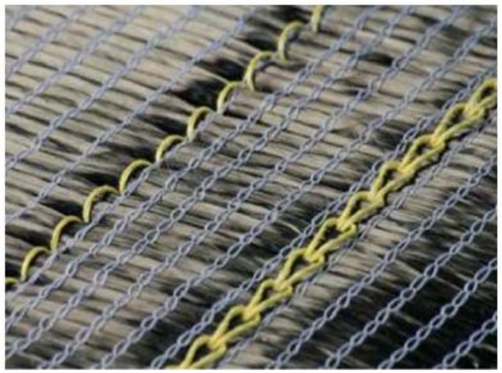


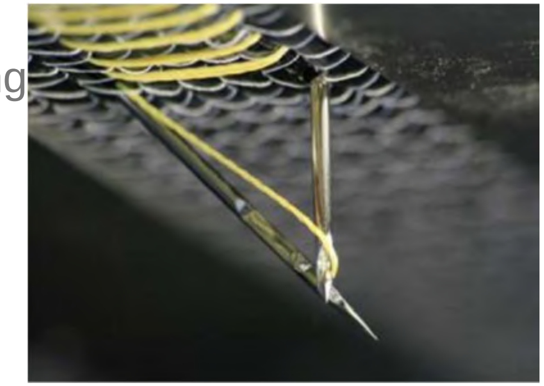
2-needles stitching



Blind stitch

- Robot-supported stitching, allowing the stitching of complex 3D-Geometries
- Experience with multiple single-sided stitching techniques.
- Further understanding of through-the-thickness reinforcement through stitching.
  - Improvement of interlaminar strength
  - Damage tolerance
  - Crack growth arrestment

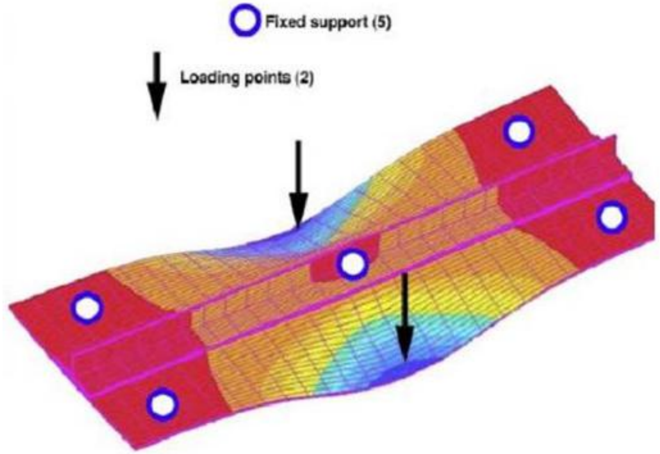


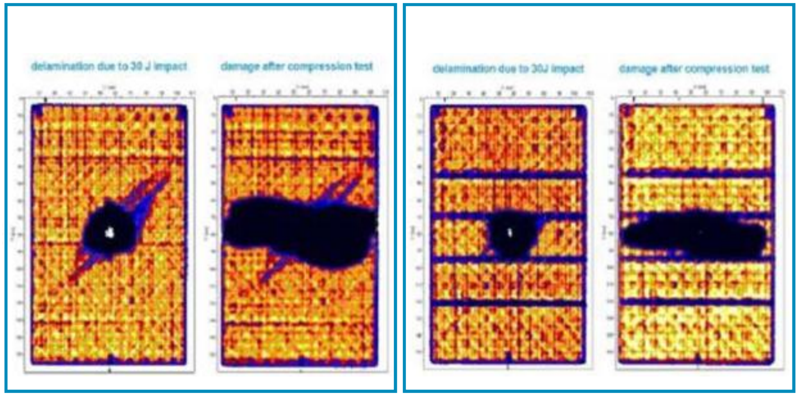


Research Focus: Selective Stitching

Identification of the most efficient stitching configurations for CFRP stiffened panels in terms of damage tolerance

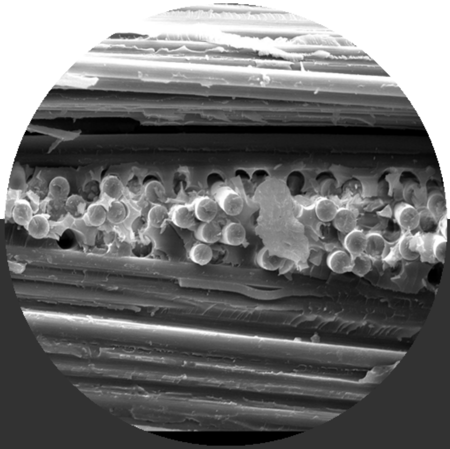
- Establishing a correlation between coupon-level and substructure-level results.
- Development of fail-safe structures that control damage growth through stitching.
- Isolation of the contribution of stitching to the inter-laminar strength of a laminate.
- Determination of the most suitable stitching techniques and positions that provide better stiffener-skin joints.
- Reduction of time and material costs, while still obtaining damage tolerant structures.
- Determination of the most appropriate method for on-line damage growth monitoring.





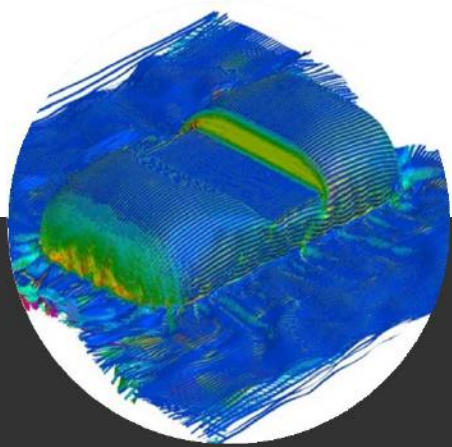
Simulation at IFB

Overview



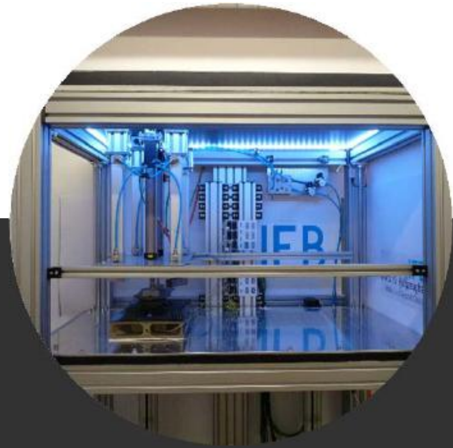
Material Characterization

- Textile Characterization
- Mechanical Testing
- Structural Testing
- Non-Destructive Testing



Numerical Simulation

- Different Simulation Methods (FEM, CFD, analytical)
- Process Simulation
- Structural Simulation

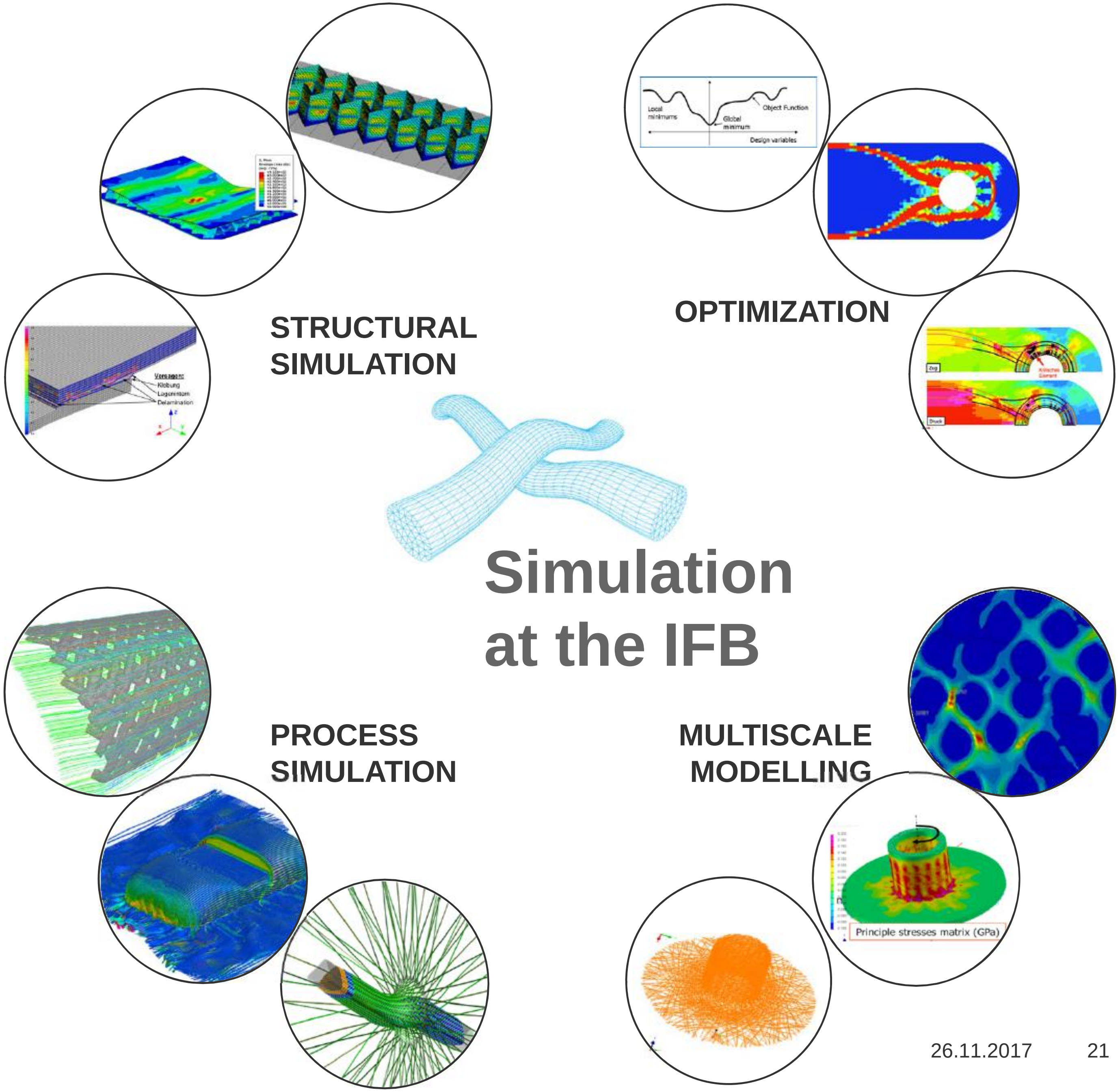


Manufacturing Process + Validation

- Textile Processing (Braiding, Draping, Tailored Fiber Process, Stitching)
- Resin Infusion (VARI, VAP, RTM)
- Prepreg

Simulation at IFB

Virtual Process Chain



15 Phd, 2 Teams

Manufacturing and Process Simulation
Braiding simulation, Draping Simulation, Infusion Simulation, CAM

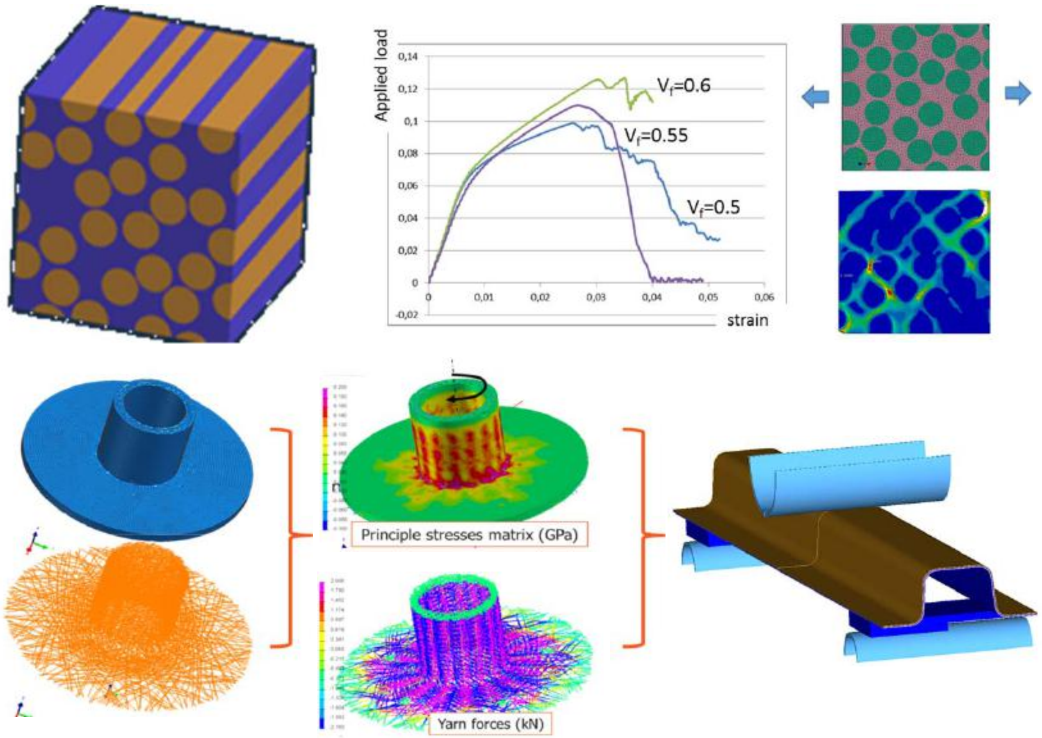
Structural Simulation
Impact, Crash, Fatigue, Design Optimization, Joints Simulation, Sandwich Structures, Effects of Defects

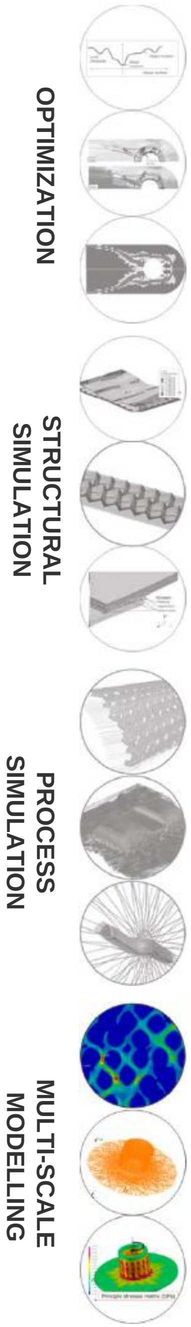
Software
ESI, Abaqus, LS Dyna, Hyperworks, Matlab, etc.

Hardware
HPC Cluster,
Intel XEON, Quad-, Octa-, 12-Core
4,7TFlops

Multi-Scale-Modeling

Overview





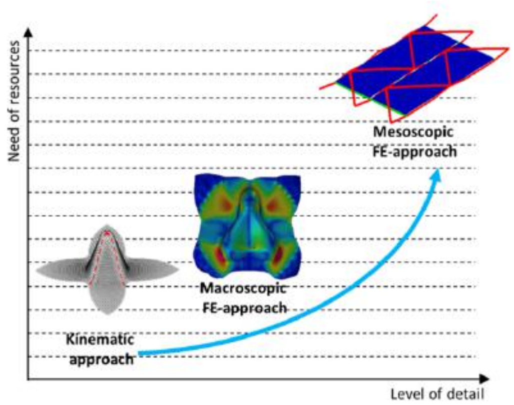
Approach

- Unit-Cell Models:
  - Stiffness and strength calculation
  - Volume fraction influence
- Preform simulation to determine real fiber orientation
- Implementation of the real composite architecture into the structural simulation
- Obtain macroscopic material model for large structural simulation

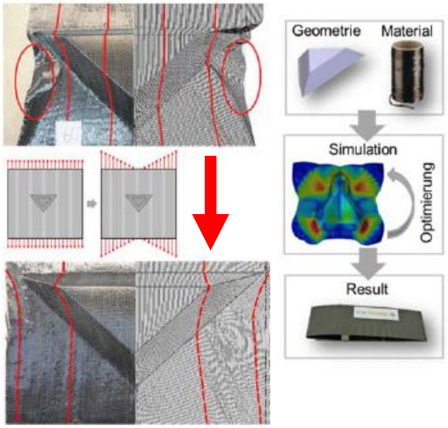
Process Simulation

Overview

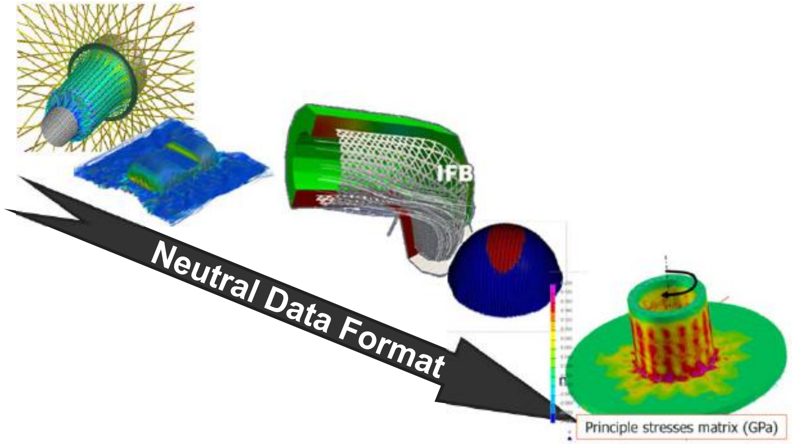
Application-oriented Modelling



Virtual Process Optimization



Data Transfer

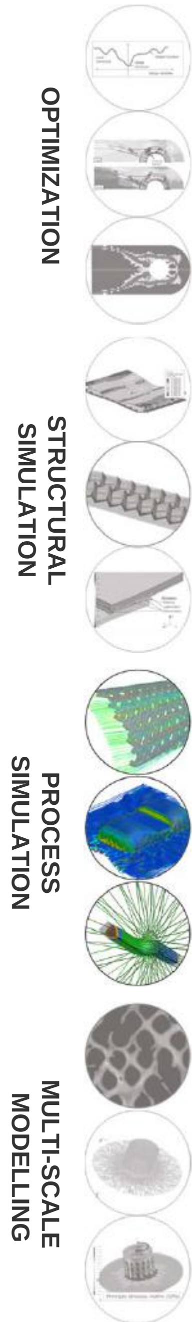


Background:

- Modelling manufacturing process of FRP Structures
- Consider physical effects
- Different levels of detail depending on application

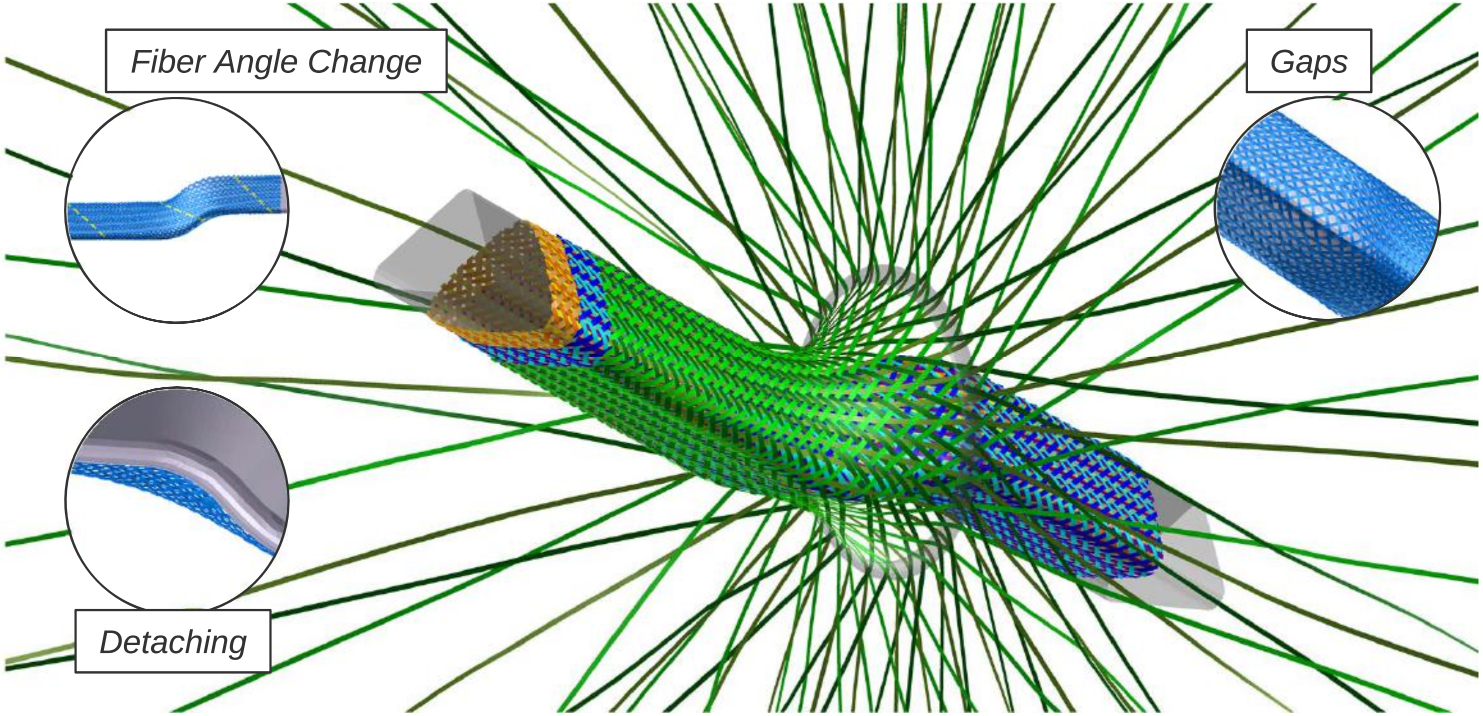
Application:

- Predict real fiber architecture for structural simulation considering influences of manufacturing process
- Neutral data format for data transfer
- CAM-Interface
- Virtual process optimization



Process Simulation

Braiding Simulation

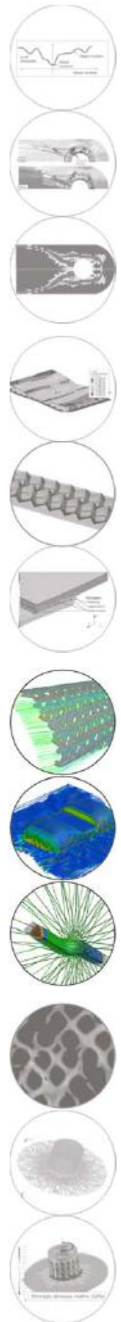


Approach:

- Mesoscopic, explicit FEM-Simulation with beams or shell elements for modelling of fibers
- Possibility of dynamic and friction effects representation
- In-house pre-processor

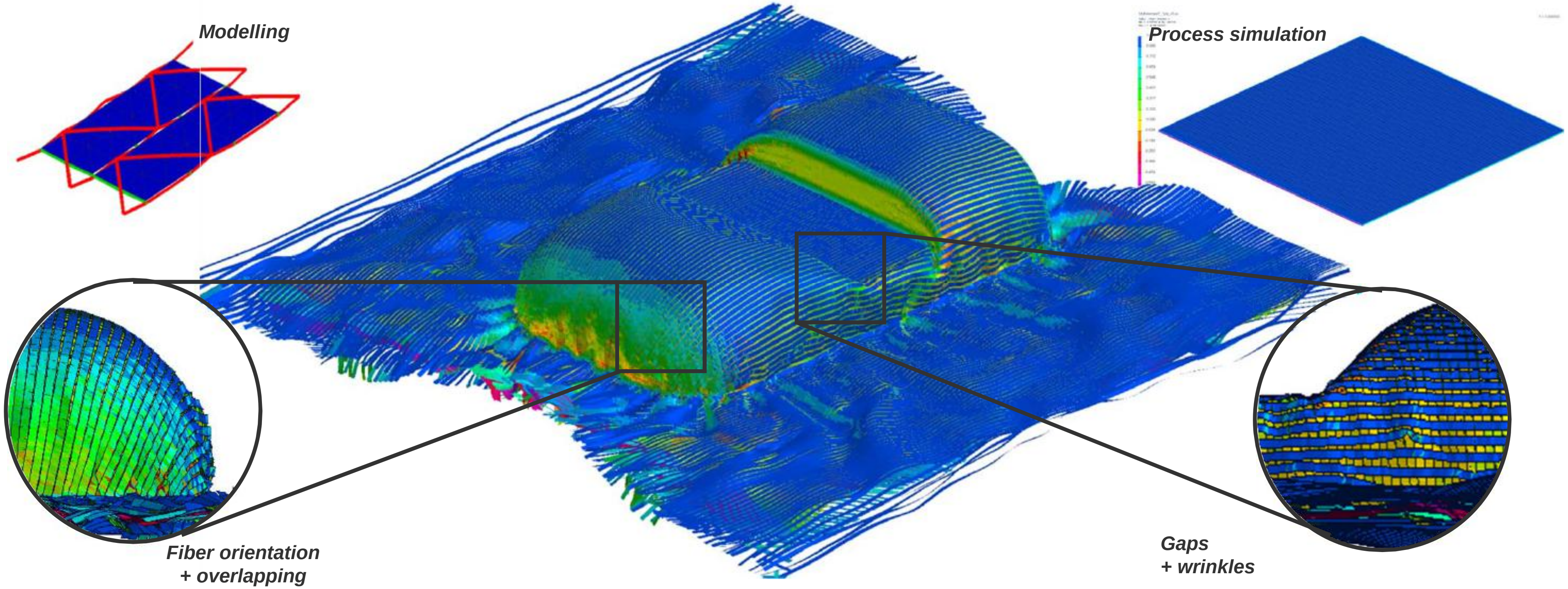
Advantage:

- Modelling of real physical phenomenon
  - Fiber angle deviation, gaps, detaching of layers, compaction effects
- Process related part design
- Process planning and optimization possible



Process Simulation

Draping Simulation

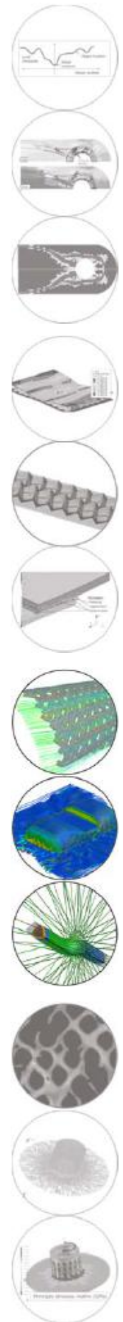


Approach:

- Application driven modelling
  - Kinematic and macroscopic FEM-simulation with reduced simulation time
  - Mesoscopic, explicit FEM-simulation with high level of detail
- Possibility of dynamic and friction effects representation

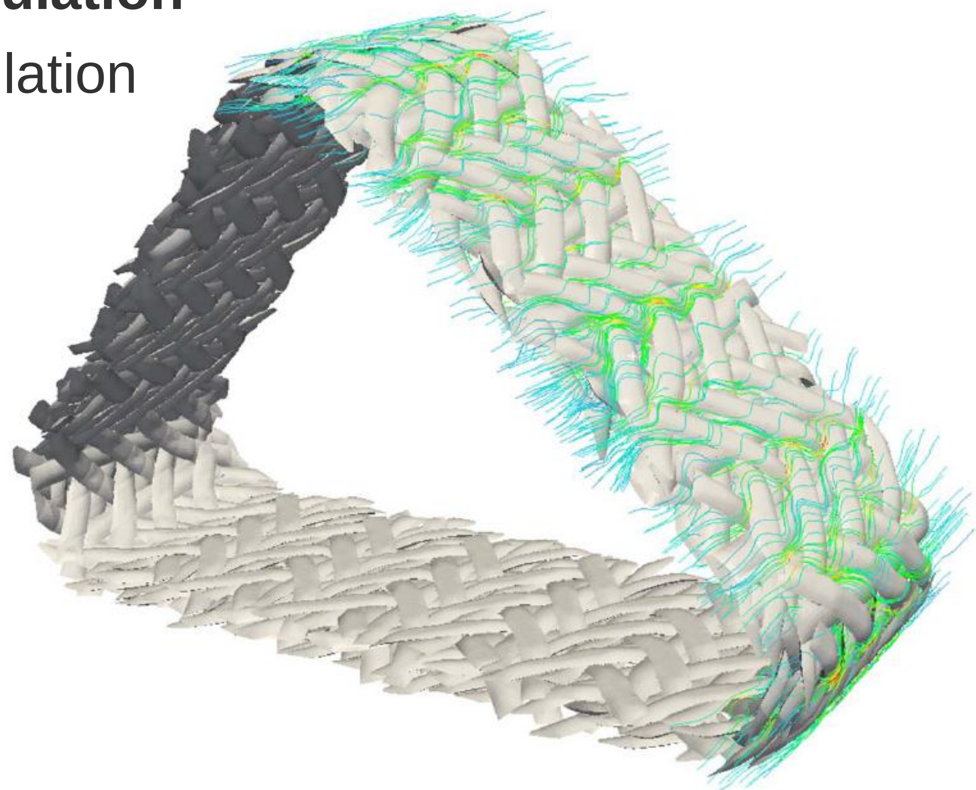
Advantage:

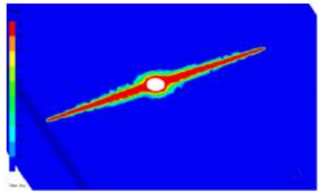
- Modelling of real physical phenomenon
  - Fiber angle deviation, gaps, detaching of layers, compaction effects
- Process related part design
- Process planning and optimization possible



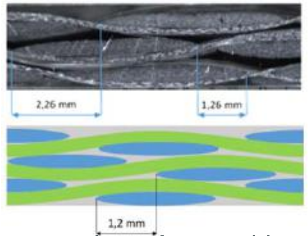
Process Simulation

Infusion Simulation

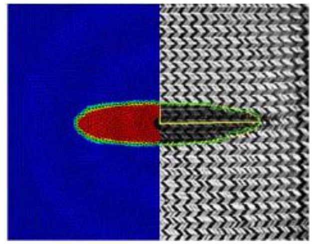




runner simulation



Mesoscopic preform architectur



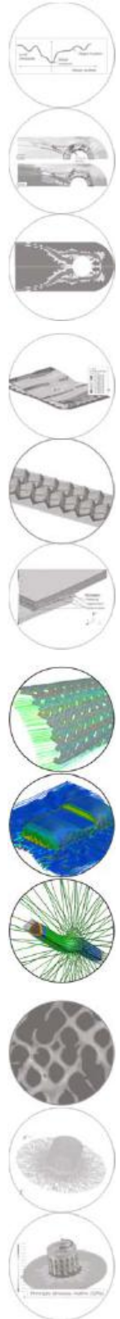
Validation of permeabillity

Approach:

- Exp. measurement of permeability (K1, K2, K3)
- Numerical calculation of permeability through CFD
- Explicit FEM macro infusion simulation + meso-macro CFD infusion simulation
- ESI, TexGen, WiseTEx, RTM-Worx, OpenFoam, InHouse-Codes

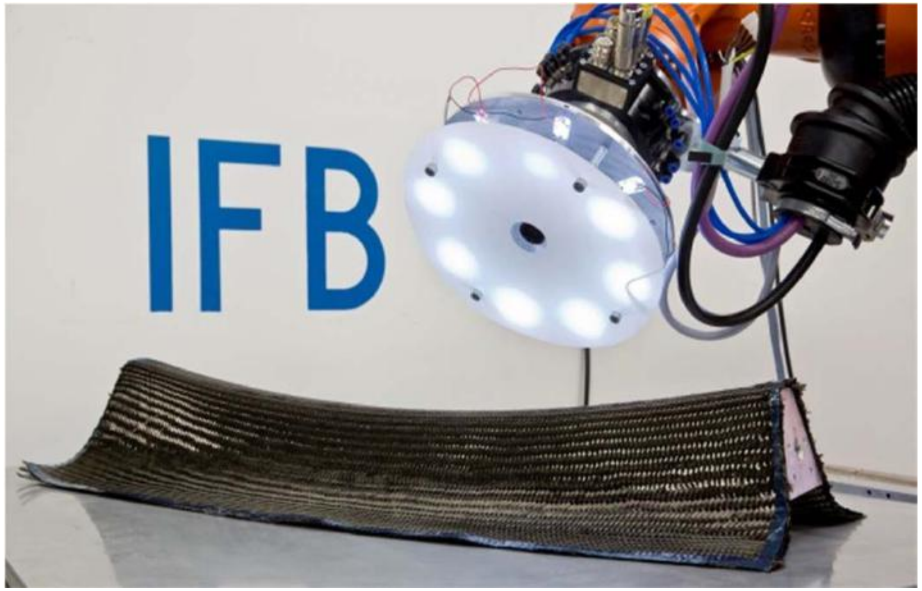
Advantage:

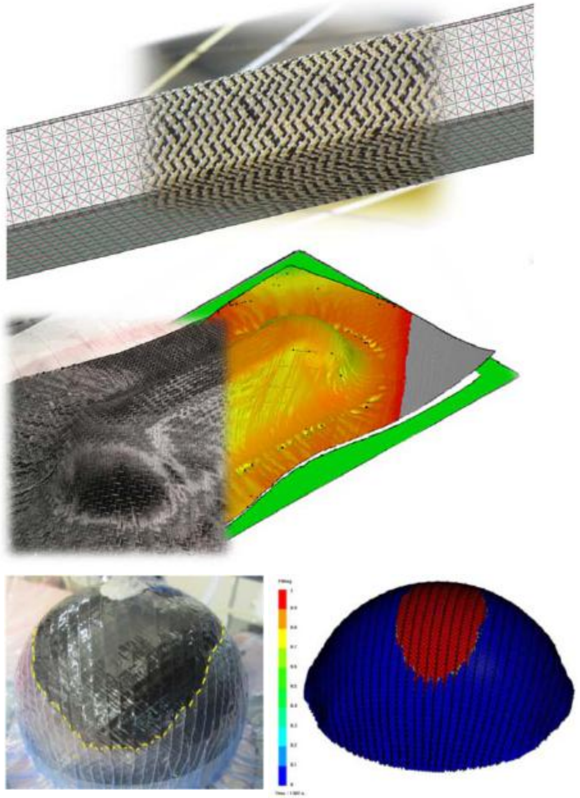
- Near net shape numerical, local permeability calculation
- Design of molding
- Detailed process understanding



Process Simulation

Validation of Simulation





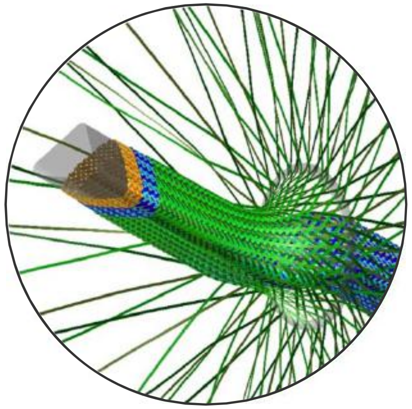
Approach:

- Compare simulation results to real parts through optical measurement of fiber architecture or ATOS
- Automatic recognition of textile effects (gapping, fiber angle, wrinkles)
- Automatic application of measured results to structural simulation

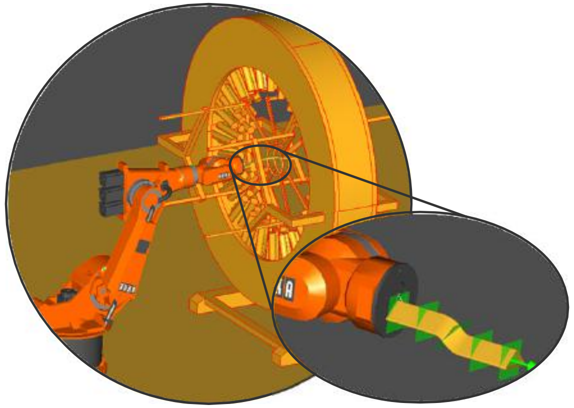
- Process design based on real preform effects
- Prediction of real material / structural behavior based on process simulation
- Virtual material characterization

Process Realization

In-house CAD/CAM Software “FlexiCAM”



Process simulation



Offline path planning and programming of industrial robots

Real manufacturing process

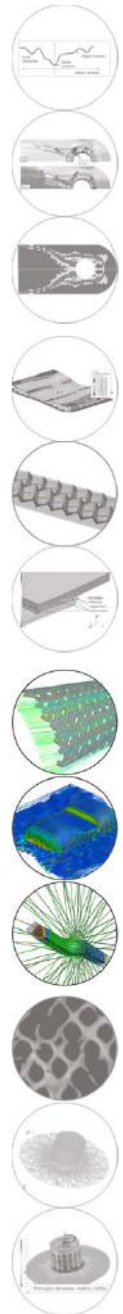
Connection between Simulation and Reality

Goal:

- Optimization of time and costs through completely offline programming of robot-based procedures and manufacturing processes
- Closing the gap between the process simulation and the real manufacturing process

Approach:

- Development of a novel knowledge-based CAM-Software (FlexiCAM) for various manufacturing processes
- Further development of FlexiCAM in regard to “Industrie 4.0”



OPTIMIZATION

STRUCTURAL SIMULATION

PROCESS SIMULATION

MULTI-SCALE MODELLING

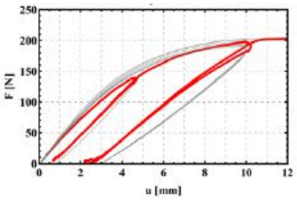
Structural Simulation

Material- / Failure and Damage Modelling

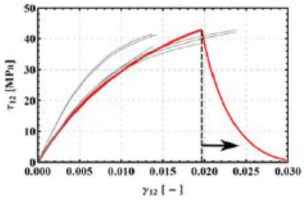
Material Model Development

Delamination

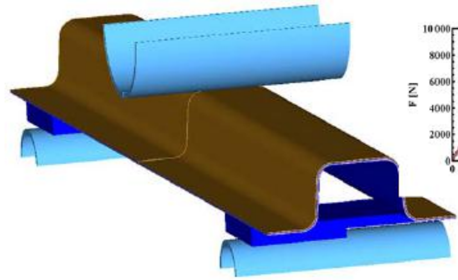
Non-linear Loading / Unloading



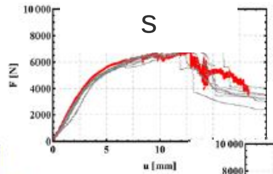
Element degradation



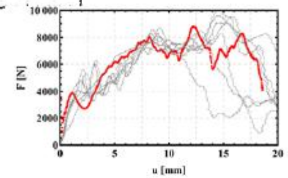
Part Simulation



0.03mm/s

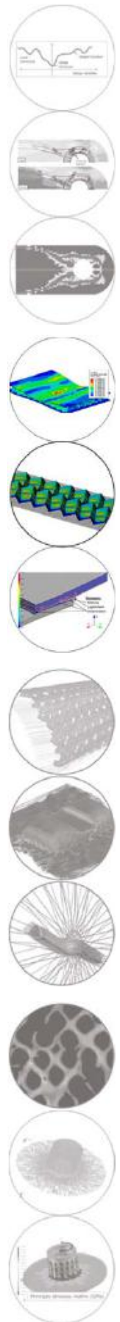


3000mm/s



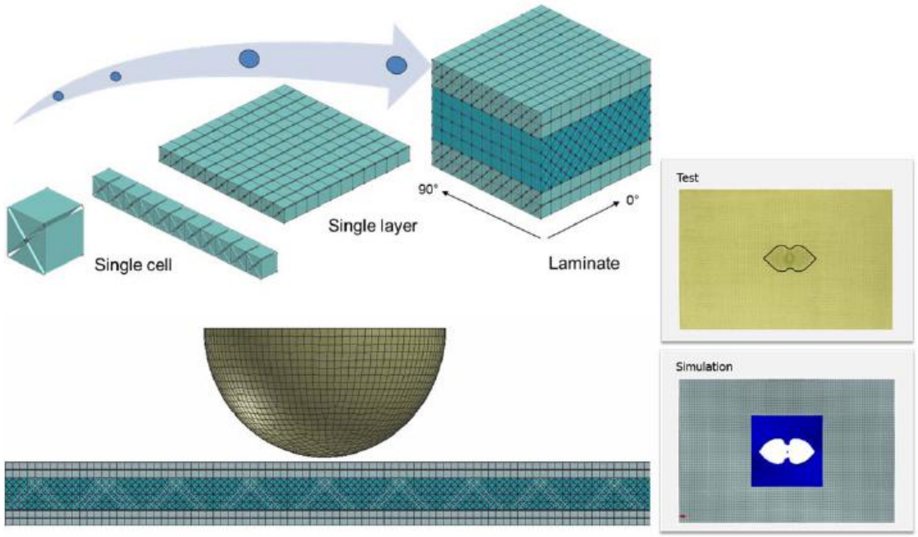
Approach: „Non-linear 3D-Puck“ for NCF

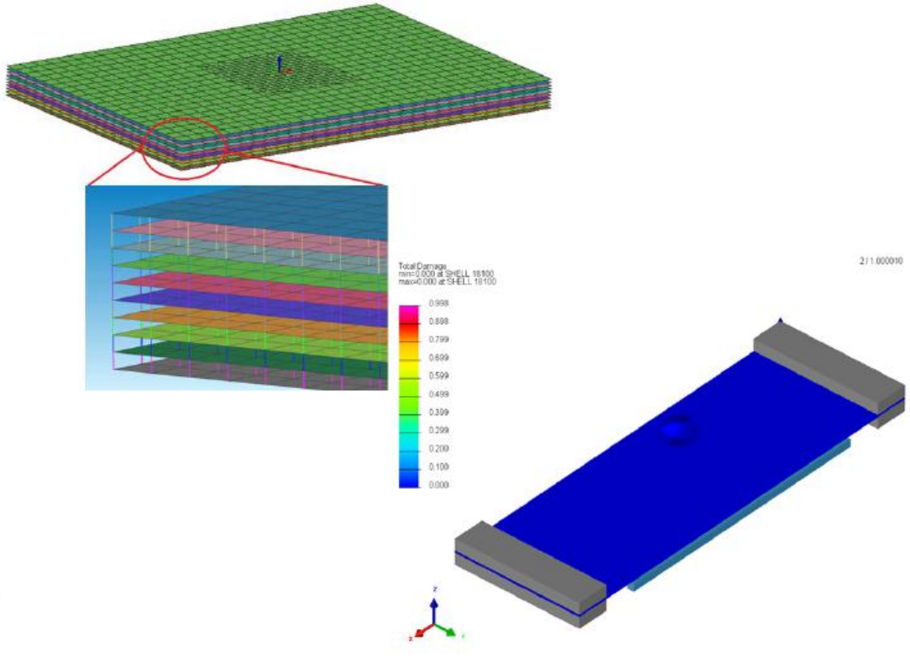
- Orthotropic Material behavior
- Non-linear material behavior in shear and transfer tension
- Puck failure criterion for 2D and 3D stress states
- Energy based post-failure damage model
- Cohesive zone elements for delamination
- High strain rate effects on strength



Structural Simulation

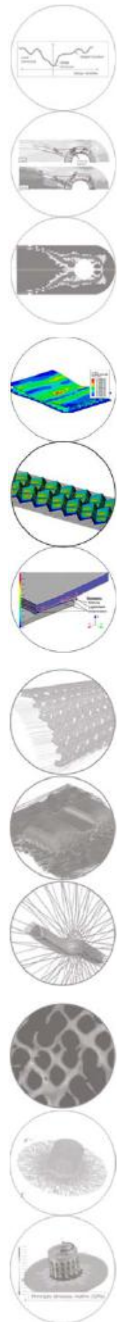
Impact and Crash





Approach:

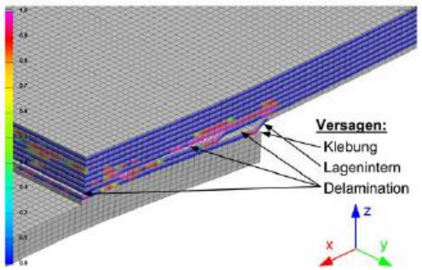
- Puck failure criterion for 2D and 3D stress states
- Delamination initiation through intra-laminar transverse crack modelling
- Inter-laminar crack growth (delamination) through cohesive zone modelling
- Discrete finite element model for arbitrary crack formation
- Stacked-Shell Modell
- Puck failure criterion for 2D and 3D stress states
- Non-linear material model

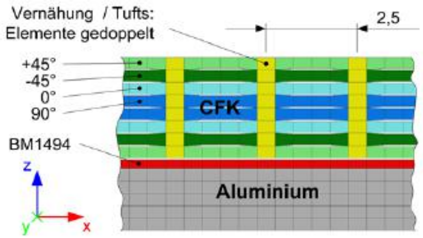


Structural Simulation

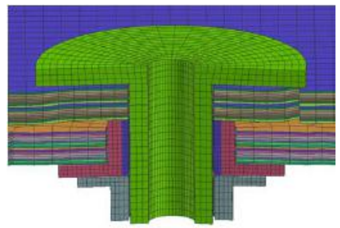
Structural Joints (static / dynamic / crash)

Tufted GFRP / Aluminum Bonding





Mesoscopic connecting elements



Goal:

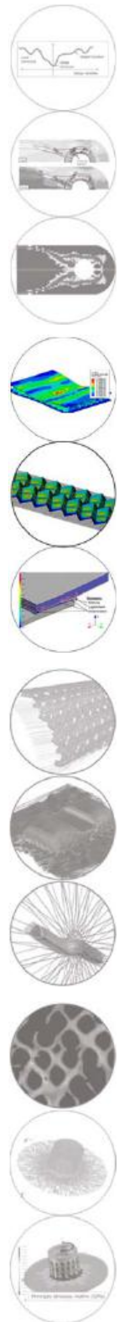
- Prediction of failure
- Simulation of entire damage process
- Maximizing energy consumption

Application:

- CFRK-CFRK Adhesive Joints: high-performance structures (aerospace, automotive)
- Tufted CFRP-Alu Joints: Crash
- Bonded & Bolted: Damage Tolerance/ Crash

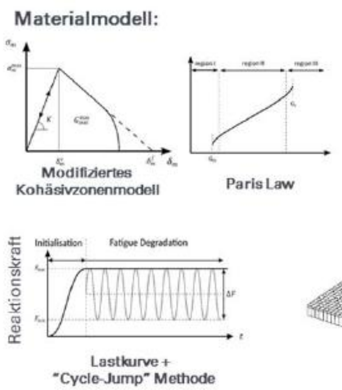
Approach:

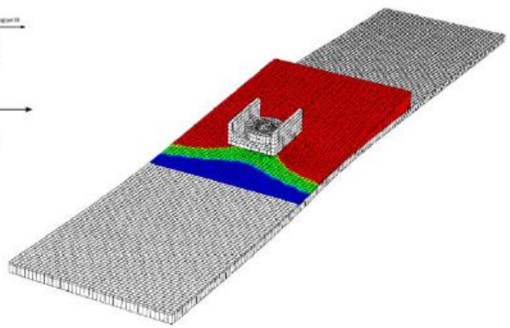
- Stacked-Shell / Stacked-Solid Model
- Non-linear material model
- 3D-Puck failure criterion
- Cohesive-Zone-Element: Delamination
- Mesoscopic modelling of joints / connections

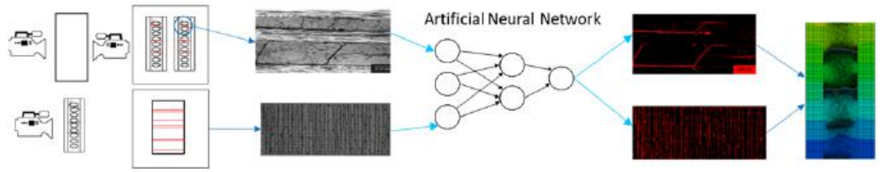


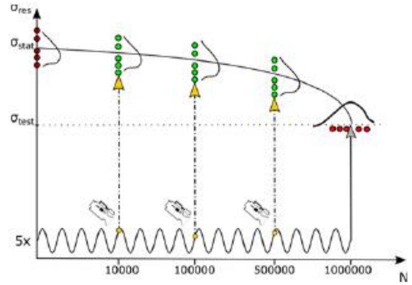
Structural Simulation

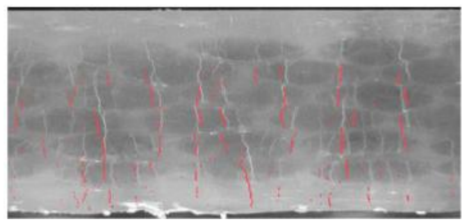
Fatigue-Simulation / Residual Strength











Goal:

- Damage Tolerance Design
- Prediction of crack growth under high cycle fatigue loading
- Prediction of residual strength
- Investigation of „crack-arresting features“

Approach:

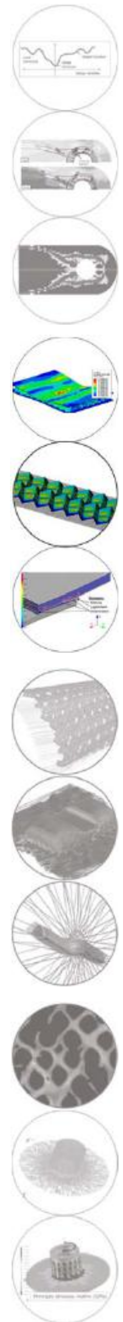
- Mesoscopic explicit simulation
- Modified cohesive zone elements for fatigue
- „Cycle-Jump“ method
- XFEM
- Artificial Neural Networks

OPTIMIZATION

STRUCTURAL SIMULATION

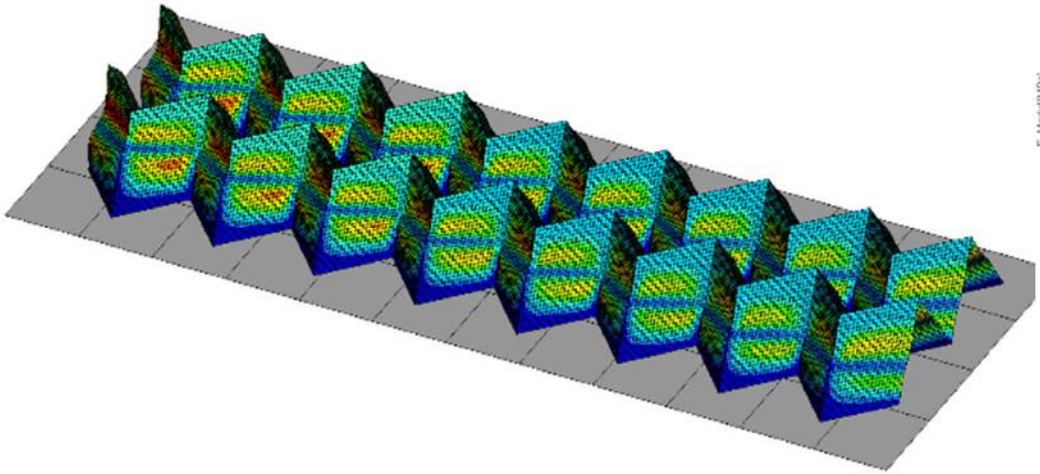
PROCESS SIMULATION

MULTI-SCALE MODELLING

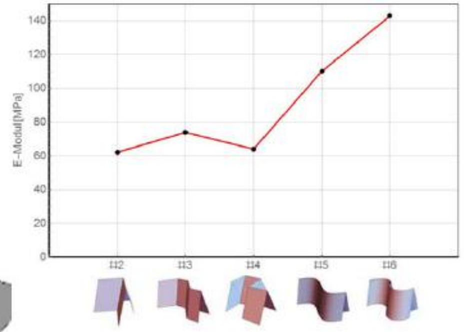


Structural Simulation

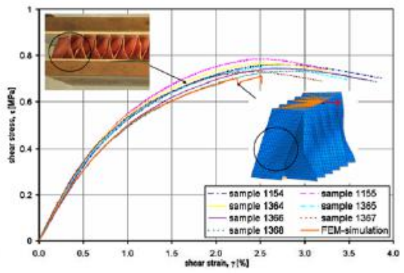
Fold Core - Sandwich Composites



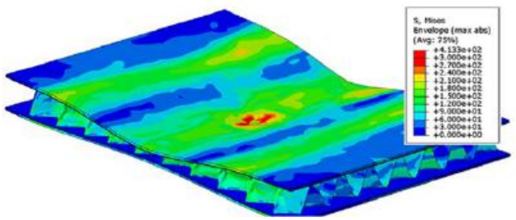
Evaluation of Core Properties



Prediction of Stiffness / Strength



Impact Simulation

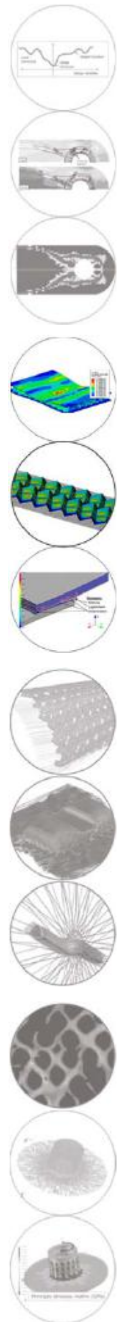


Goal:

- Prediction of stiffness and strength under static loading
- Modelling of failure in core and sandwich composites
- Preliminary design of sandwich components
- Impact modelling and energy consumption

Approach:

- Non-linear, explicit simulation
- Mesoscopic modelling of fold cores
- Shell (metal) and layered-shell (composite) elements
- User-subroutines for material modelling



OPTIMIZATION

STRUCTURAL SIMULATION

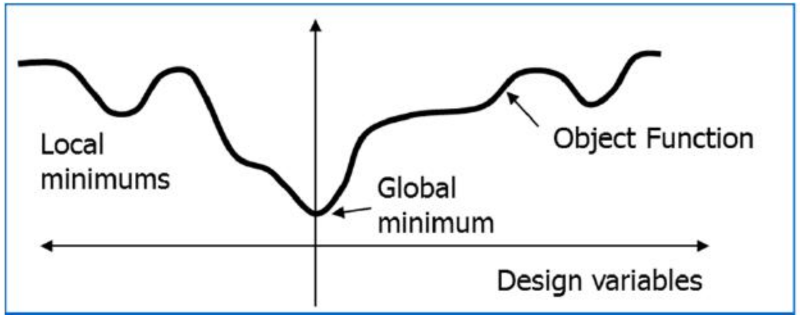
PROCESS SIMULATION

MULTI-SCALE MODELLING

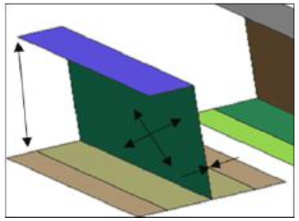
Optimization

Design for Performance, Weight and Cost

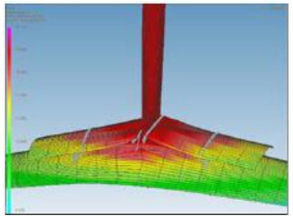
Objective function minimisation



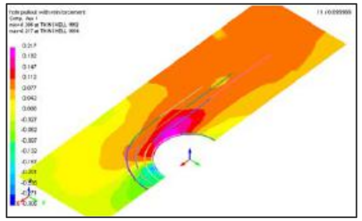
a) Laminated layups, fiber direction and thicknesses



b) Stitch positions



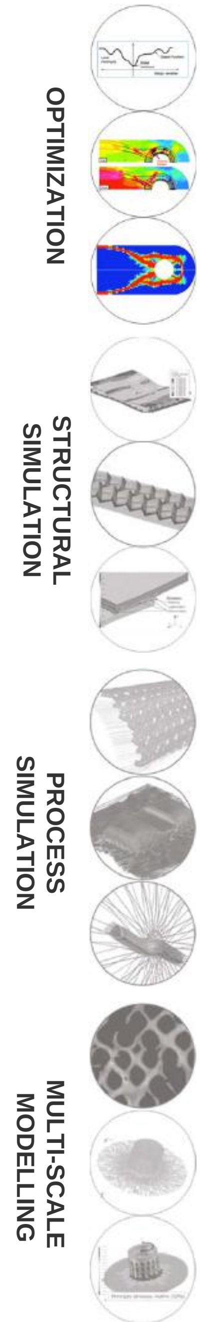
c) TFP design



Approach:

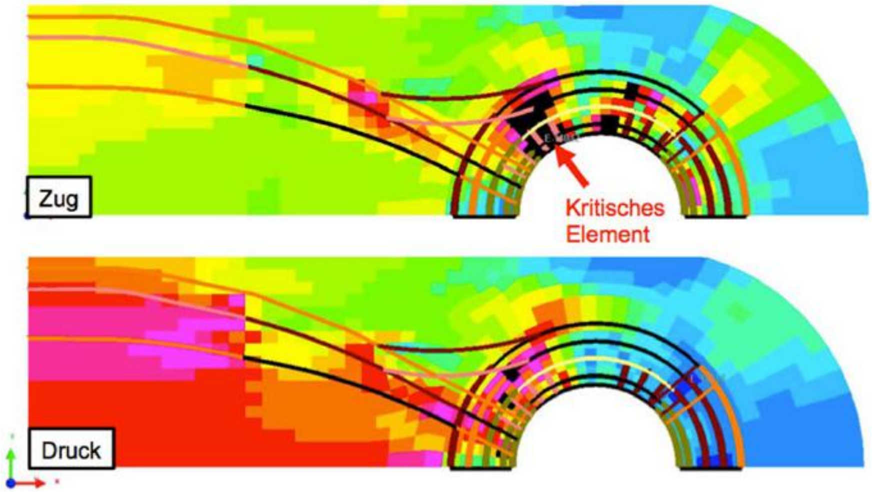
- Identification of design variables:
  fiber orientation, tufting location, reinforcement fibers
- Definition of optimization functions → multiple criteria: Weight, Cost, Stiffness
- Gradient based or genetic optimization

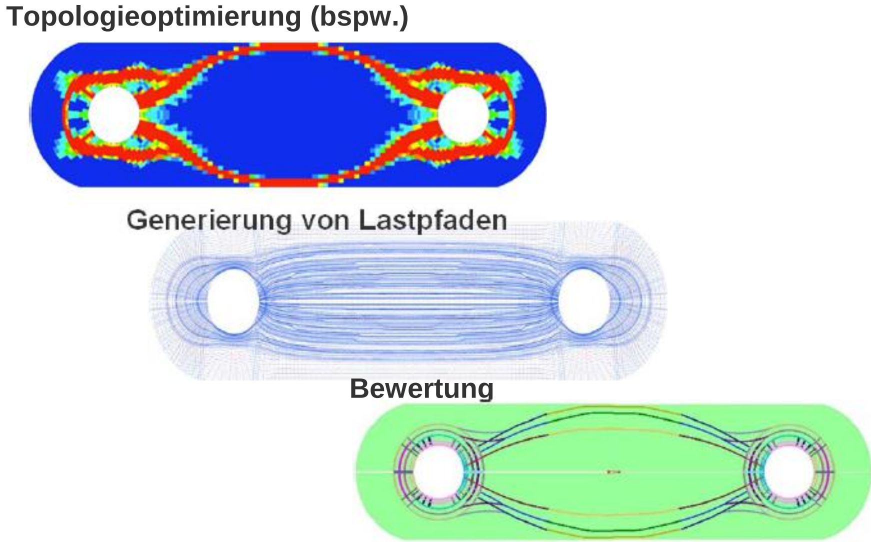
- Fiber orientation to maximize stiffness-to-weight and stiffness-to-strength ratio
- Tufting location for optimal impact behavior
- Optimized Single-Fiber Layup (tailored fiber placement)



Optimization

Stress-Based Single Fiber Path Generation for CFRP-Structures





Approach:

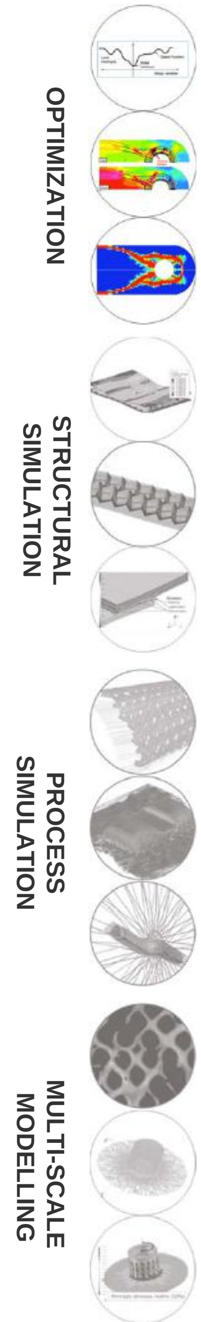
- Application of standard software tools (HyperWorks, Abaqus, Nastran, LS-Dyna etc.)
- In House tool / interface development for specific applications of specialized CFRP design
- Consideration of multiple load cases

Generation of Fiber Paths

- Topology optimization
- Principle stress analysis
- Automation of evaluation
- Automation of fiber path generation
- Optimized stiffness- and strength-to-weight

Analysis Optimized Design

- Meso-modelling of discrete fibers
- Considering manufacturing boundaries



Institute of Aircraft Design

Overview Material Testing

Quasistatic Testing

- Standard and non-standard tests for composites material
- Temperatures from -55°C to +250°C
- Testing loads: 500N, 2, 5, 20, 25 and 250 KN

Dynamic Testing

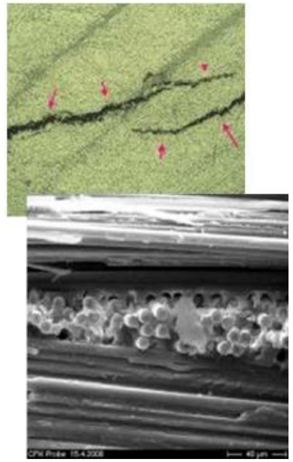
- 5 axial actuators (10 – 100 KN)
- 1 rotary cylinder (2 KNm)
- Test bay for structural and subcomponent testing

Laminate manufacturing for testing

- Goods issues testing for NCF material

Chemical laboratory

- FVC determination, Microscopy (optical, SEM)
- TGA, DMA, DSC
- Density determination

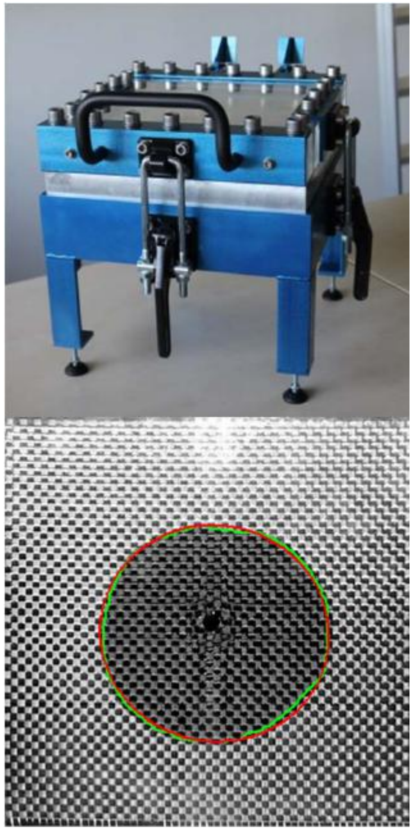





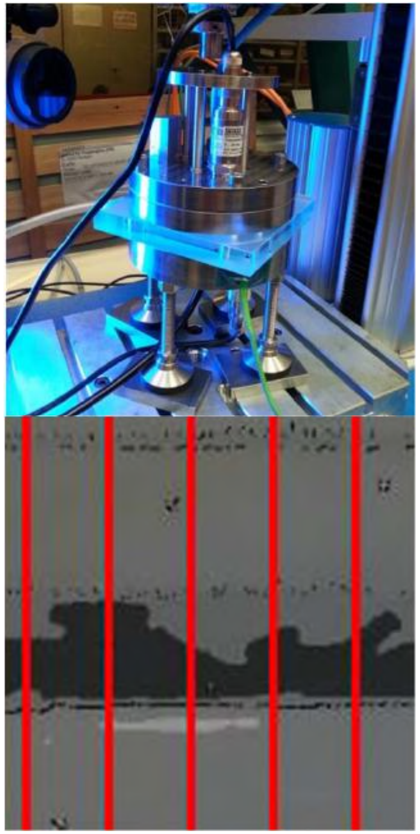
Institute of Aircraft Design

Overall Permeability Characterization

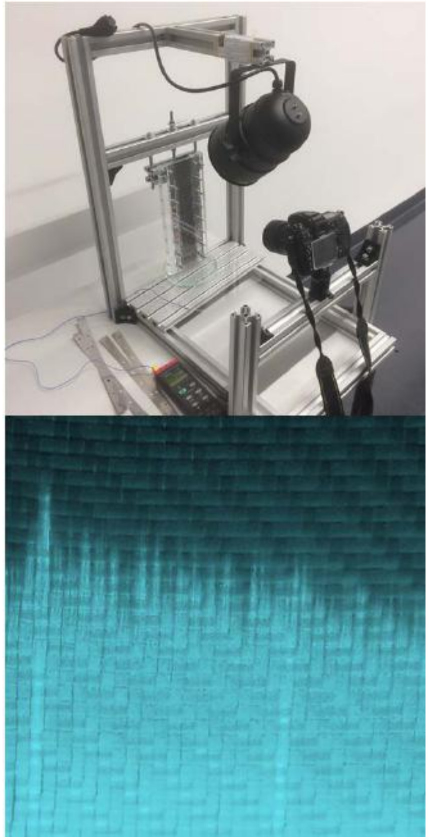
Linear/Radial Permeability Determination (2D)



Through Thickness Permeability Determination (3D)



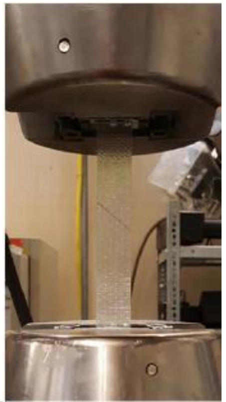
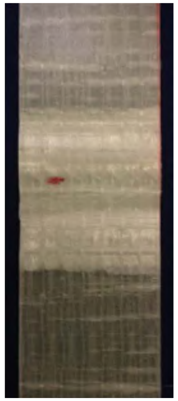
Yarn Permeability Determination (Micro Infiltration)



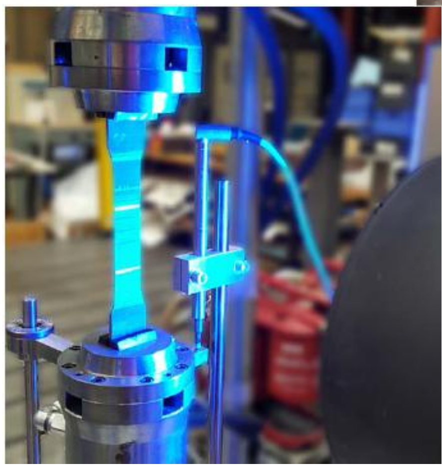
Fatigue Testing at IFB

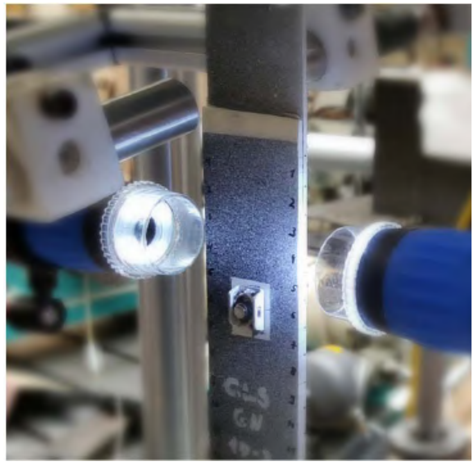
Coupon level

- Tension-Torsion testing
  - 100kN axial and 2kNm torsional
- 10kN and 25kN axial Test-machines
- In-Situ optical damage measurement


Loading	Force / Moment	Displaceme nt
Axial 10	10kN	250mm
Axial 25	25kN	250mm
INSTRON	100kN 2kNm	125mm

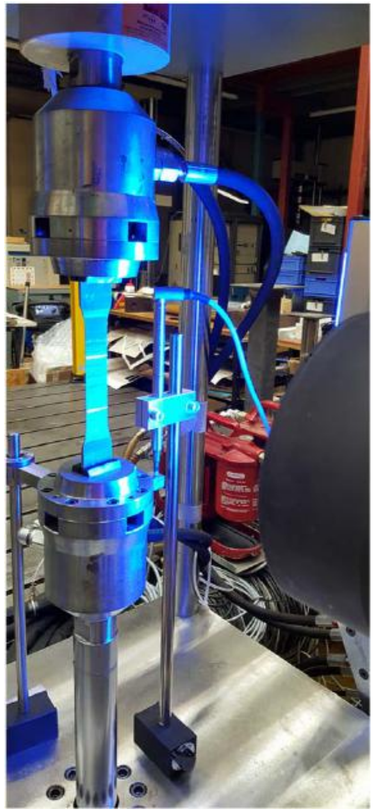




Fatigue Testing @ IFB

Structural Detail level

- Test rig development after specification
- Strain measurement
  - Optical – Videoextensometer, DIC
  - Mechanical
- 64 Channels for various DAQ measurements
- Random and spectrum loading
- Up to 250kN

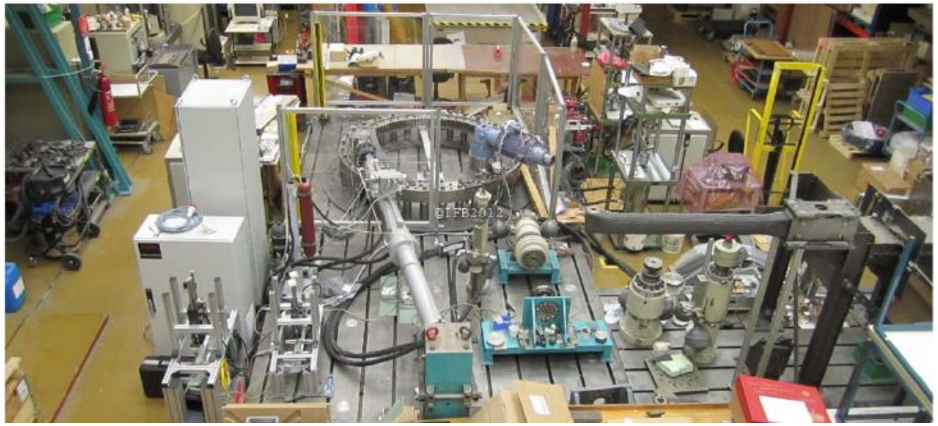


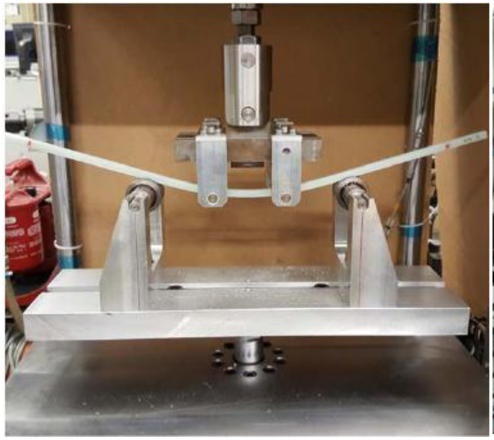
Fatigue Testing @ IFB

Structural level

- Structural Test-bed
  - 6x3m and 2x3 m
- Servohydraulic test cylinders
  - Axial and Torsional
- Multiaxial structural testing possible

Loading	Force / Moment	Displacement
Axial 16	16kN	250mm
Axial 100	100kN	250mm
Axial 250	250kN	125mm
Torsional	4kNm	



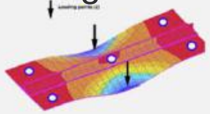


IFB Equipment Summary

Preforming

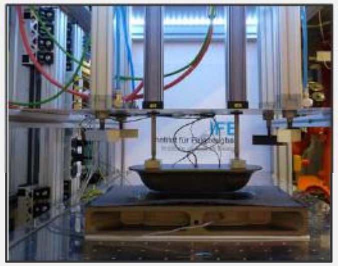
Braiding

3D Stitching



TFP

Draping

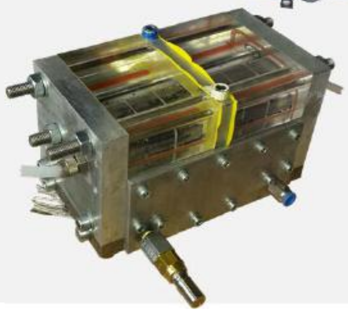


Resin Injection

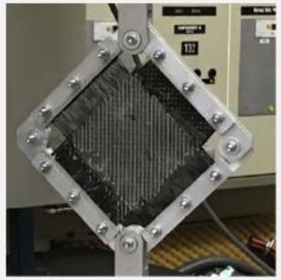
VAP / VARI

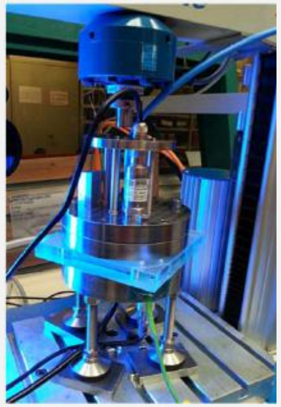
Compression molding

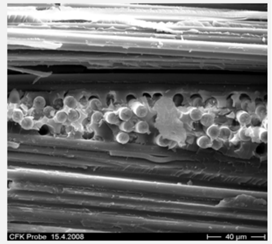
RTM



Material characterisation



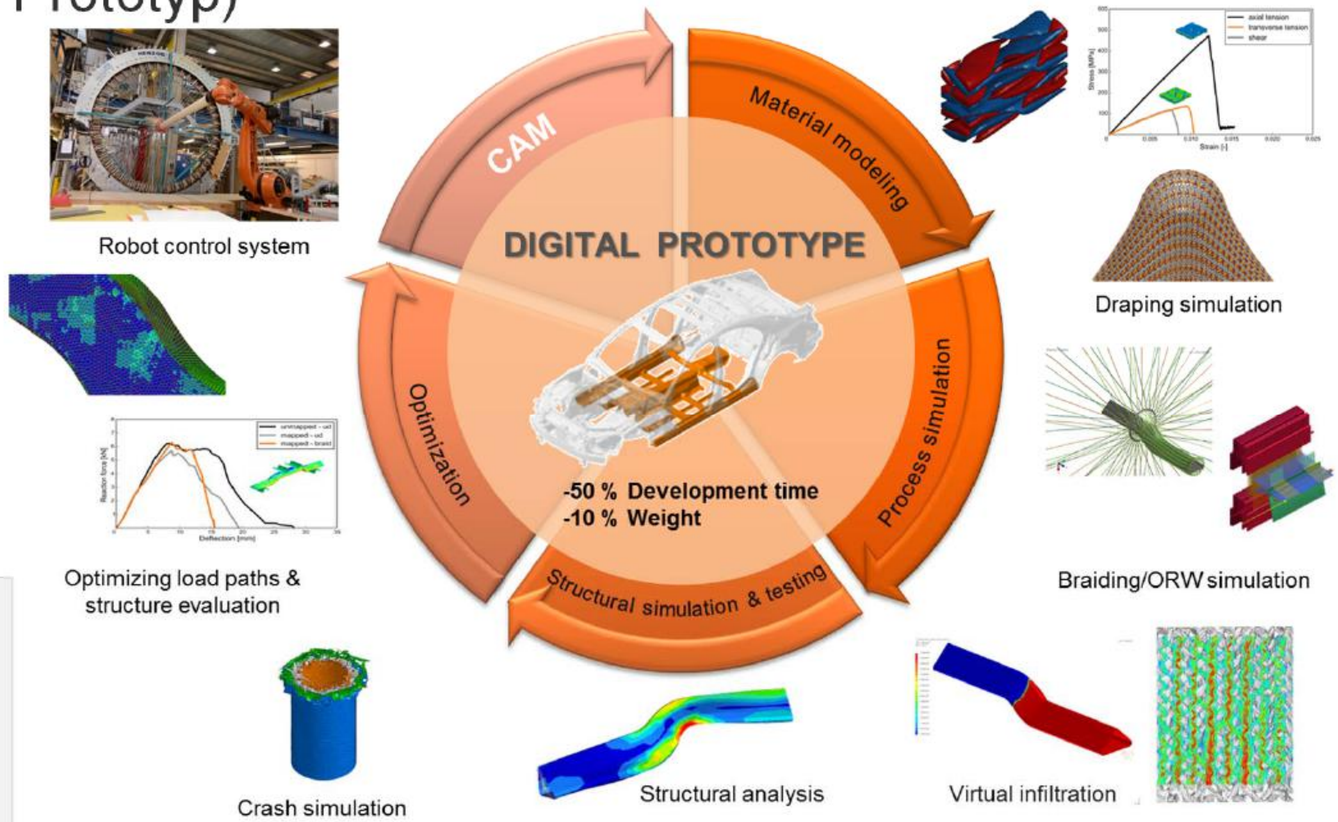




Projects

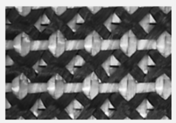
ARENA2036 DigitPro (Digitaler Prototyp)

- Closed process chain
- From CAD design to final product
- Micro-, meso- and macroscopic modelling
- Different simulation tools
- HDF5 data Format



– Braided structures
– **O**pen-**R**eed-**W**eaving-structures

- 50 % Development time
- 10 % Weight



Numerical closed process chain for support of product design processes of FRP structures

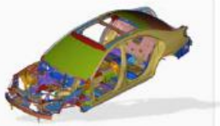
Projects

ARENA2036 Leifu (Leichtbau mit Funktionsintegration)

Approaches to be integrated scopes

Electric
Inductive charging and battery system

Mechanical
Improvement of stiffness, stability, NVH

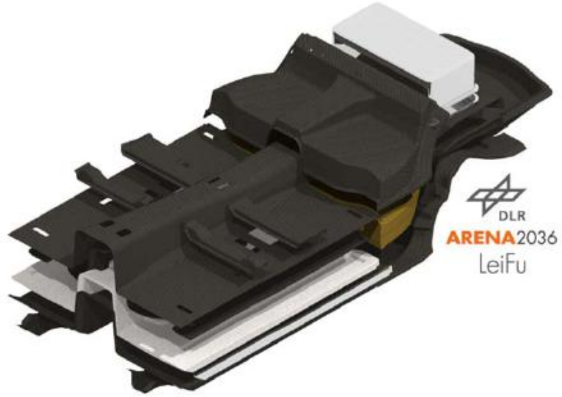


Functions

Thermal
Active heating and cooling function

Sensors
Structural integrated crash sensor

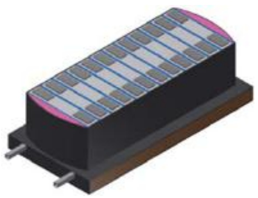
DAIMLER



Concept for a demonstrator with functional integration

TFP process for inductive charging modules

Integration of carbon heating textile



FRP battery housing with integrated sensors

Printed liquid detections sensors on textile preform

In LeiFu different approaches of functional integration are developed, implemented and evaluated on the basis of a FRP demonstrator module.

Additive Manufacturing @ IFB

Processes

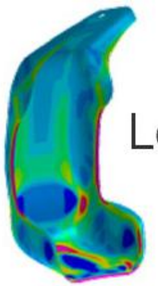
Selective Laser Sintering (SLS)

Stereolithography (SLA)

Fused Deposition Modeling (FDM)

ARENA2036

Research & Applications

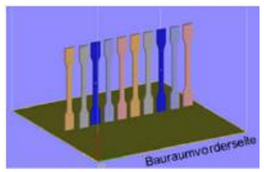


Load optimized design

Functional prototypes

UV curing & post-process optimization

Material characterization



3D-printed moulds & soluble cores

Fiber-reinforced 3D printing

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Thank you!

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