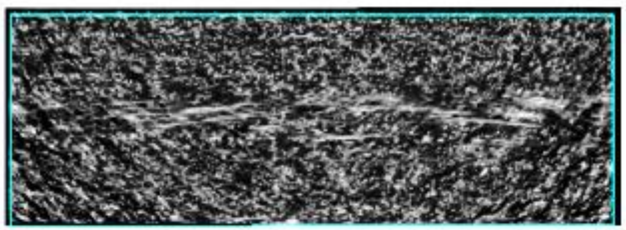
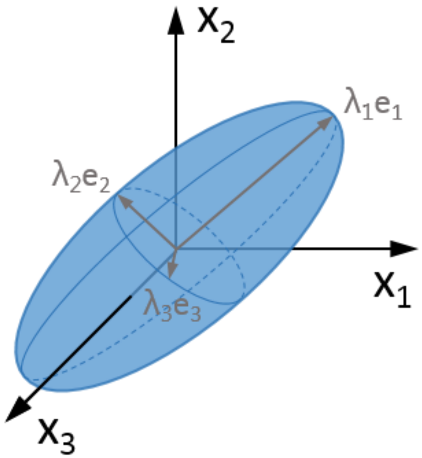
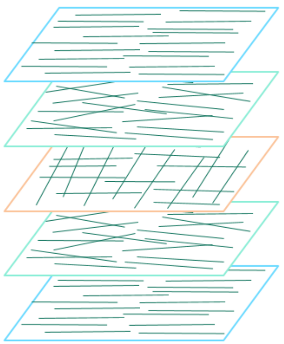
MODELING OF FIBER-REINFORCED PLASTICS TAKING INTO ACCOUNT THE MANUFACTURING PROCESS







Cherry Ann Reclusado
Ernst-Mach-Institut, Freiburg

German LS-DYNA Forum
9th June, 2016

Fraunhofer EMI

OVERVIEW

- Introduction and motivation
- Modeling method
- Validation
- Summary and conclusion

Introduction and motivation

The challenge of a modern lightweight construction material

Special requirements on a construction material in the automotive industry

- Decrease vehicle weight
- Absorb kinetic energy / stay intact after crash
- Large production volume
- …

[1]

[2]

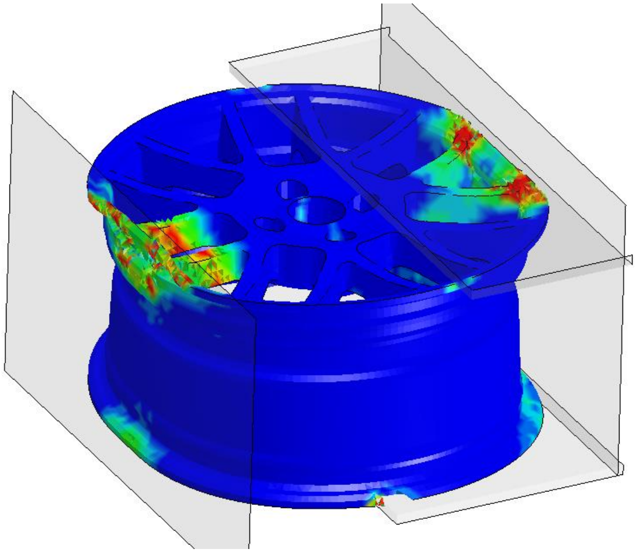
[2]© Picture (detail): Stan Shebs, License: Creative Commons Attribution-Share Alike 3.0 Unported

[1]Picture: Eco-marathon Shell, License: Free Art License 1.3

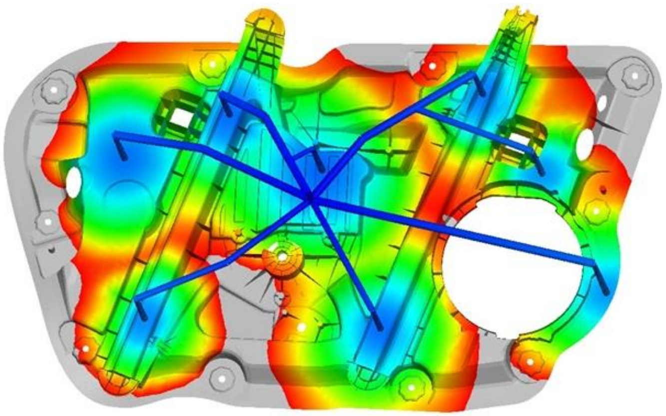
Introduction and motivation

FE-simulation in the automotive industry

Structural simulation



Process simulation (injection molding)



[3]

- Reduce cost and time
- Virtual manufacturing and component testing

→ Predictive power depends on appropriate modeling of load case, geometry and material model

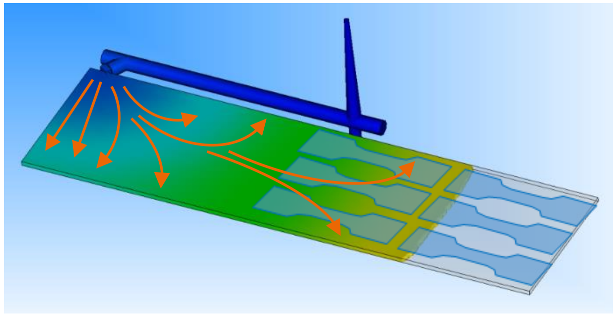
[3]Simulation: SABIC, Geleen, NL

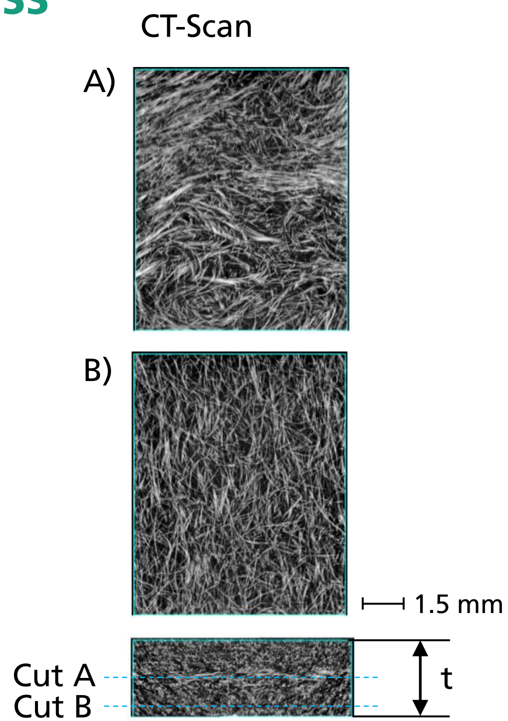
Fraunhofer EMI

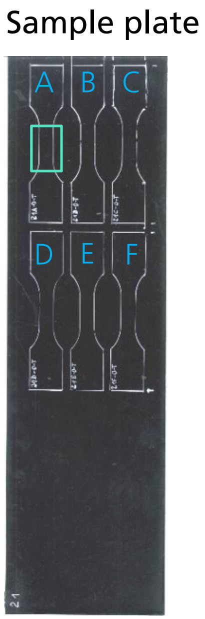
Modeling of long glass fiber reinforced plastic (GFRP)

Characteristic due to production process

Injection molding simulation







- Different flow directions in component
  → Mechanical behavior depends on position
- Flow velocity varies between surface and core
  → Various layers are formed

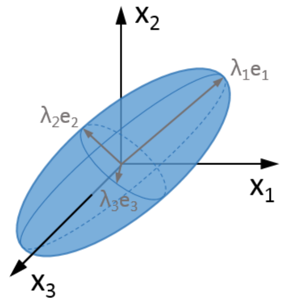
Modeling of GFRP

Fiber orientation and degree of freedom

Second order orientation tensor

$$a_{ij} = \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ & a_{22} & a_{23} \\ sym. & & a_{33} \end{bmatrix} \rightarrow \begin{matrix} Eigenvectors: e_i \\ Eigenvalues: \lambda_i \end{matrix}$$

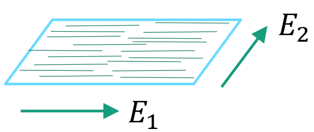
Orientation ellipsoid



Assumption for <u>long</u> fiber reinforced material

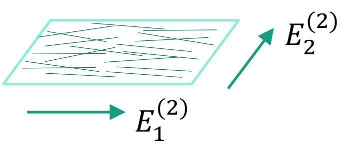
$$\lambda_1 + \lambda_2 + \lambda_3 = 1$$

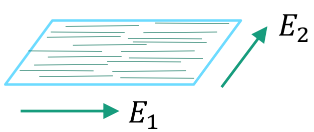
$\lambda_3 \approx 0$



Same orientation
Different degree of anisotropy

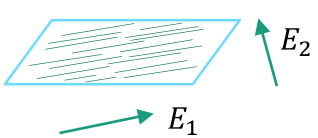
λ_1





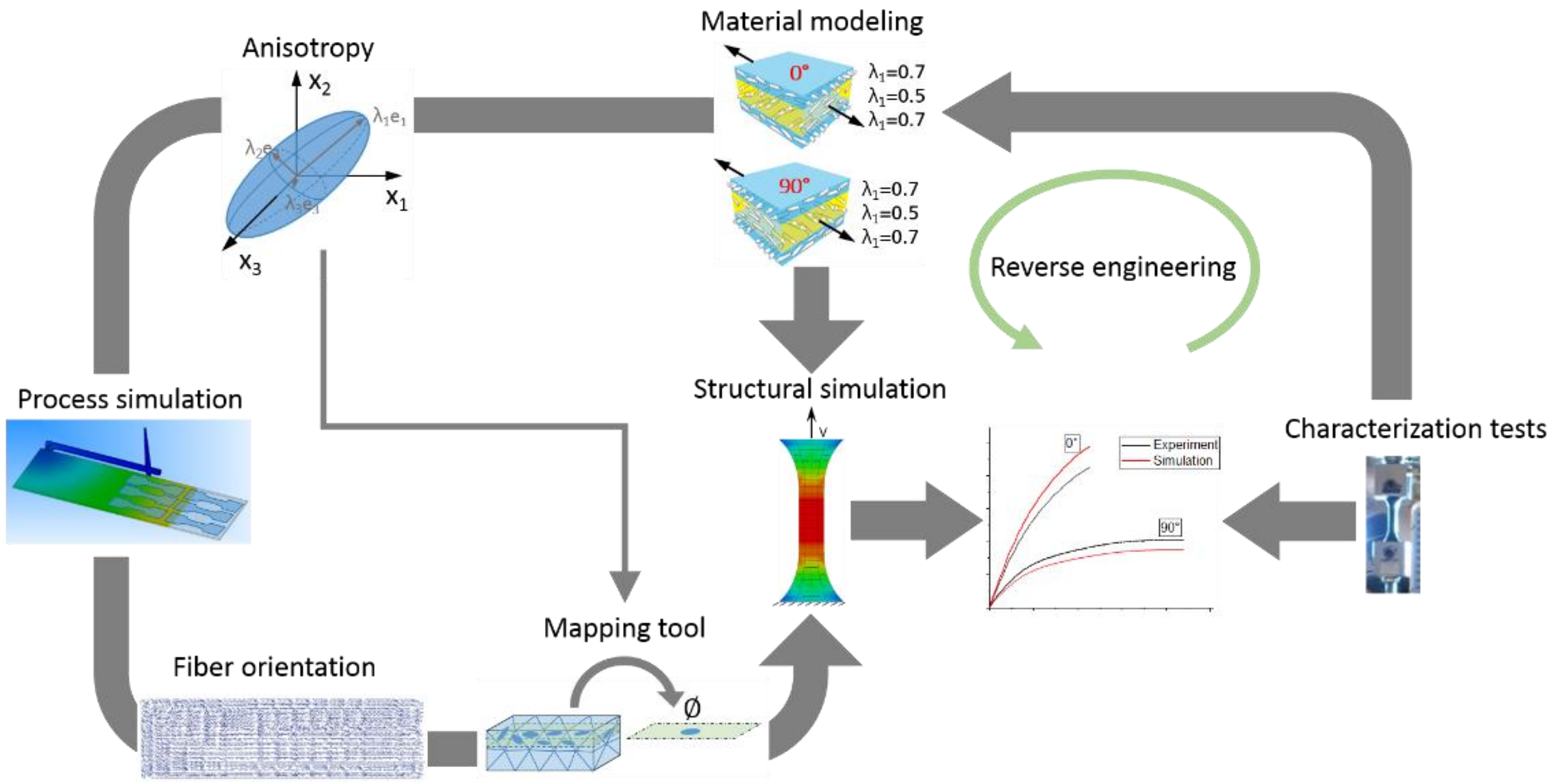
Different orientation
Same degree of anisotropy

e_1

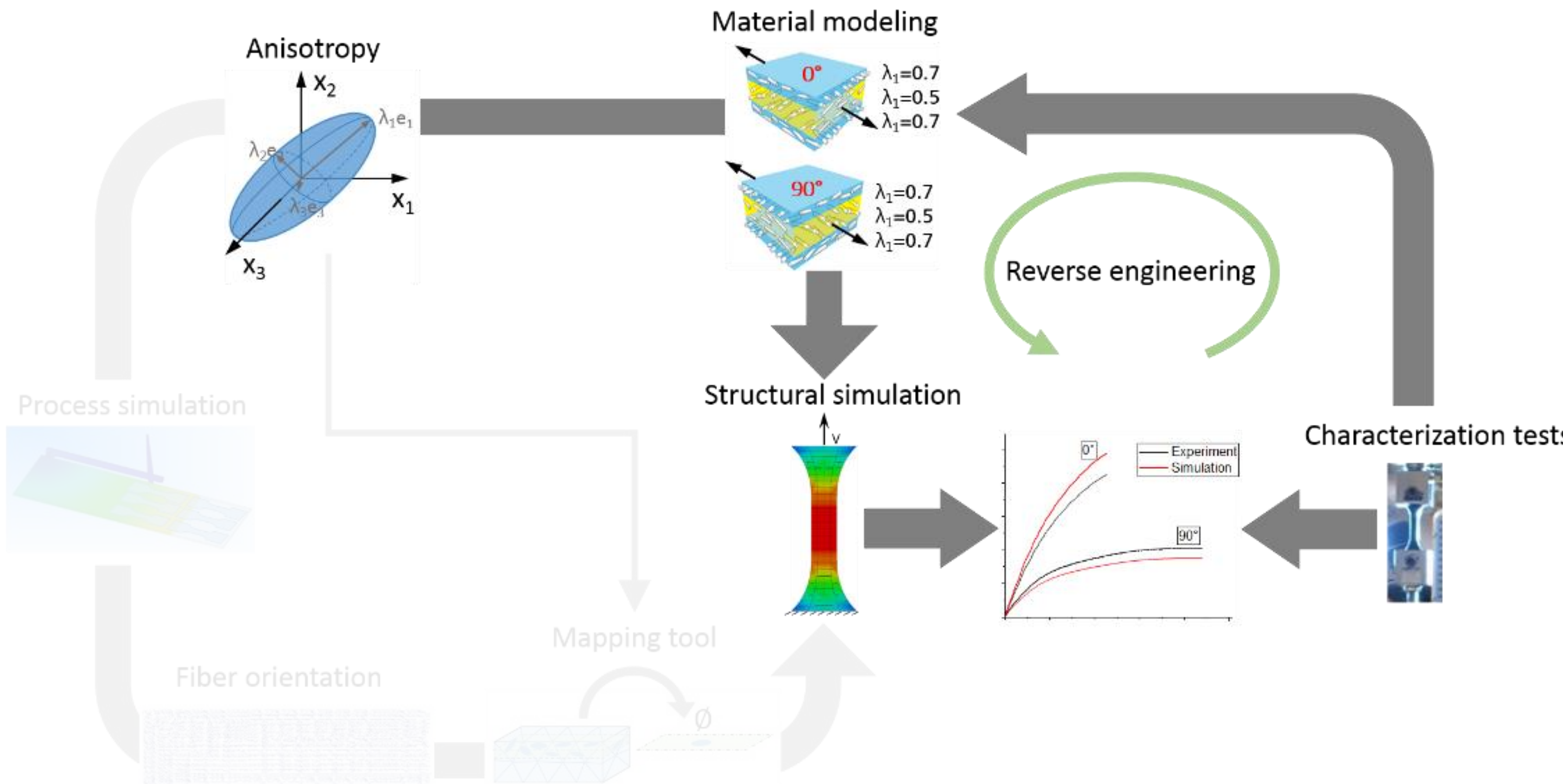


Modeling of GFRP

Methodology of the realized integrative simulation



Modeling of GFRP
Methodology of the realized integrative simulation



Fraunhofer EMI

Elastic properties of various orientation states

From UD to real material

Ranges of largest eigenvalue

$0.8 \leq \lambda_1 \leq 1.0$ → Class 1

$0.6 \leq \lambda_1 < 0.8$ → Class 2

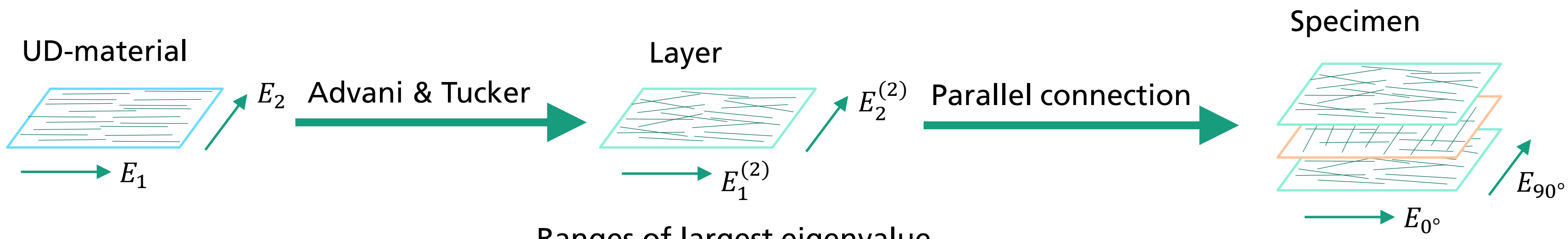
$0.5 \leq \lambda_1 < 0.6$ → Class 3

- Property of UD-material and orientation tensor known
- Calculation of mechanical properties of layer with arbitrary orientation state
- One material card per class

*S.G. Advani, C.L. Tucker, The Use of Tensors to Describe and Predict Fiber Orientation in Short Fiber Composites. Journal of Rheology, 31(8), 751-784, 1987

Elastic properties of various orientation states

From UD to real material



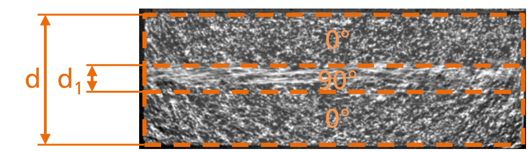
Ranges of largest eigenvalue

$0.8 \leq \lambda_1 \leq 1.0$ → Class 1
$0.6 \leq \lambda_1 < 0.8$ → Class 2
$0.5 \leq \lambda_1 < 0.6$ → Class 3

$$E_{0°} = \eta E_2^{(3)} + (1-\eta)\, E_1^{(2)}$$

$$E_{90°} = \eta E_1^{(3)} + (1-\eta)\, E_2^{(2)}$$

$$G_{0°/90°} = \eta G_{12}^{(3)} + (1-\eta)\, G_{12}^{(2)}$$



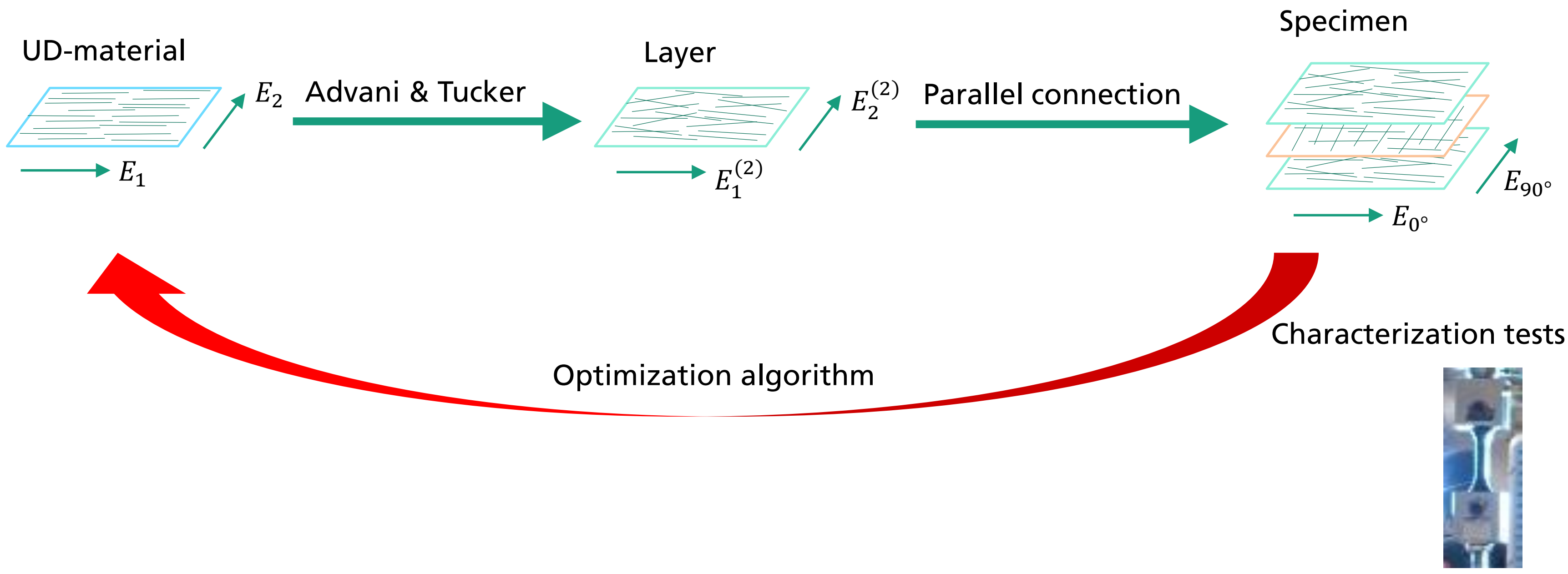
$$\eta = \frac{d_1}{d} = \frac{1}{5}$$

- Parallel connection of various layers yields specimen property

Fraunhofer EMI

Elastic properties of various orientation states

From UD to real material

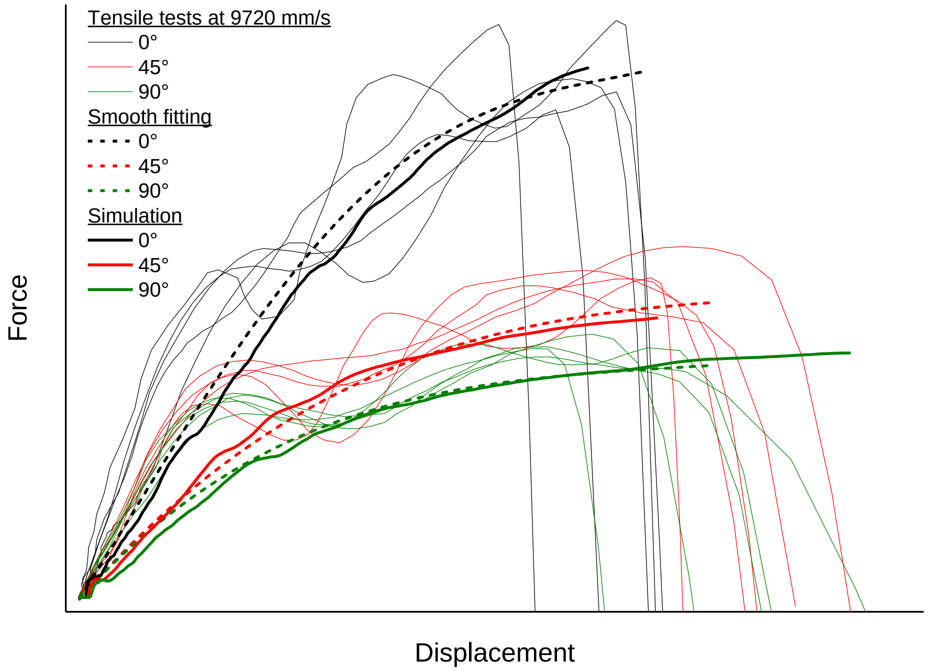


- Solving of the inverse problem: From characterization test to UD-material

Fraunhofer EMI

Plastic and failure parameters
Material parameters for MAT_108 in LS-DYNA

Simulation of tensile tests in 0°-, 45°-, and 90°-direction

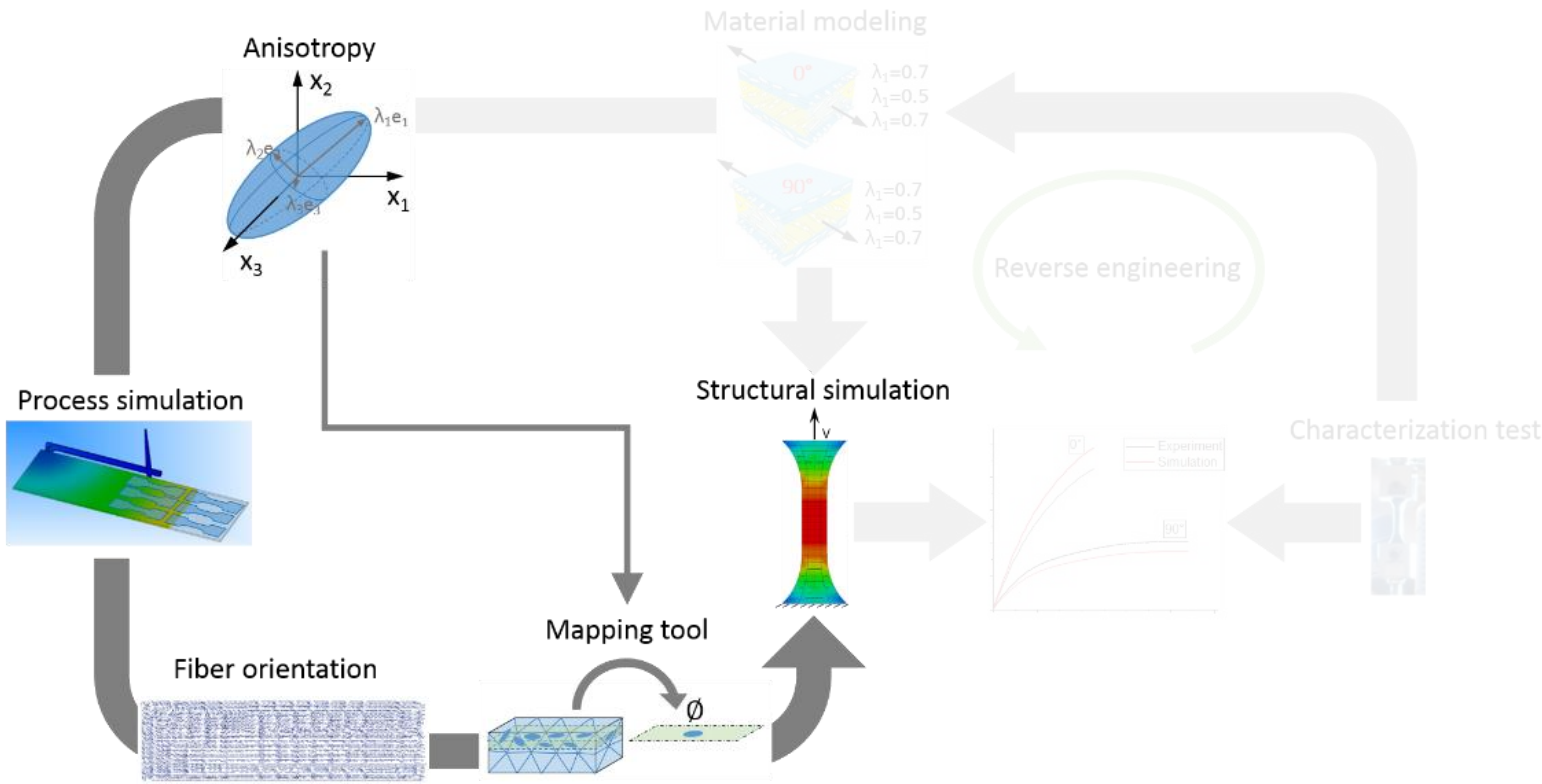


- Plastic parameters determined using LS-OPT
- Failure modeled with MAT_ADD_EROSION
- For all material classes the same plastic and failure parameters are used

Fraunhofer EMI

Modeling of GFRP

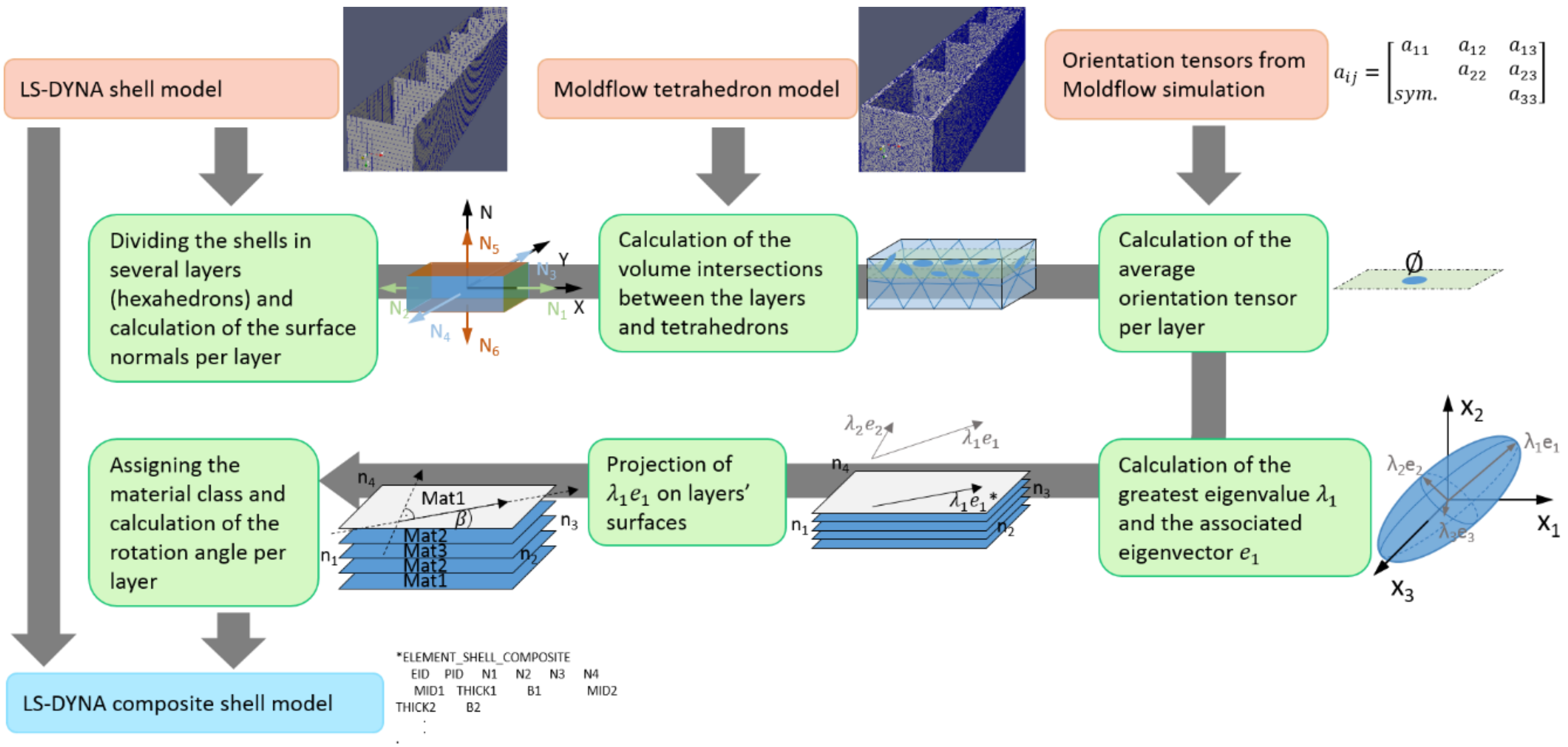
Methodology of the realized integrative simulation



Fraunhofer EMI

Mapping of orientation and degree of anisotropy

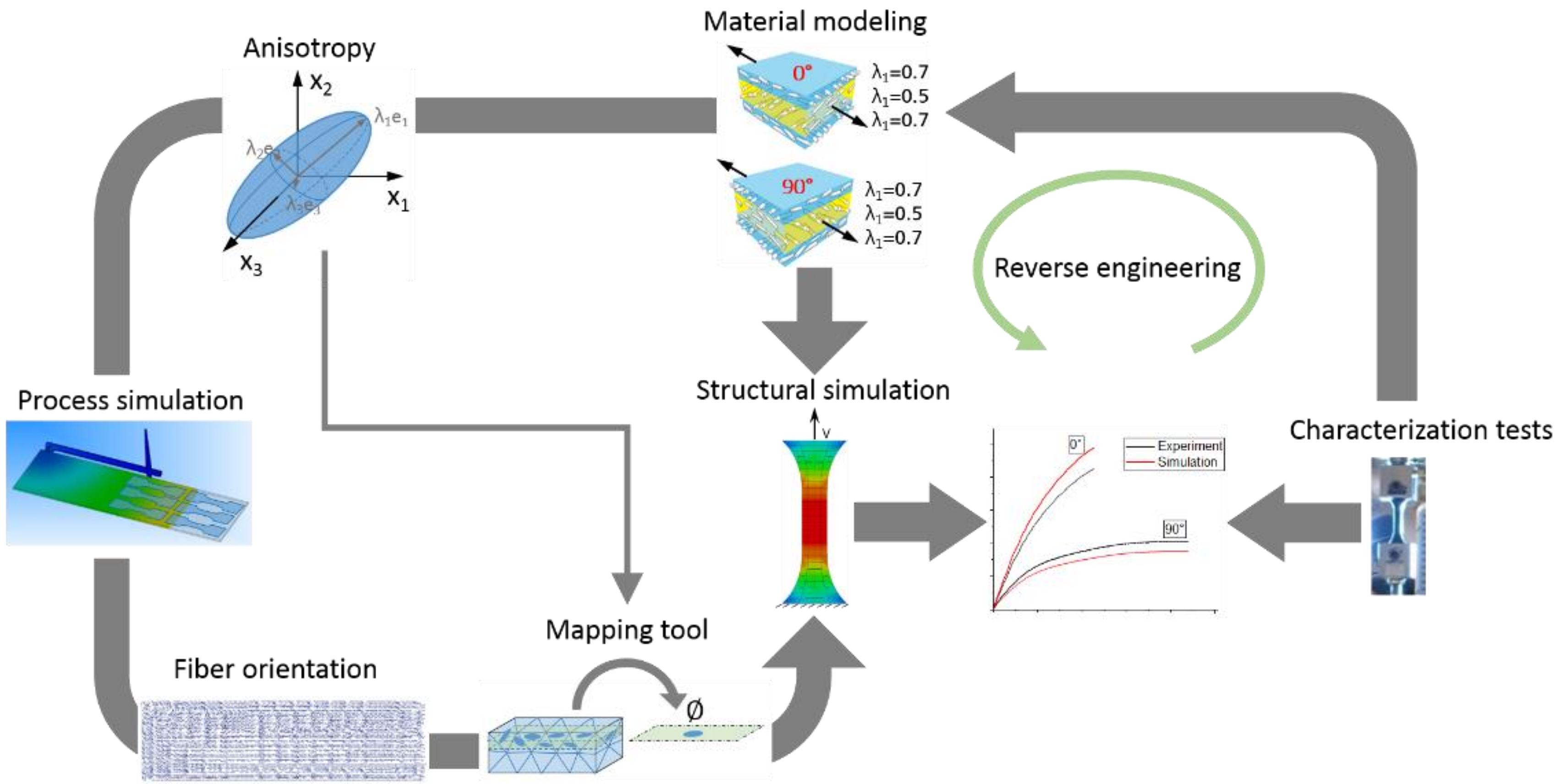
Flow-chart of developed mapping-tool



Fraunhofer EMI

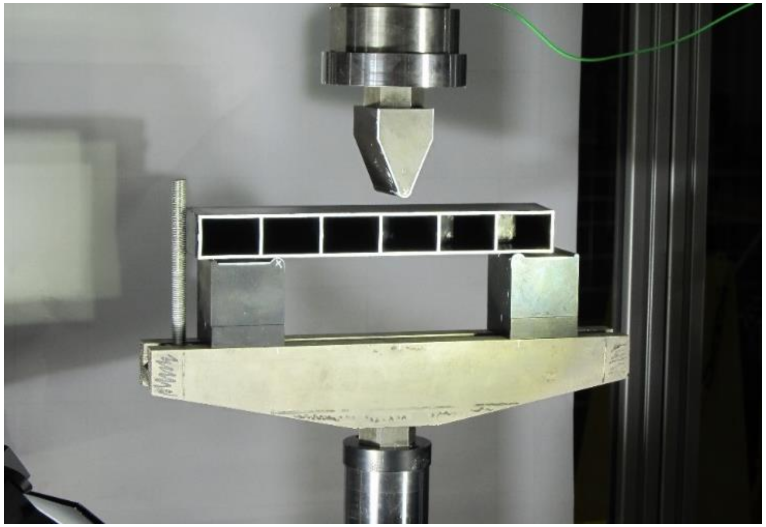
Modeling of GFRP

Methodology of the realized integrative simulation

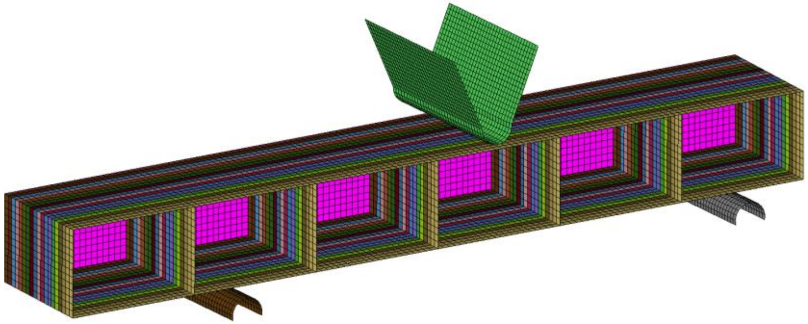


Validation of the method
Dynamic three-point bending test

Test set-up



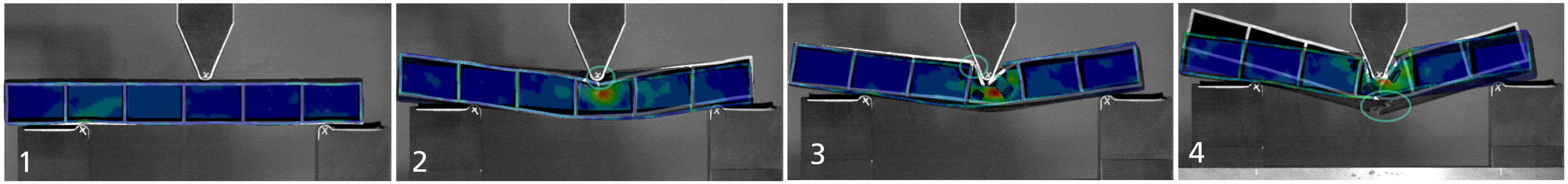
Simulation model

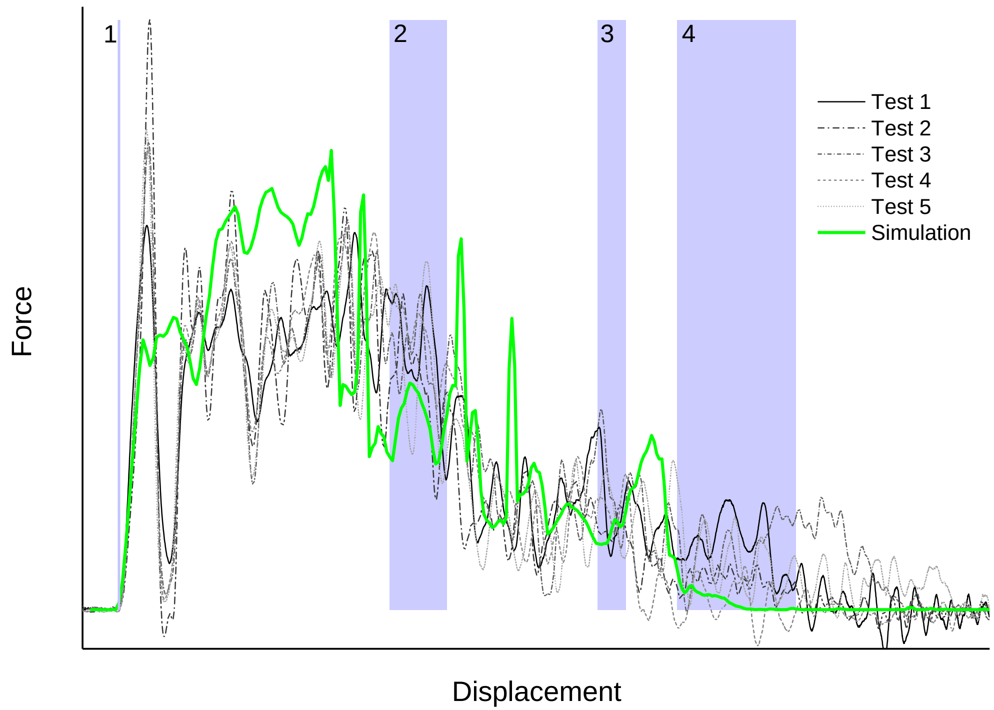


- Haul-off speed 7000 mm/s

Validation of the method

Force-displacement curve and deformation behavior





- Good agreement of experiment and simulation
- Simulation sensitive to additional numerical and friction parameters

Fraunhofer EMI

Impact of considering degree of anisotropy
Comparison with less complex modeling approaches

Considering only fiber orientation

- Without Advani and Tucker / Only one material card
- Elastic and plastic parameters derived directly from characterization tests
- Tensile tests in 0°-direction → Parameters in longitudinal direction
- Tensile tests in 90°-direction → Parameters in transversal direction

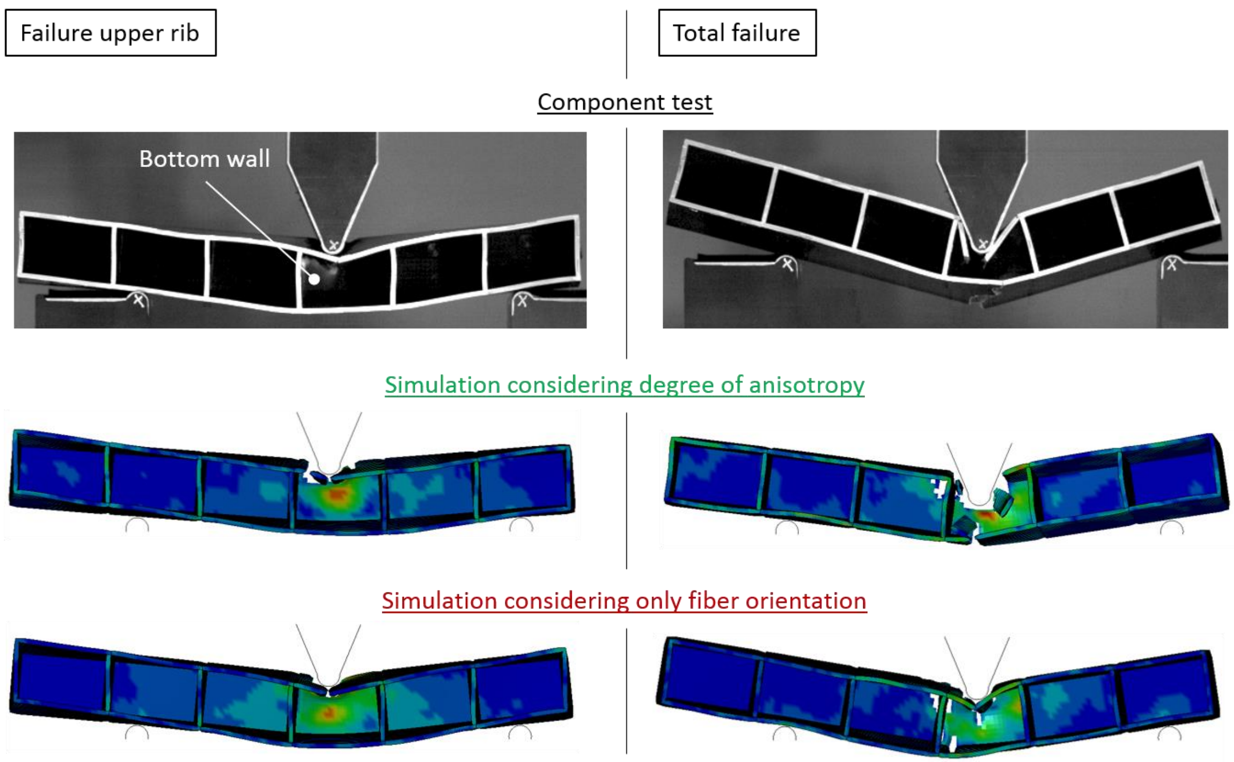
Isotropic material behavior

- Material parameters derived from average stress-strain curves in 0°- and 90°-direction

→ Simulation of dynamic three-point bending test using same values for additional numerical and friction parameters

Impact of considering degree of anisotropy

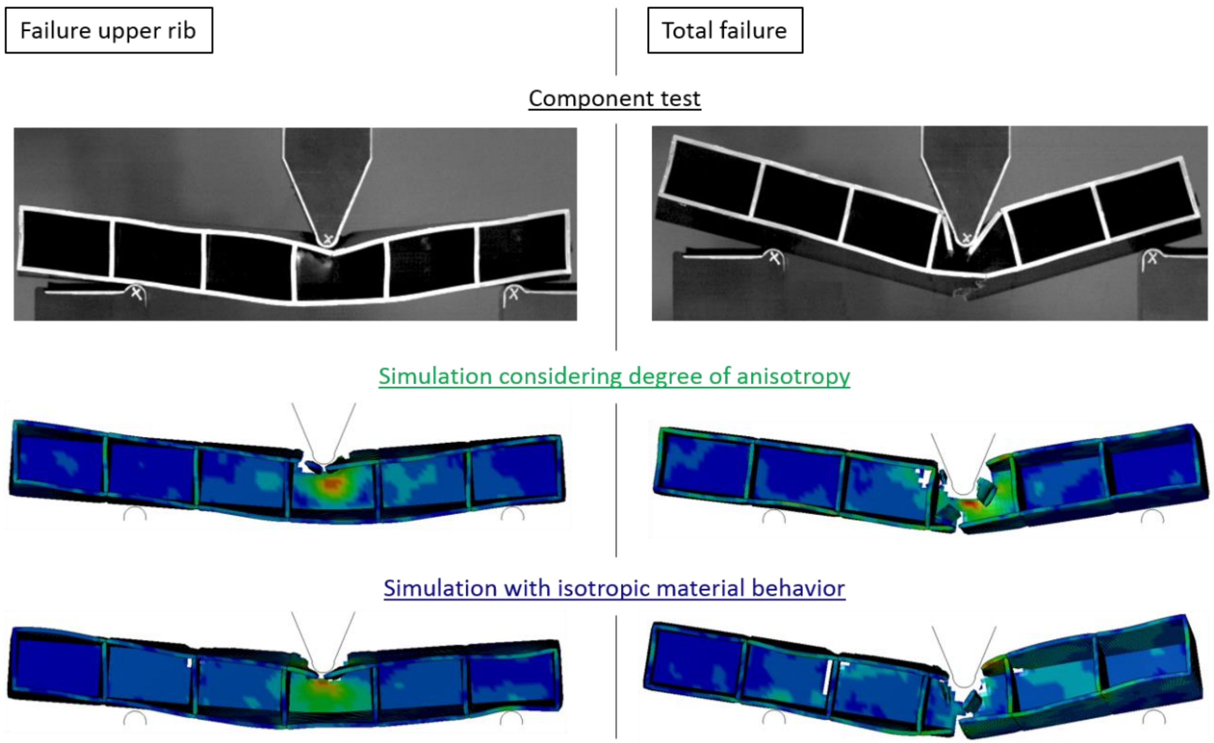
Simulation considering only fiber direction



- Upper part of bottom wall remains intact longer
- Upper rib is not bent

Impact of considering degree of anisotropy

Simulation using isotropic material behavior



- Upper part of bottom wall fails in a larger region
- Edge between upper and bottom wall is not impressed

Summary and conclusion

- Approach for considering fiber orientation distribution in material model
- Development of a mapping tool
- Validation by means of dynamic three-point bending test
- Impact of degree of anisotropy on simulation results