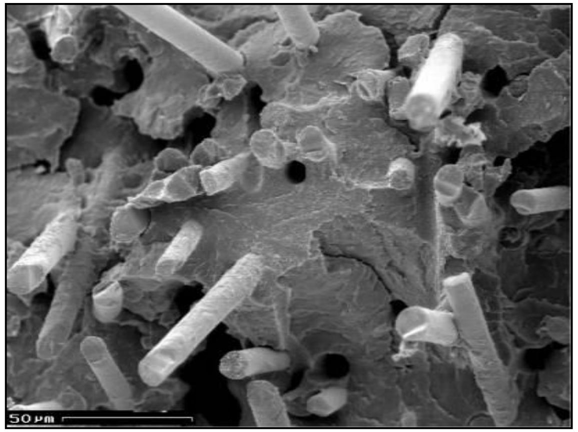

failure criteria SFRT and LFRT

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Prof. St. Kolling (IMM, TH Mittelhessen), Prof. J. Schneider (ISM+D, TU Darmstadt)
contact: peter.reithofer@4a.at

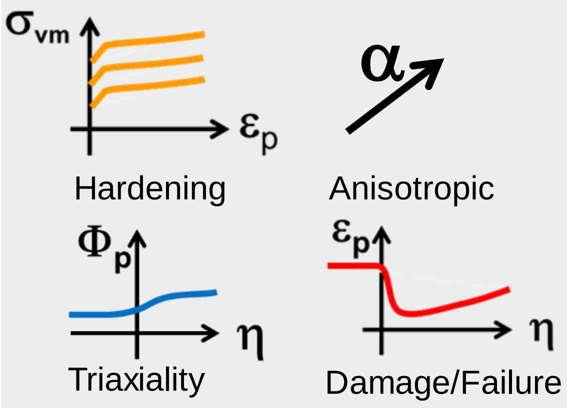
THM TECHNISCHE HOCHSCHULE MITTELHESSEN
IMM Institute of Mechanics and Materials
ISM+D Institute of Structural Mechanics and Design
Institut für Statik und Konstruktion

AGENDA

- What's new at 4a
- Introduction / overview
- mechanical design criteria
- deformation behavior – material models
- micro mechanical motivated model
- material characterization
- Case study sleeve
- Summary & Outlook

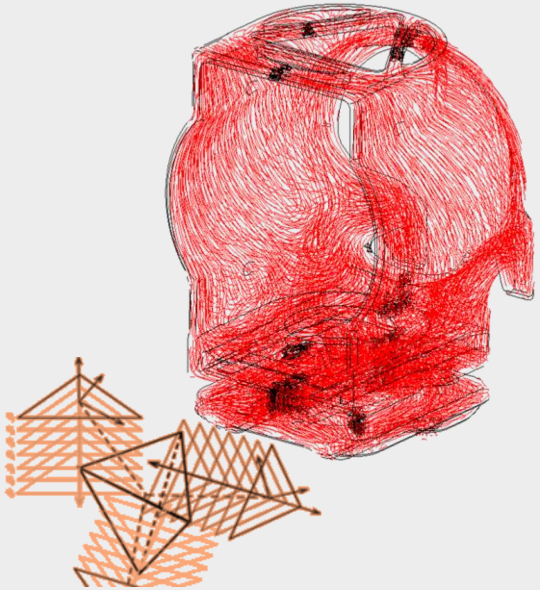
intelligent reliable solutions for plastics, composites, metals, foams, ...

VALIMAT



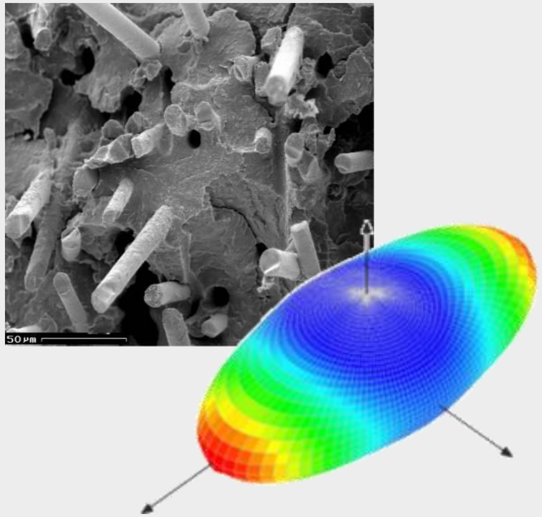
from test to validated material cards

FIBERMAP



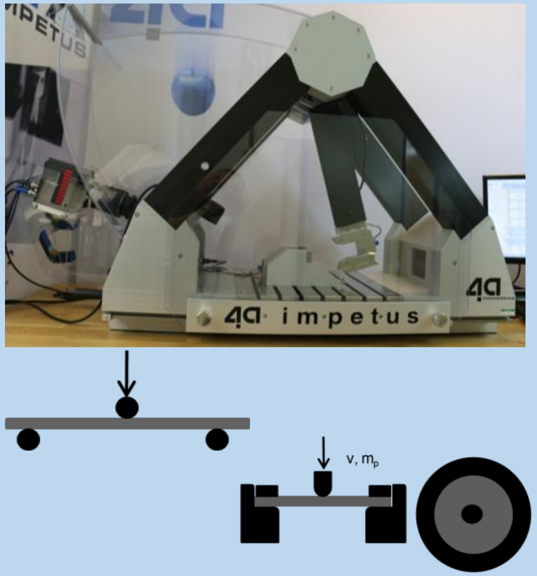
individual mapping process information

MICROMEC



3D anisotropic material cards

IMPETUS



efficient dynamic testing

Overview

Failure criteria / Damage

Material Model (Deformation)		Material Characterization	
Micro Mechanic	Idealization	SFRT/LFRT	
Easy to use	Mapping	Uniaxial	Biaxial

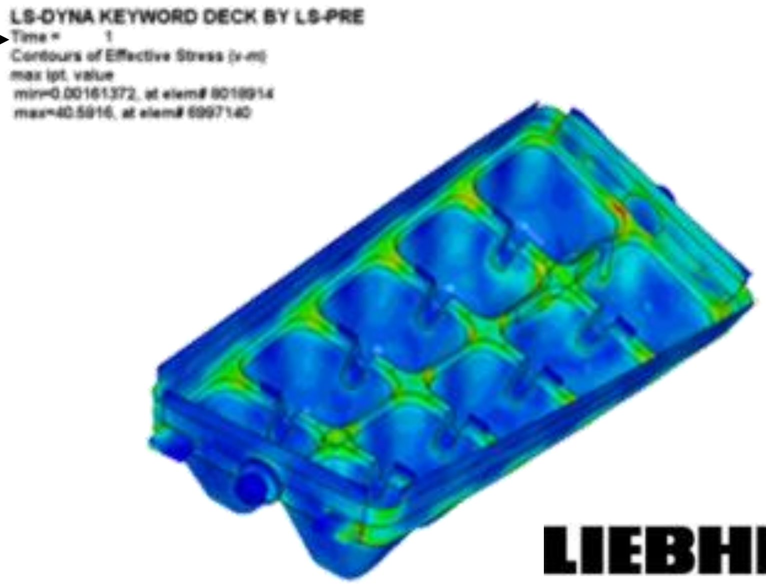
mechanical design criteria - classical equivalent failure criteria

failure criteria

Stress based			Strain based		
equivalent	principal	composite	equivalent	principal	damage

MISES: $\sigma_v = \sqrt{\frac{1}{2}\left[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2\right]}$ →

TRESCA: $\sigma_v = max(|\sigma_1 - \sigma_2|; |\sigma_2 - \sigma_3|; |\sigma_3 - \sigma_1|)$

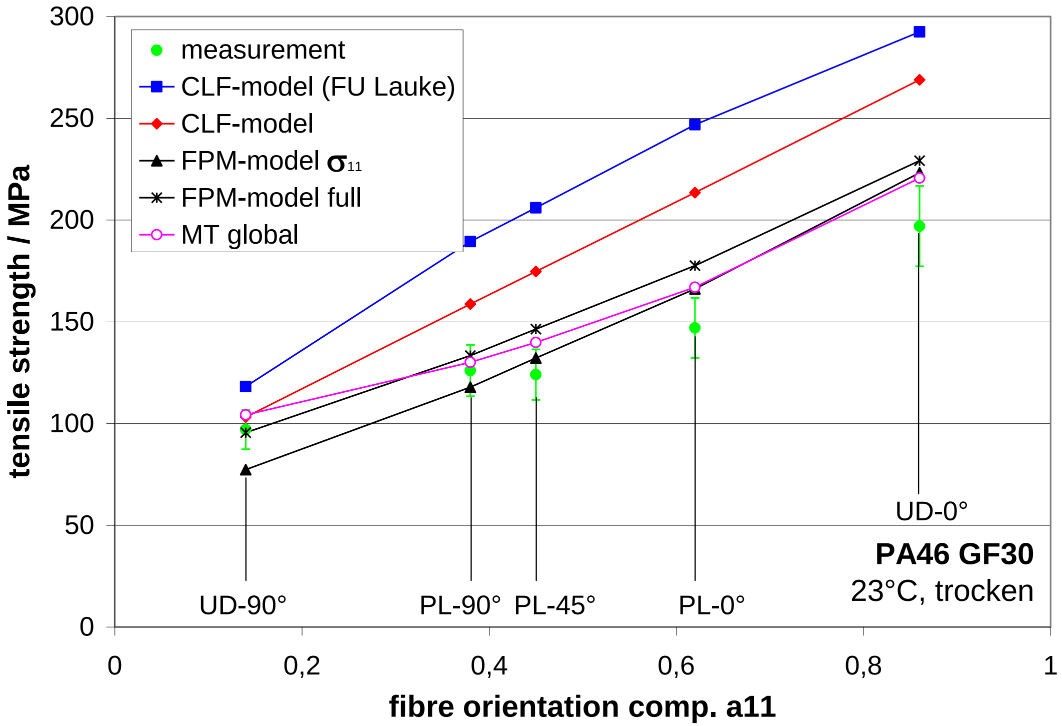


LIEBHERR

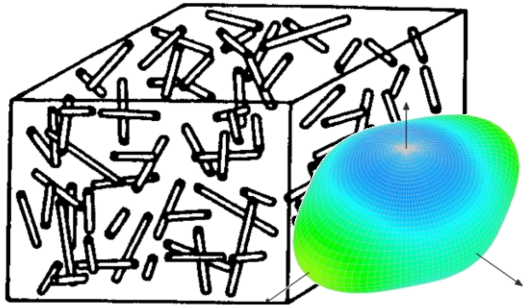
mechanical design criteria - composites – equivalent anisotropic criteria

failure criteria

Stress based | Strain based



CLF - Critical Fiber Length
FPM – Fracture Plane Method
MT – Mori Tanaka



SFRT / LFRT

source: Mlekusch B.A., *A Physically Based Failure Hypothesis for Short-Fibre Reinforced Thermoplastics for Finite-Element-Analysis*, PPS 18, Portugal (2002)

mechanical design criteria - composites – equivalent anisotropic criteria

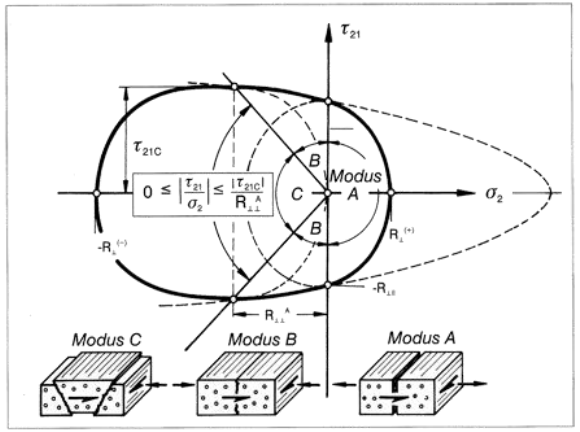
failure criteria

Stress based			Strain based		
equivalent	principal	composite	equivalent	principal	damage

well known criteria

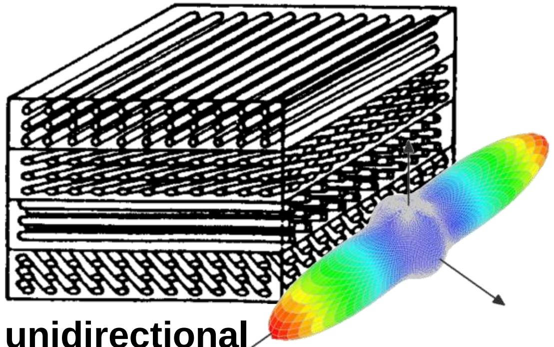
- Hill
- TSAI-Hill
- TSAI-Wu
- Hoffmann
- Chang-Chang
- **Puck**
- Cuntze
- …

Inter fiber failure



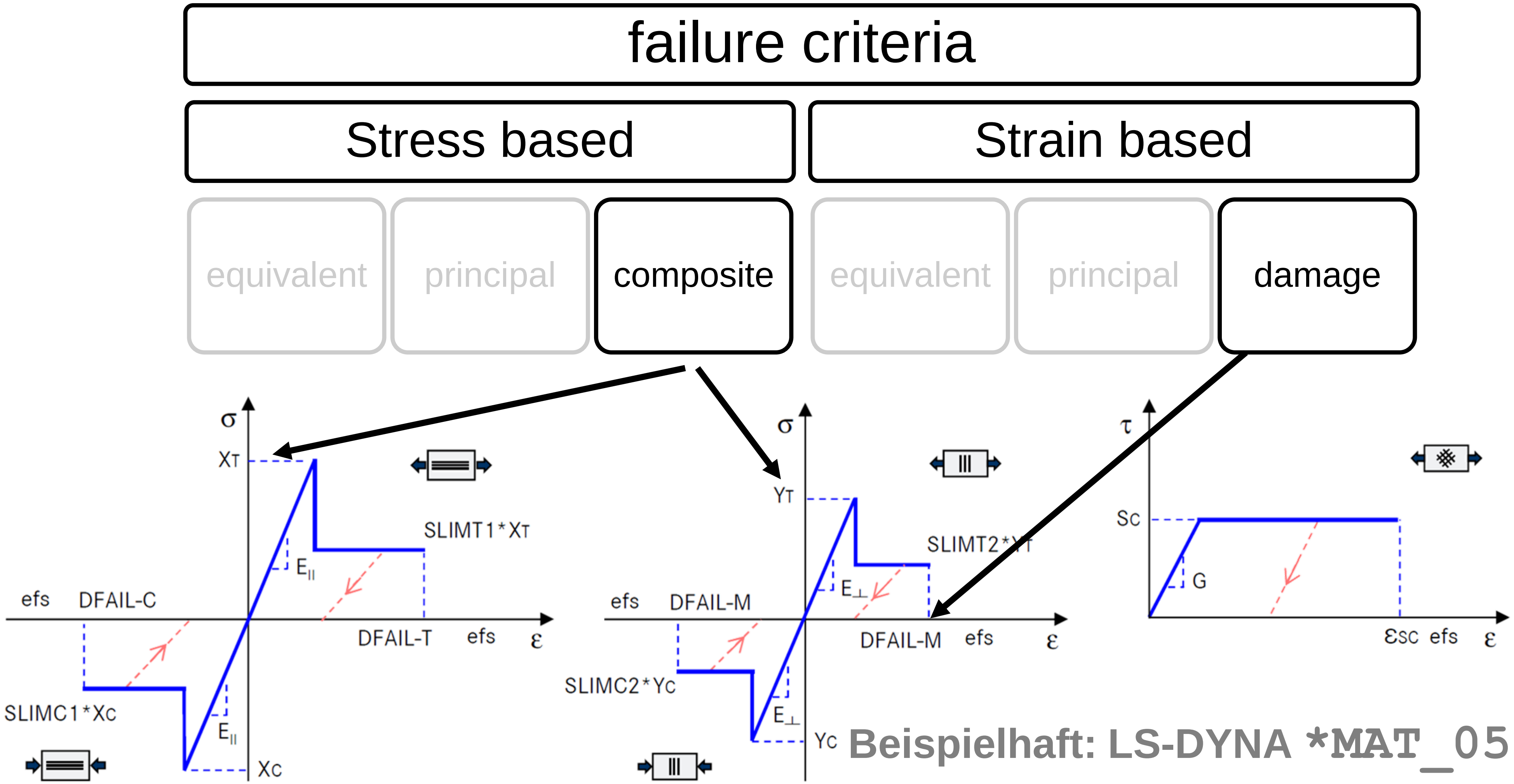
Quelle: Alfred Puck; Festigkeitsanalyse von Faser-Matrix-Laminaten: Modelle für die Praxis. Carl Hanser Verlag München Wien, 1996

Fiber failure



unidirectional fiber laminate

mechanical design criteria - composites – equivalent anisotropic criteria



Beispielhaft: LS-DYNA *MAT_054

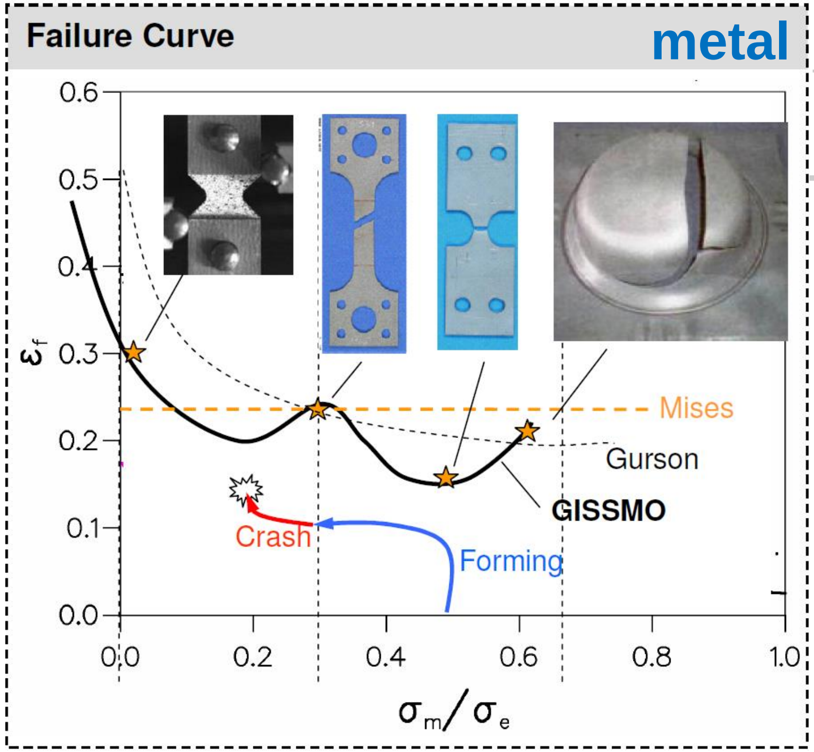
source: F. Köster, Daimler AG - *Characterization and model validation of laminate failure and partial damage in industrial applications*, NAFEMS Leipzig 2014

mechanical design criteria - composites – equivalent anisotropic criteria

failure criteria

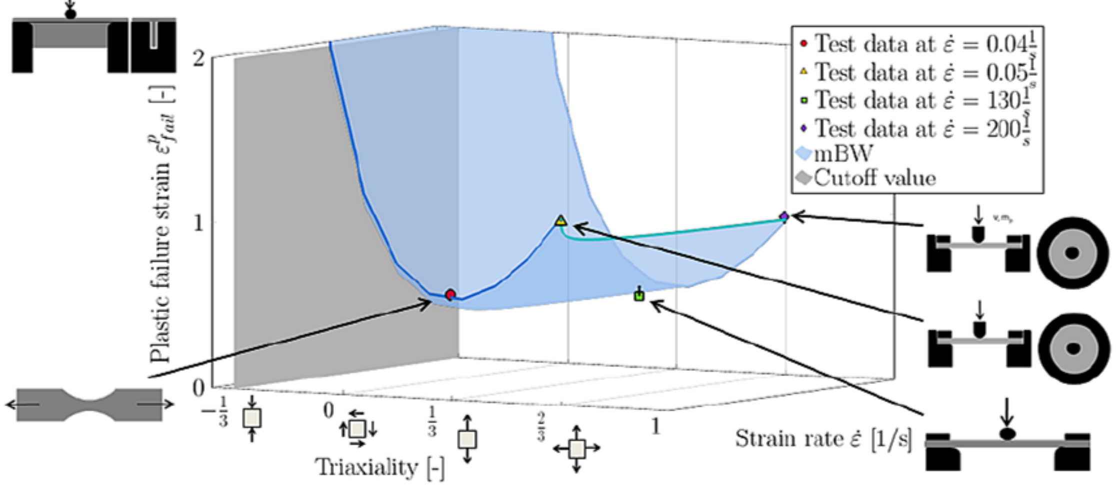
Stress based | Strain based

equivalent | principal | damage



source: F. Neukamm – *GISSMO – Material modeling with a sophisticated failure criteria*, LS-Dyna Developer Forum 2011, Stuttgart

plastic

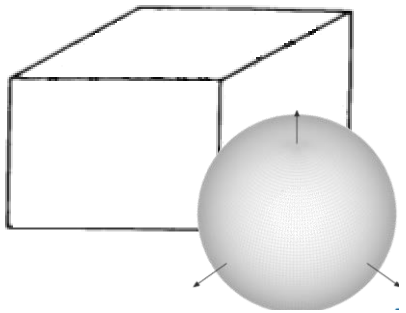


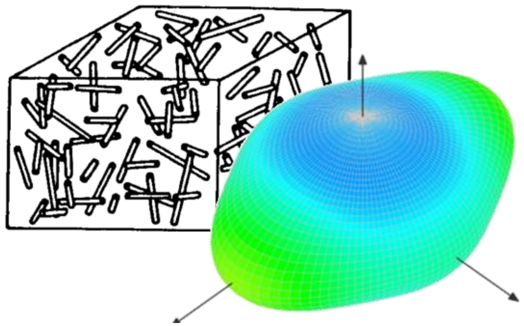
source: H. Staack, - *Application oriented failure modeling and characterization for polymers in automotive pedestrian protection*, COMPLAS 2015, Barcelona

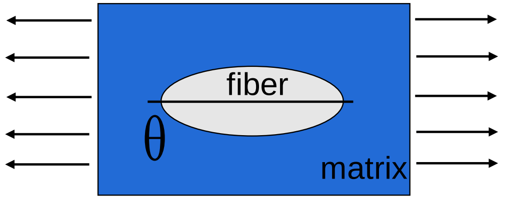
Overview

Failure criteria / Damage			
Material Model (Deformation)		Material Characterization	
Micro Mechanic	Idealization	SFRT/LFRT	
Easy to use	Mapping	Uniaxial	Biaxial

Material models – actual approaches





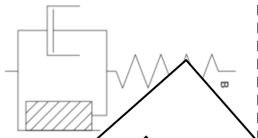


Eshelby Tensor

macro scale **constitutive law → composite**	**micro scale** **homogenization**

Mises plasticity

- quick & dirty
- critical loading transversal to fiber o n



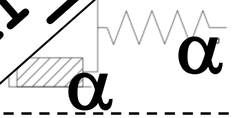
*MAT_024

elastic

- orthotropic
- anisotropic

elastic viscoplas

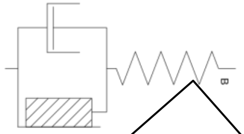
- Hill plastici



*MAT_157

M… matrix

- isotropic elastic viscoplastic



F… fiber

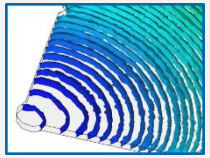
- isotropic elast

*MAT_215

α – orientation dependent

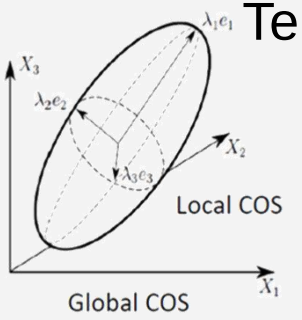
Material models – actual approaches

Process simulation



$$a_{ij} = \begin{bmatrix} a_{xx} & a_{xy} & a_{xz} \\ & a_{yy} & a_{yz} \\ & & a_{zz} \end{bmatrix}$$

Tensor 2nd order



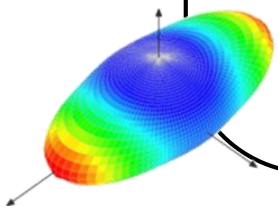
CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

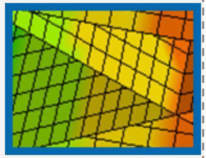
FIBERMAP

$$C^{-1} = \begin{bmatrix} \frac{1}{E_1} & -\frac{\nu_{21}}{E_2} & -\frac{\nu_{31}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{12}}{E_1} & \frac{1}{E_2} & -\frac{\nu_{32}}{E_3} & 0 & 0 & 0 \\ -\frac{\nu_{13}}{E_1} & -\frac{\nu_{23}}{E_2} & \frac{1}{E_3} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{21}} \end{bmatrix}$$



MICROMEC

Structural simulation

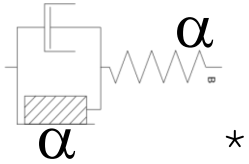


Homogenization (Micro Scale)
Mean Field Theory

$$\bar{\sigma}^C = \varphi \bar{\sigma}^F + (1-\varphi)\bar{\sigma}^M$$

*MAT_215

Composite (Macro Scale)
Hill Plasticity



*MAT_157

LSTC Livermore Software Technology Corp.
LS-DYNA®

Material models – current implementation – micro mechanical motivated

MICROMEC

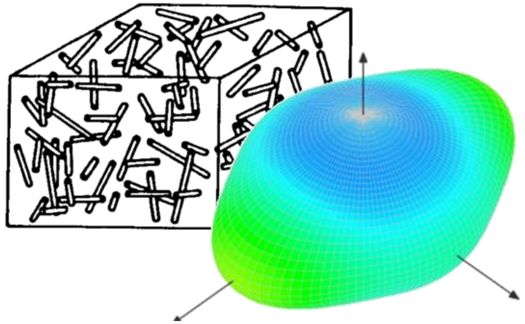
Standalone product

Library→4a impetus

usermaterial

*MAT_4A_MICROMEC

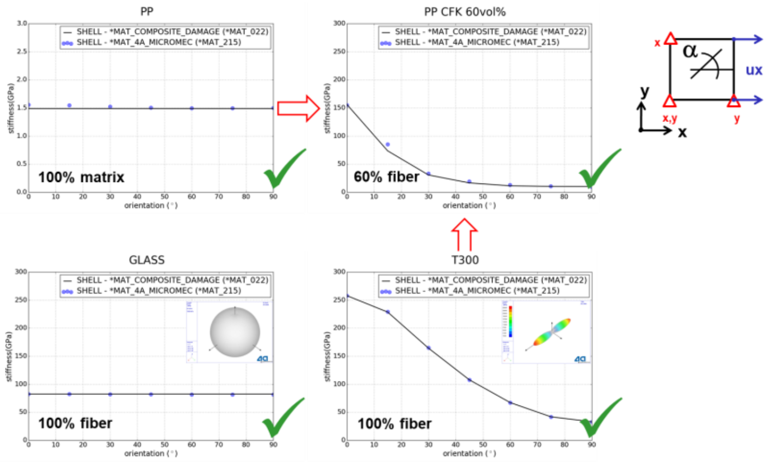
→ **LS-DYNA R10**



$$\overline{\sigma}^{C} = \varphi \overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

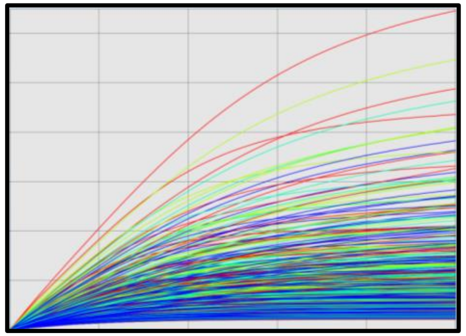
C...composite, F...fiber, M...matrix

Verifications

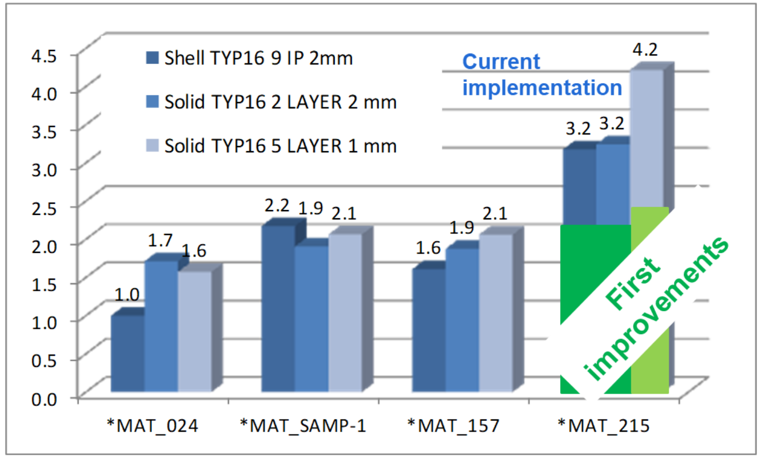


Robustness

DOE - RUNS
without an error



Performance



Material models – current implementation – micro mechanical motivated

failure criteria

Stress based | Strain based

equivalent | principal | cipal | damage

MEAN FIELD APPROACH

$$\overline{\sigma}^{C} = \varphi \overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

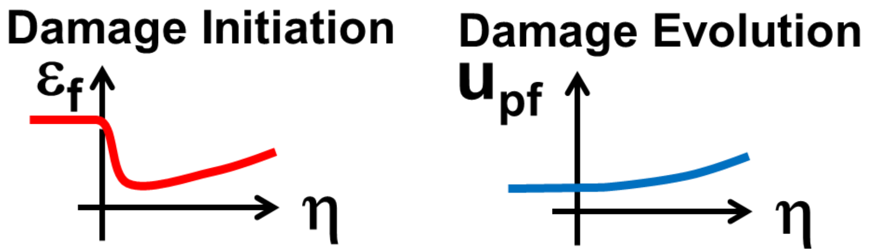
C...composite, F...fiber, M...matrix

assumption elliptical inclusion
(Eshelby Tensor)

*MAT_215

FAILF: Fiber failure

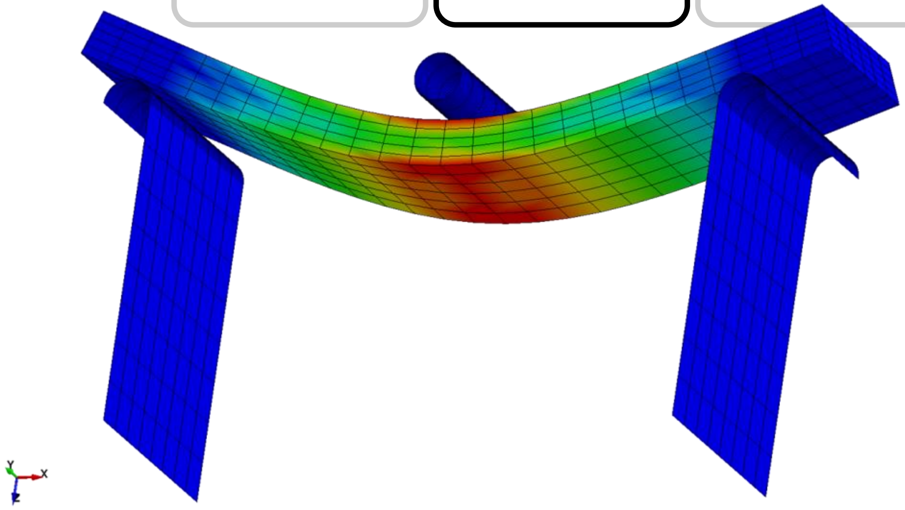
FAILM: Matrix failure – ductile DIEM-Model



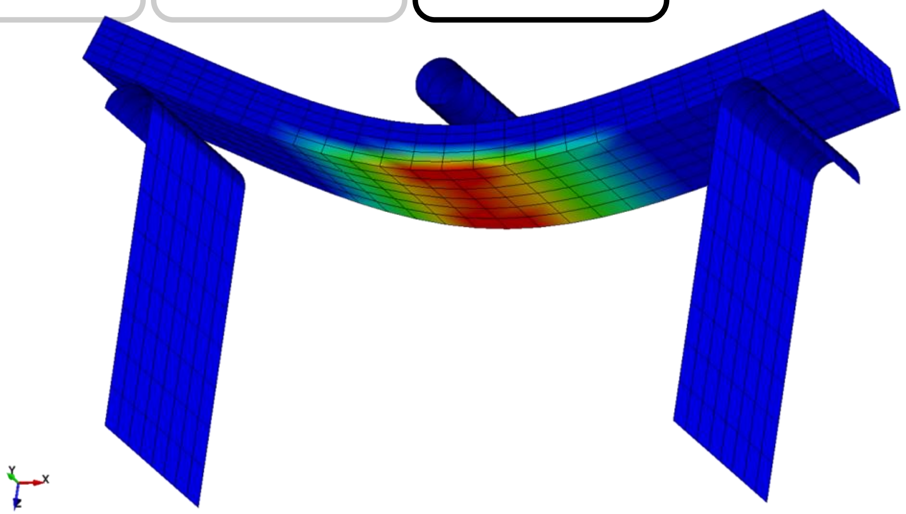
Material models – current implementation – micro mechanical motivated

failure criteria

Stress based			Strain based		
equivalent	principal	composite	equivalent	principal	damage



History#6 (step8: 0-0.13):
Fiber damage init.

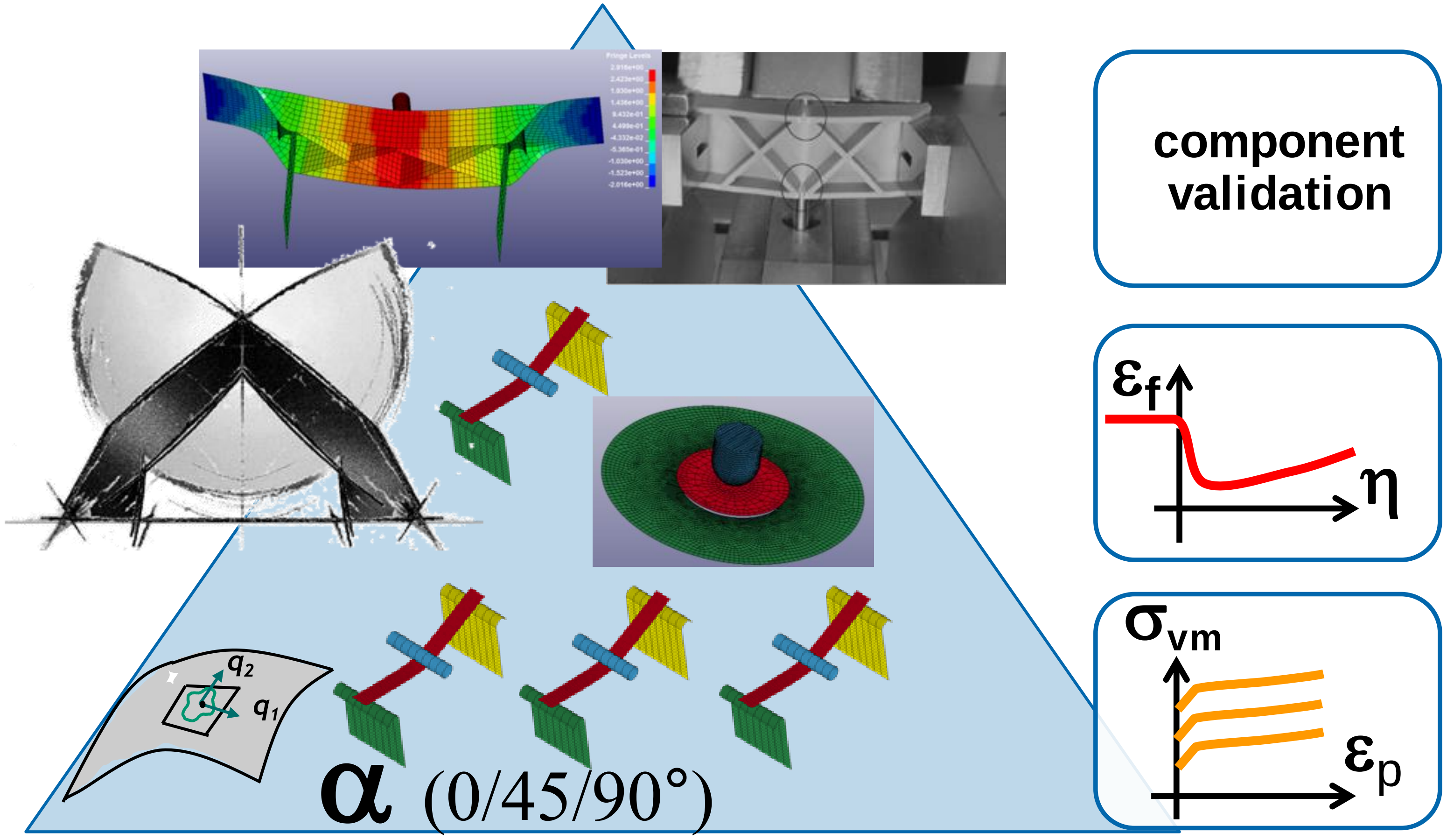


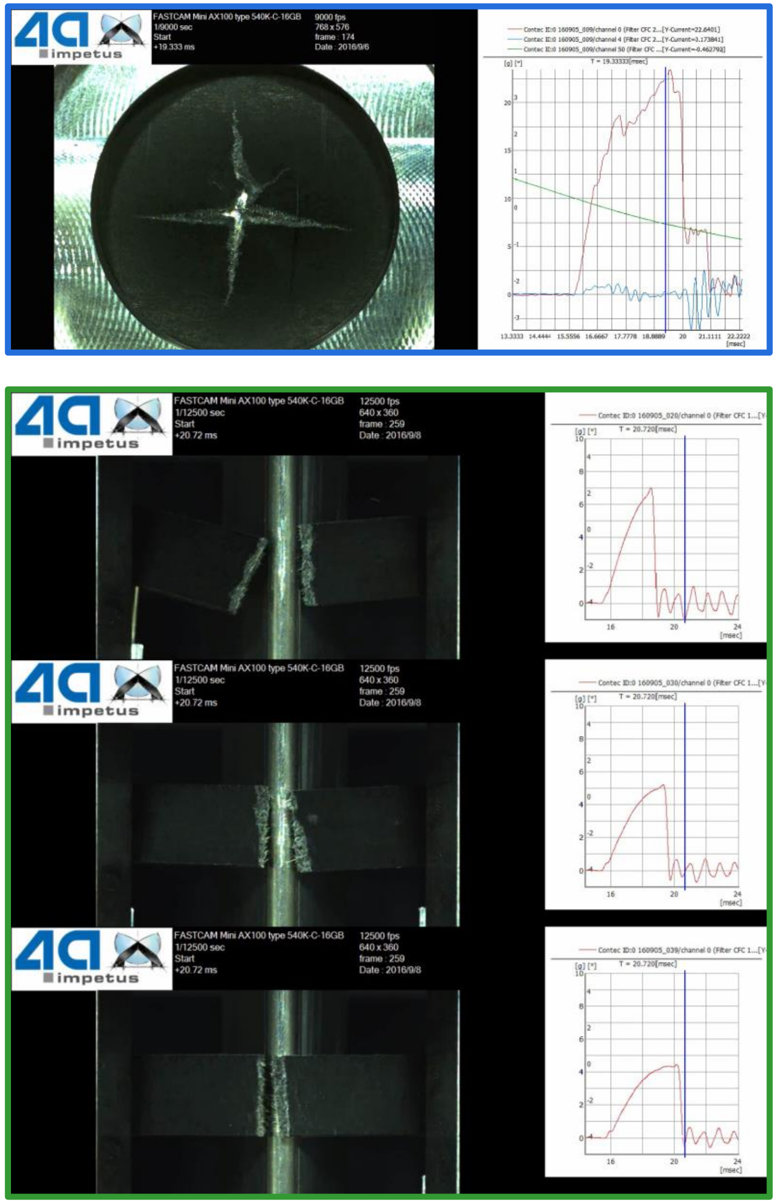
History#4 (step8: 0-0.81):
dm - matrix damage init.

Overview

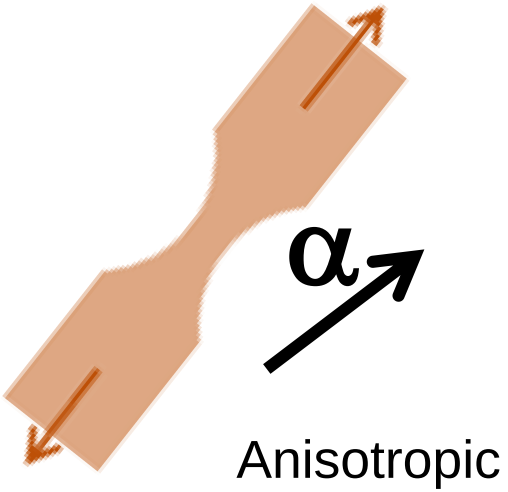
Failure criteria / Damage			
Material Model (Deformation)		Material Characterization	
Micro Mechanic	Idealization	SFRT/LFRT	
Easy to use	Mapping	Uniaxial	Biaxial

material characterization pyramid



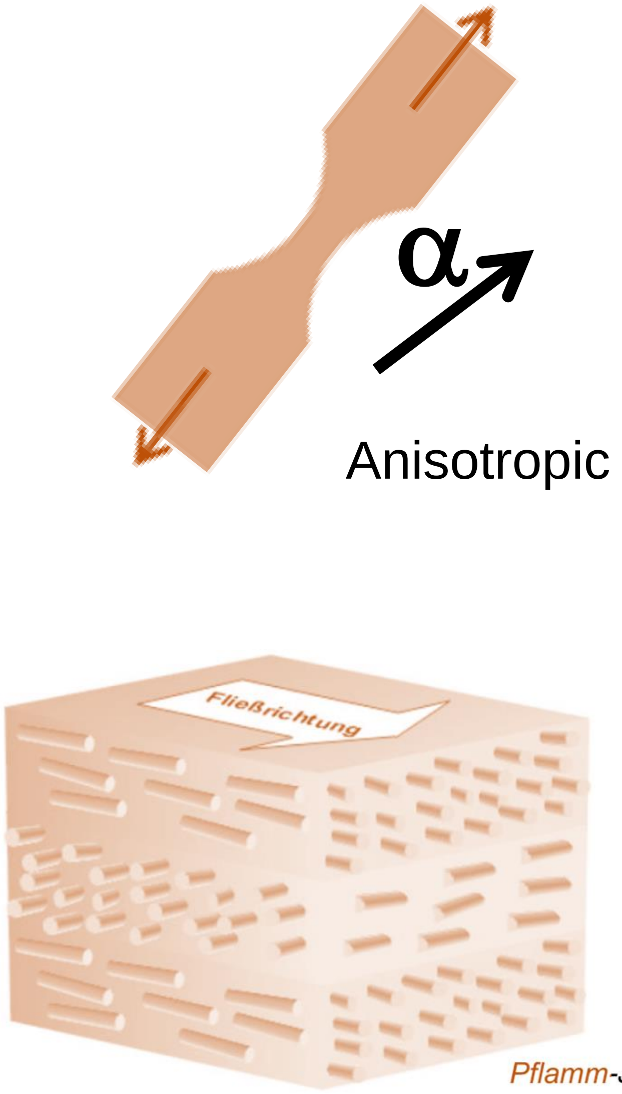


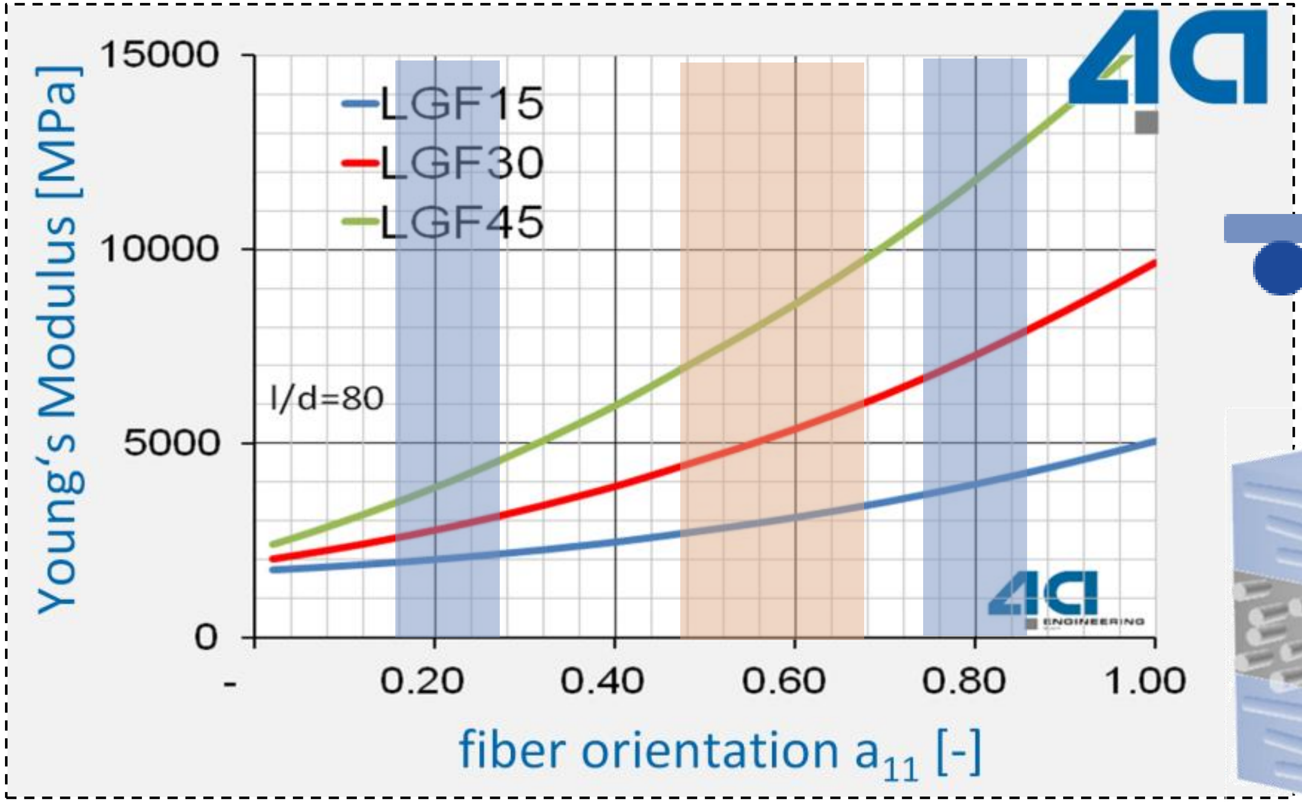
See more: P Reithofer, et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

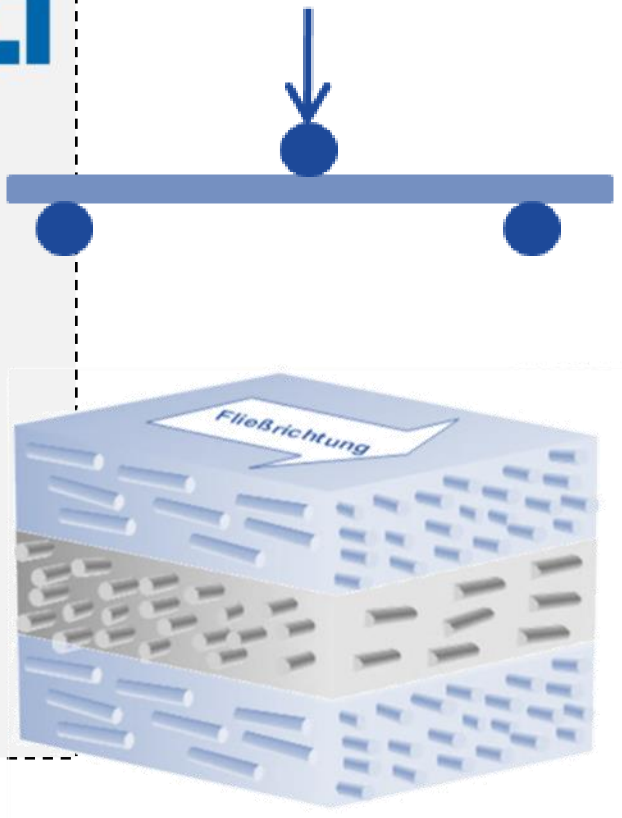


Why not tension (only)?

Why not tension (only)?

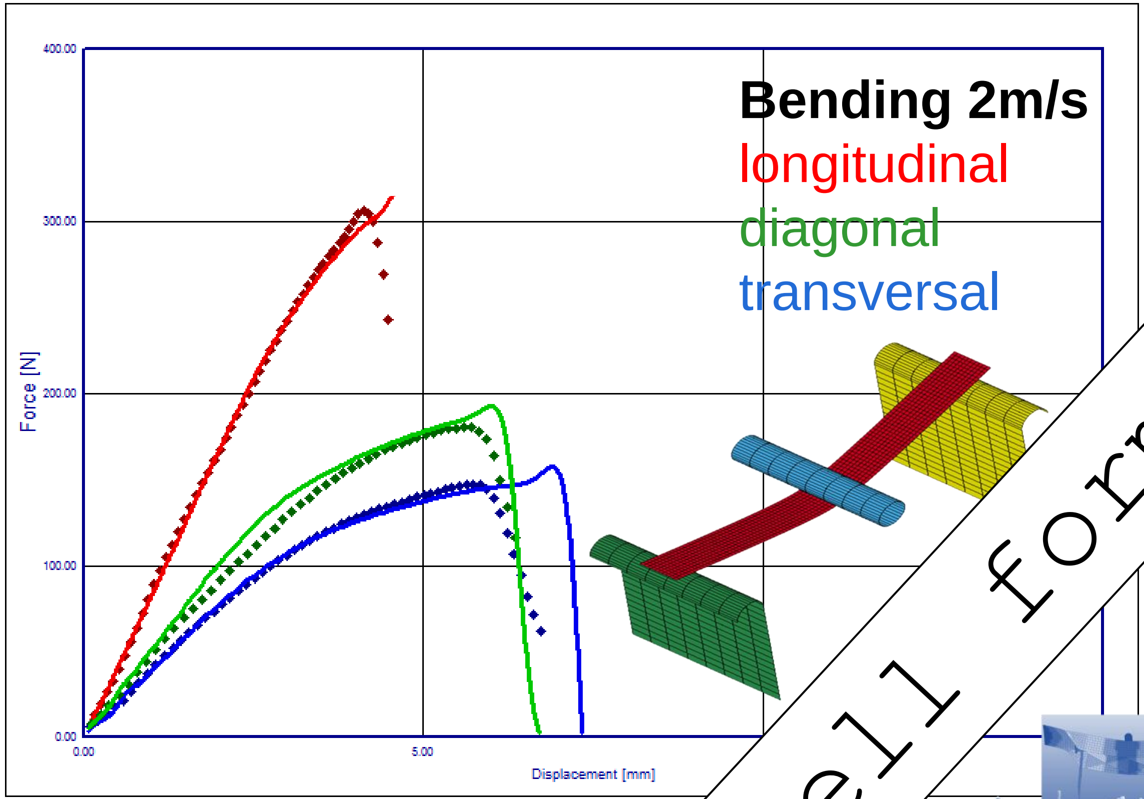




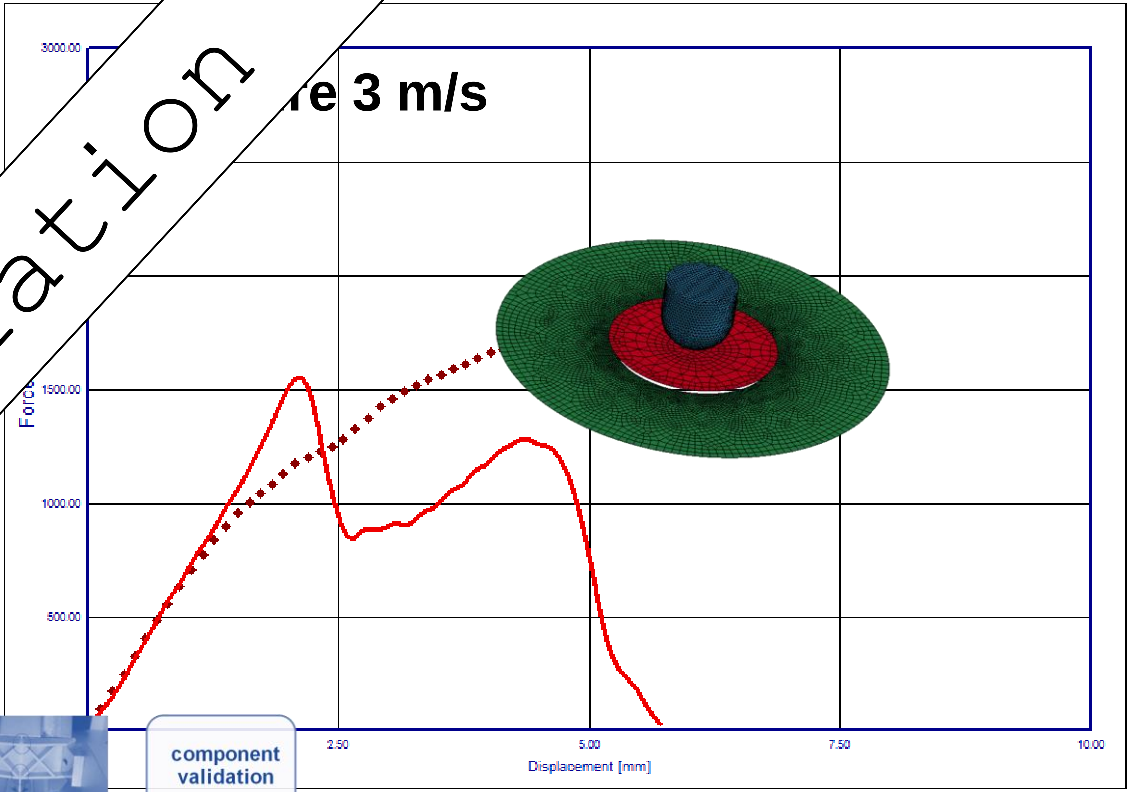


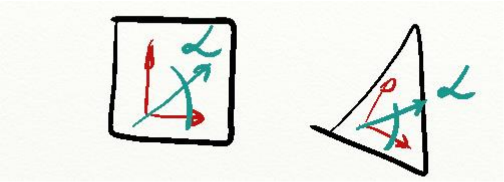
Pflamm-Jonas 2001

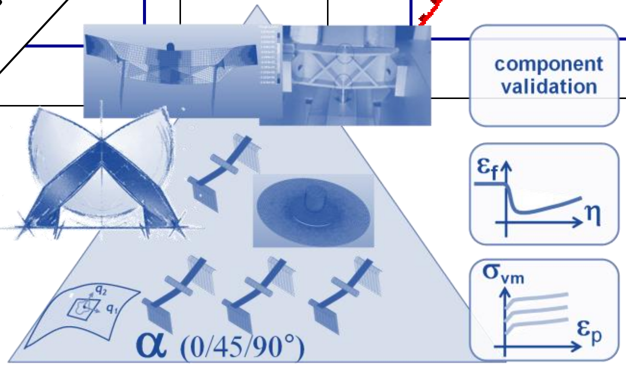
Validation - *MAT_/215



Shell formulation ?



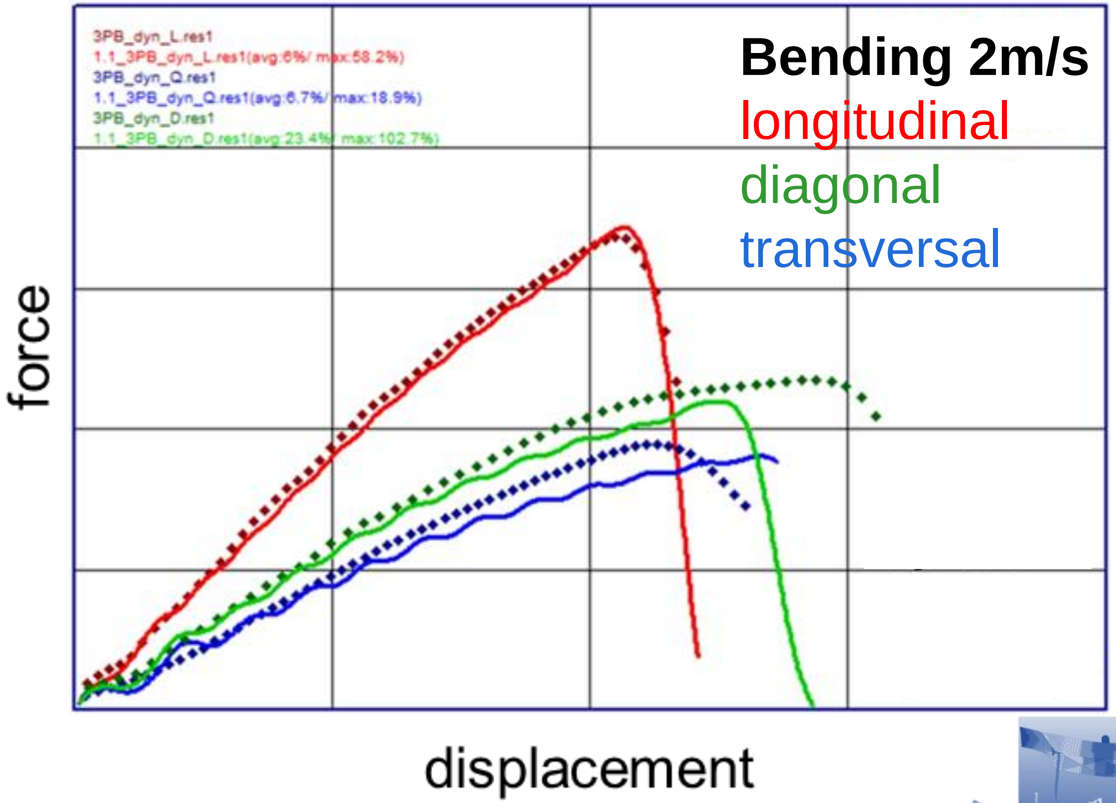


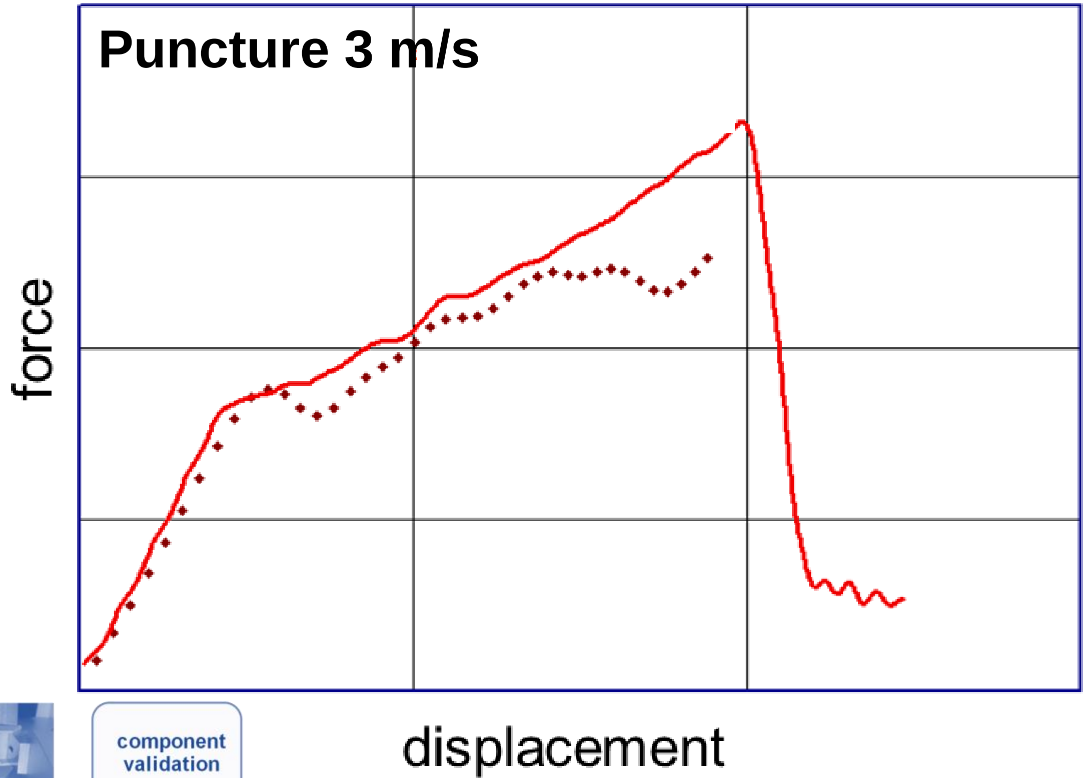


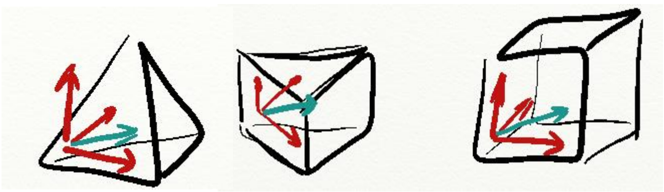
···· averaged test curves
— result of simulation

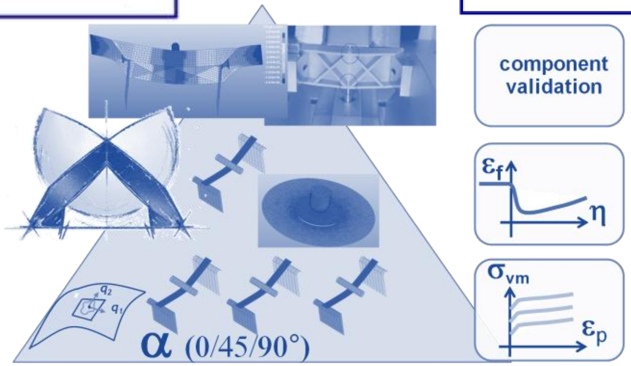
See more: P Reithofer , et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

Validation - *MAT_215*





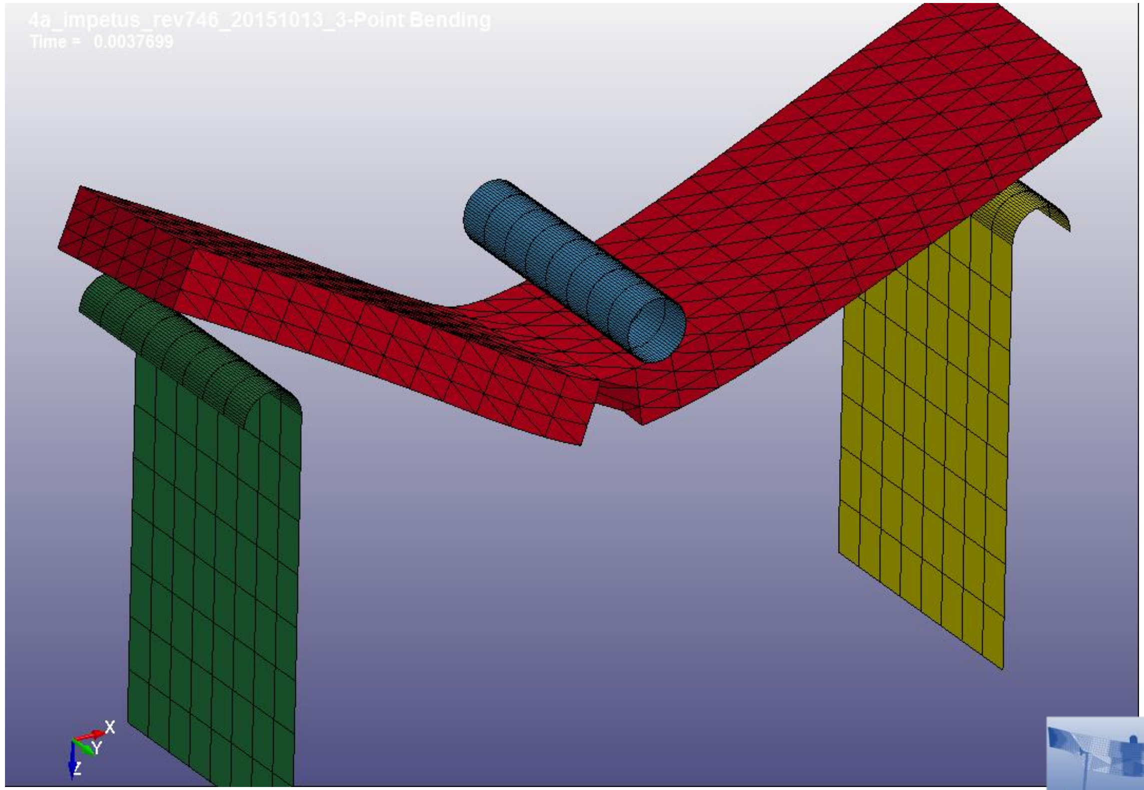


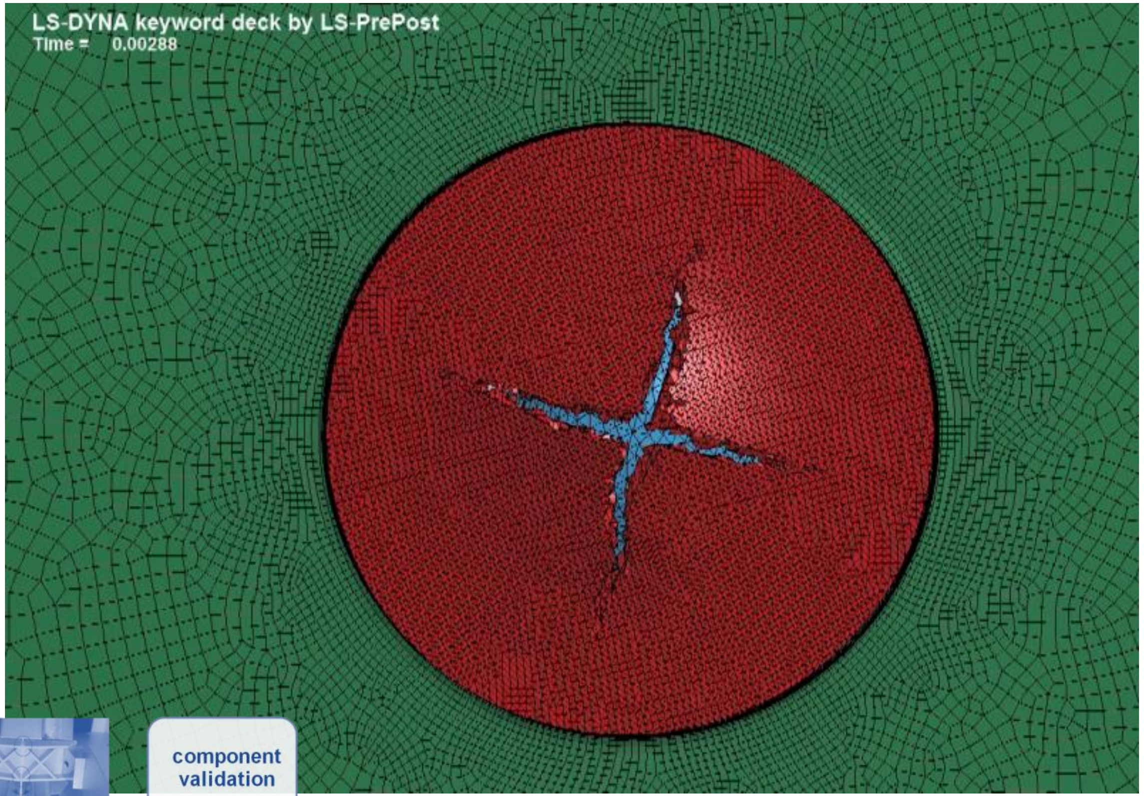


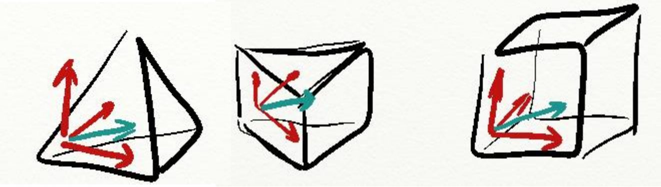
···· averaged test curves
— result of simulation

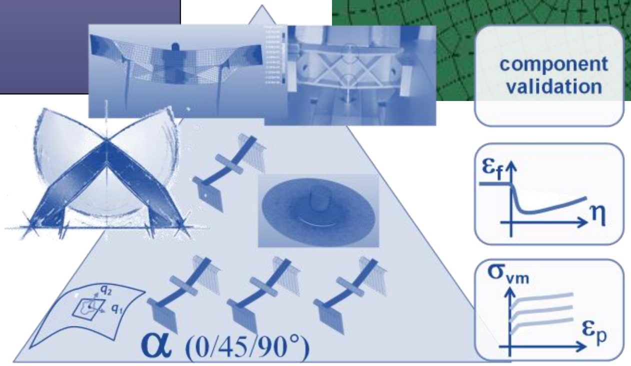
See more: P Reithofer , et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

Validation - *MAT_215



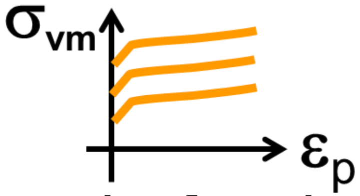


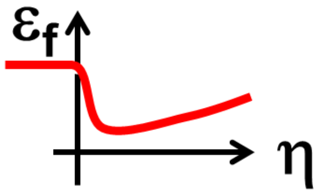


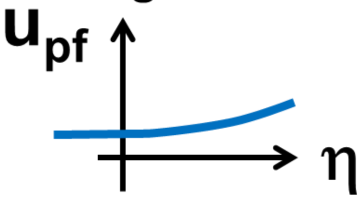


See more: P Reithofer , et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

First results on current *MAT_215 implementation

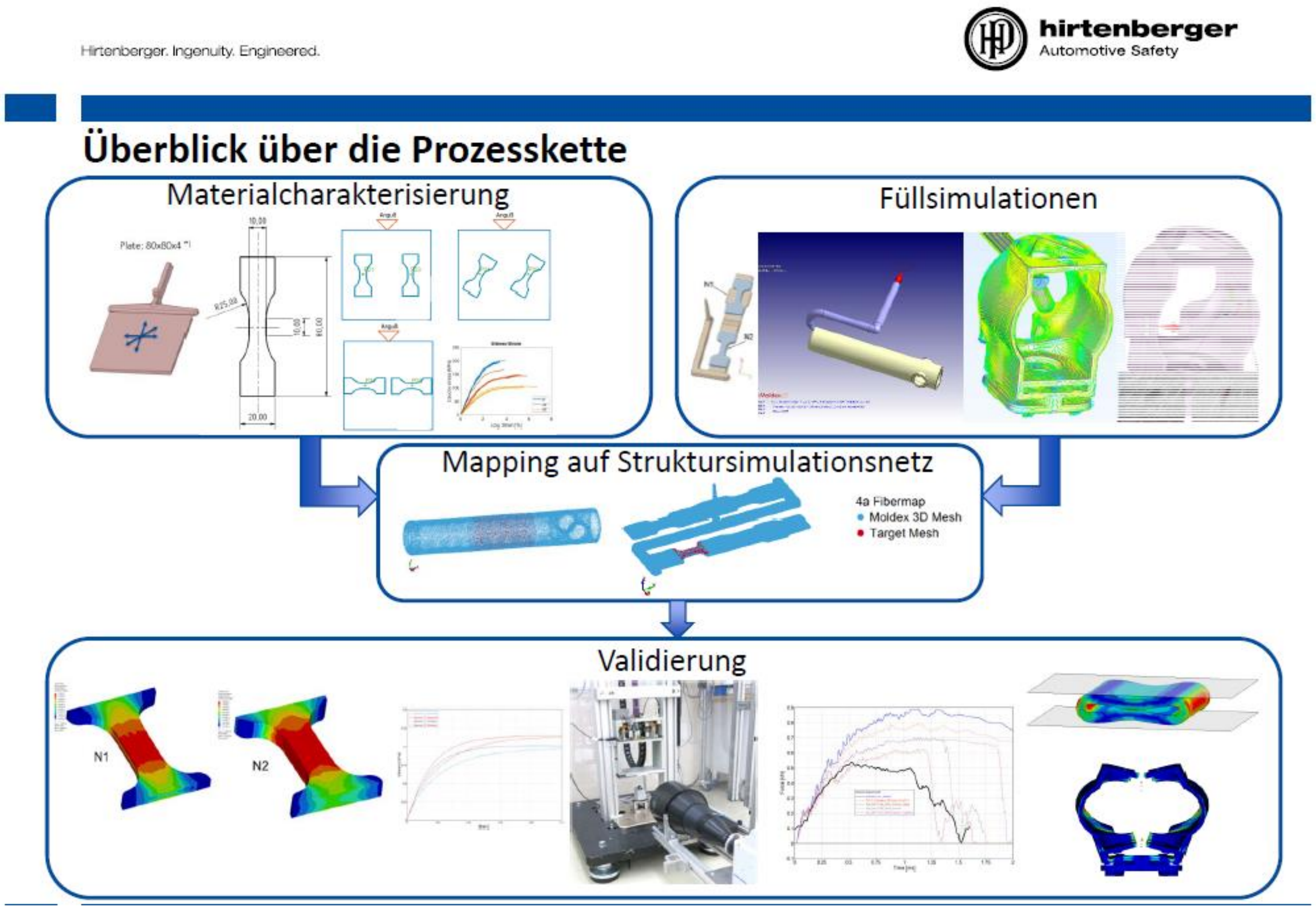


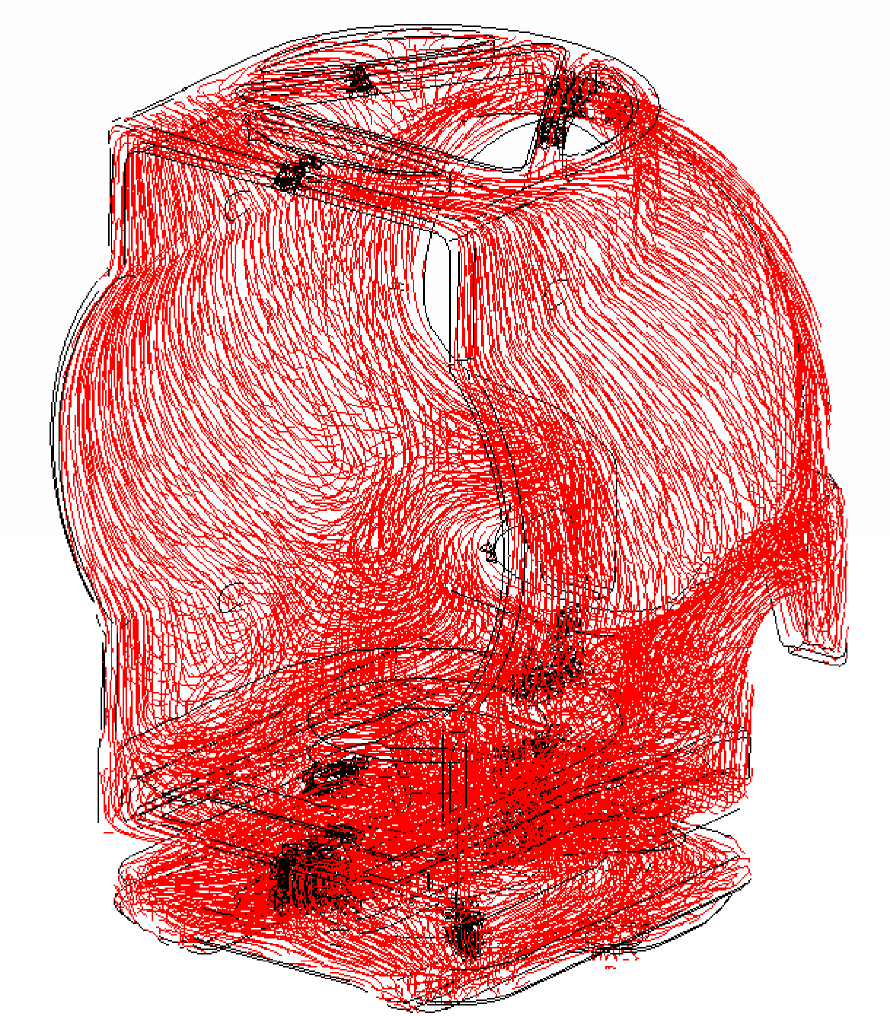




	Fiber	Hardening inelastic deformation	Damage Initiation initial Failure	Damage Evolution Failure Evolution
PP LGF30	LFRT l/d ~ 50	✓	✓	~
PBT GF30	SFRT l/d ~ 20	✓	✓	✓
PA6 GF30 impact modified	SFRT l/d ~ 30	✓	~	✗

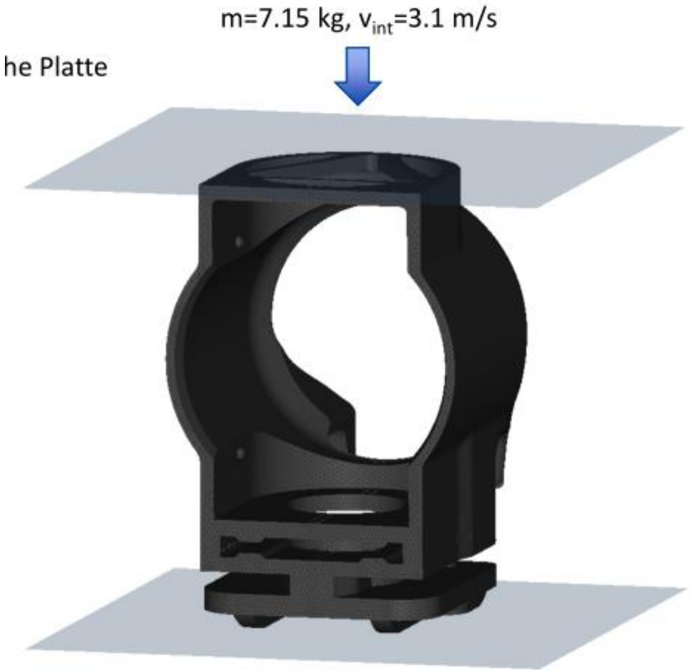
CASESTUDY - SLEEVE





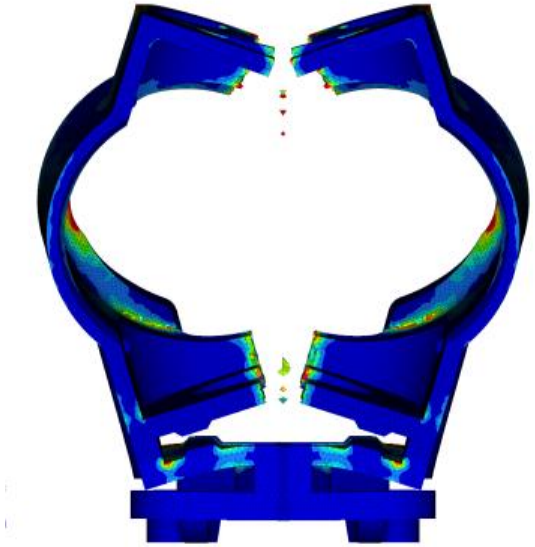
See more: R. Steinberger, et.al. Hirtenberger Automotive Group – *Considering the Local Anisotropy of Short Fiber Reinforced Plastics, European Dynaforum 2017*

CASESTUDY - SLEEVE

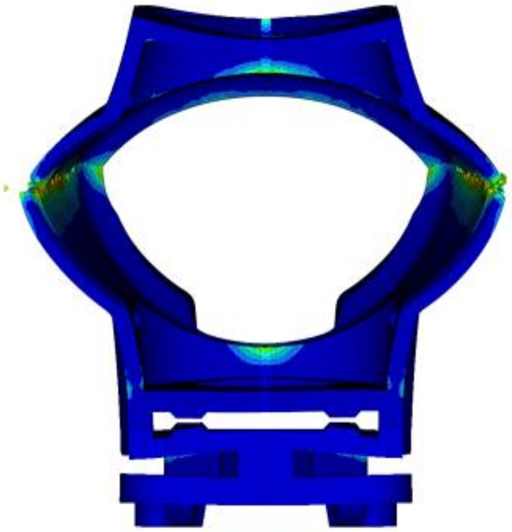


test

***MAT_157/215**
local anisotropy



***MAT_24**
isotropic



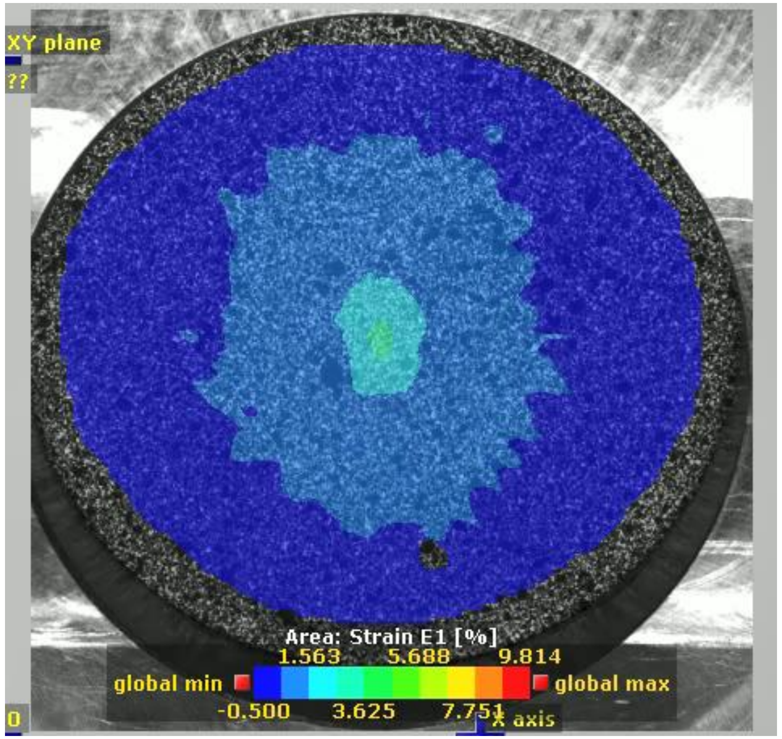
Typische Elementgröße: 0.25mm
Elementtyp: Tetrahedron Type 10
Elementanzahl: 469 470

hirtenberger
Automotive Safety

See more: R. Steinberger, et.al. Hirtenberger Automotive Group – *Considering the Local Anisotropy of Short Fiber Reinforced Plastics, European Dynaforum 2017*

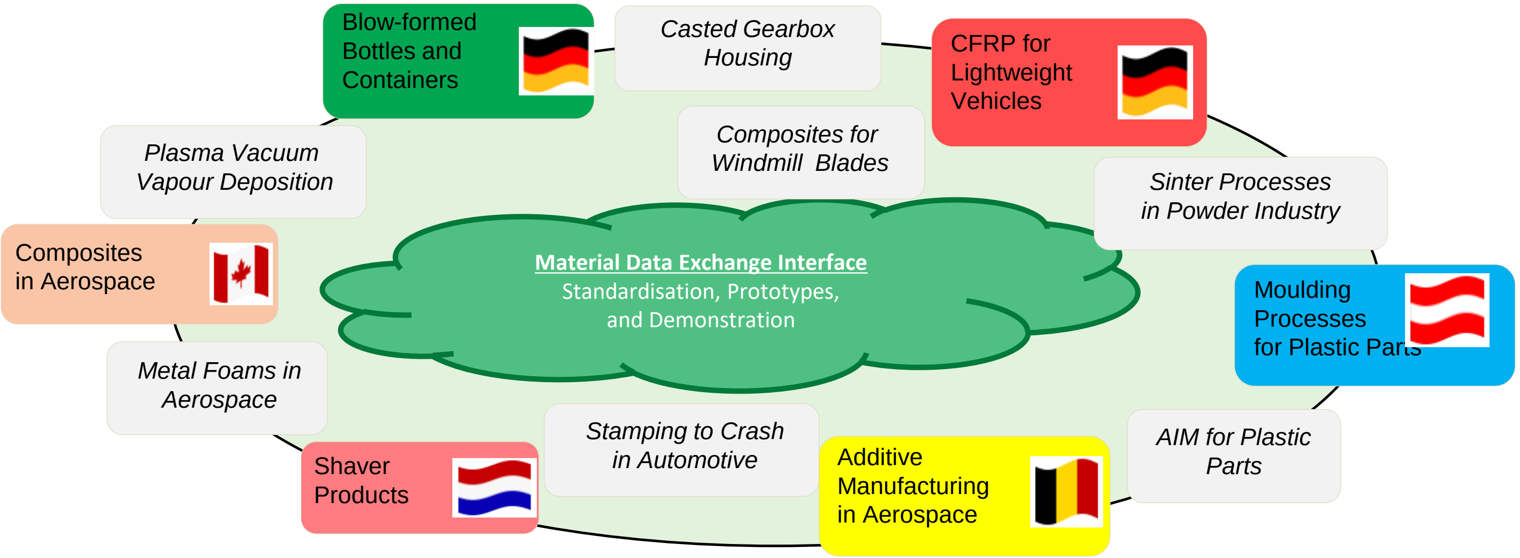
Summary & Outlook

- advantages micro mechanical approach
  - model understands → ***fiber orientation, aspect ratio***
  - simulation process chain considering local anisotropy
    process → structural
- Validation results (coupon and component level)
  - Good correlation in deformation behavior
  - promising results in capturing failure
    → improvement post failure especially shells
- Outlook
  - failure/damage → further research
  - DIC measurement – biaxial behavior
  - Usage for endless fiber reinforced materials



See more: Master Thesis, Christine Jantos - THM

A new Interface Standard for Integrated Virtual Material Modelling in Manufacturing Industry



VMAP