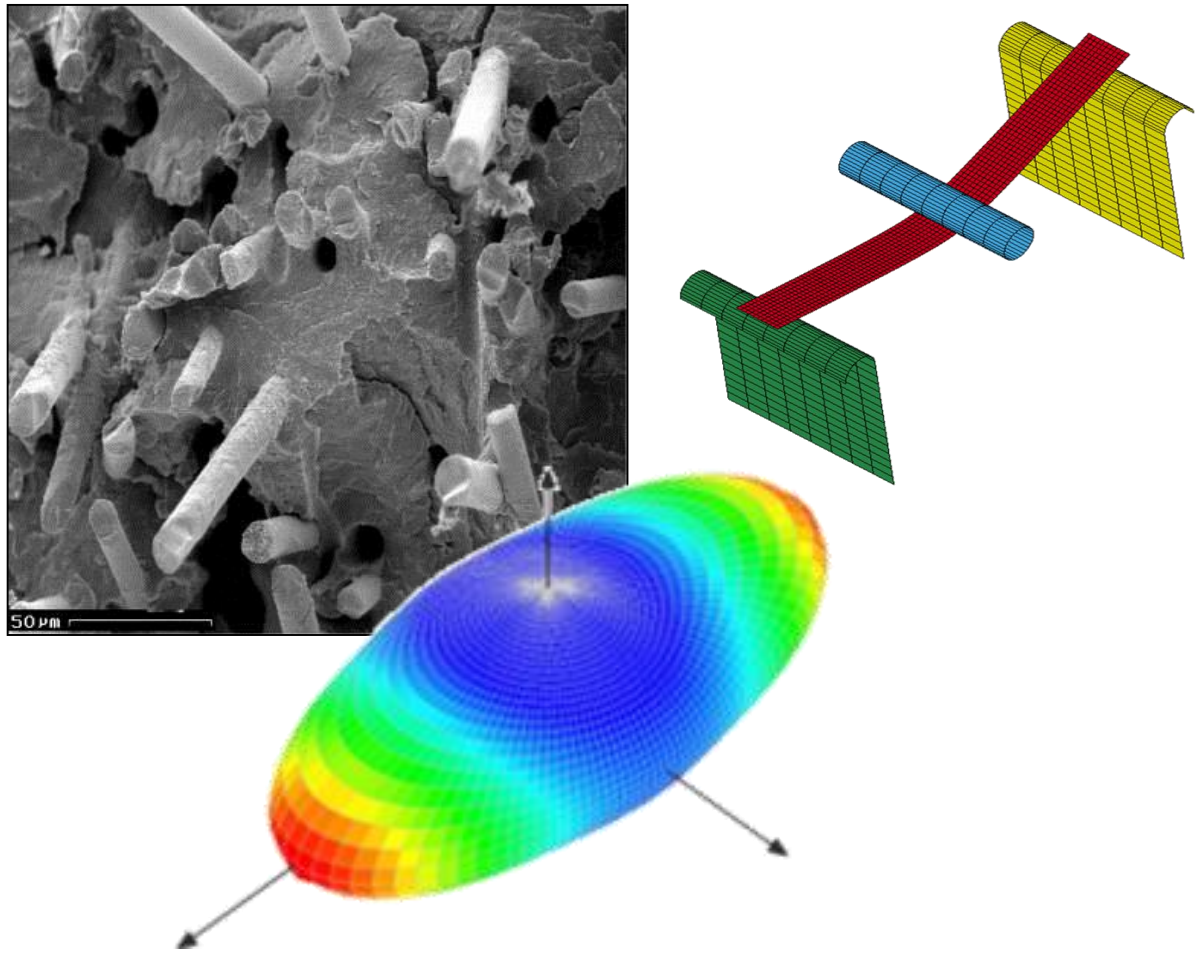
Fiber Reinforced Thermoplastics Under Dynamic Loading
From Deformation To Failure

P. Reithofer, B. Jilka, A. Fertschej (4a engineering GmbH)

Infotag Composites
12.3.2018 Stuttgart

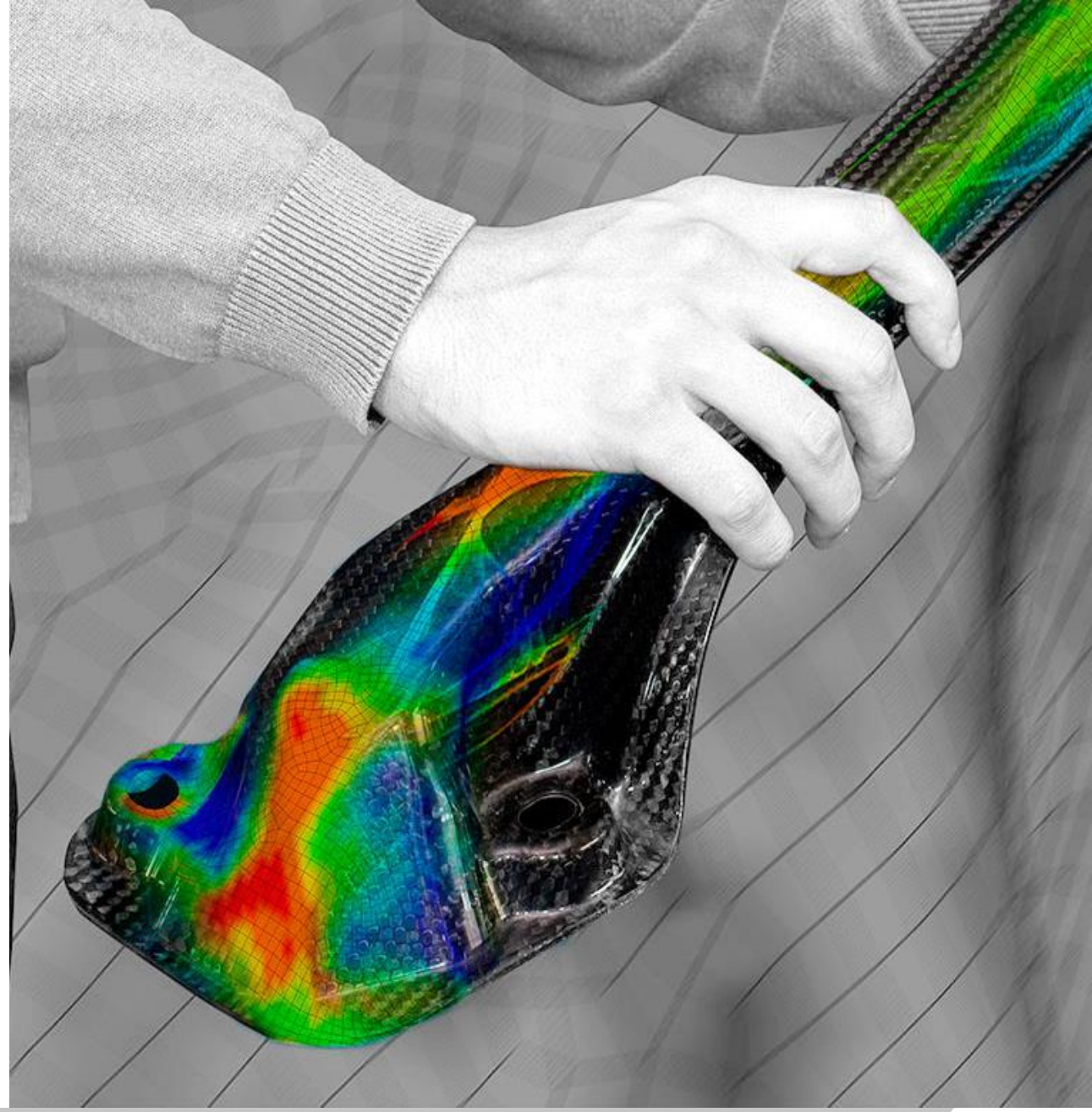
Content

- Introduction 4a engineering
- IMPETUS
  - Motivation & History
  - Short Summary
- Short & long fiber reinforced thermoplastics
  - Characterization
  - Models (***MAT_024** → ***MAT_215**)
  - Simple Case Studies



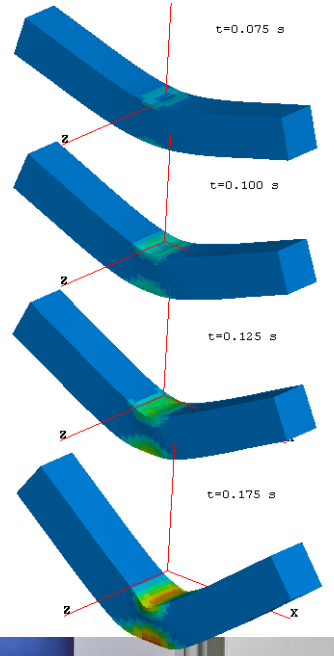
ENGINEERING
GmbH

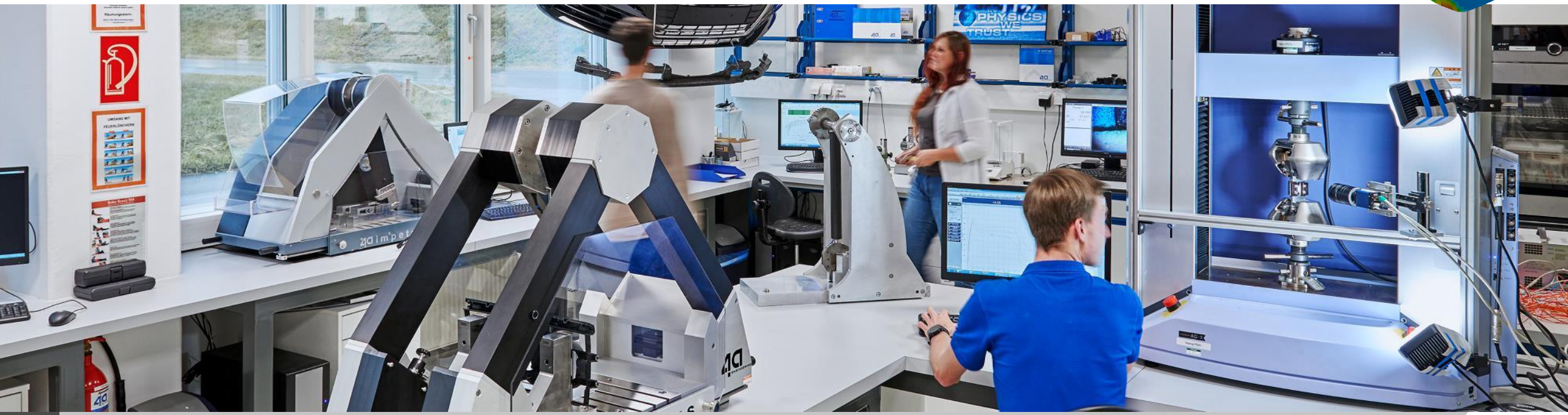
- product development
- polymer and materials science
- numerical simulation methods
- fiber reinforced plastics and composites



material characterization - services

- efficient high-dynamic testing
- dynamic material behaviour
- plastics, foams, composites, …
- **validated material cards ready to use for your crash-simulation**





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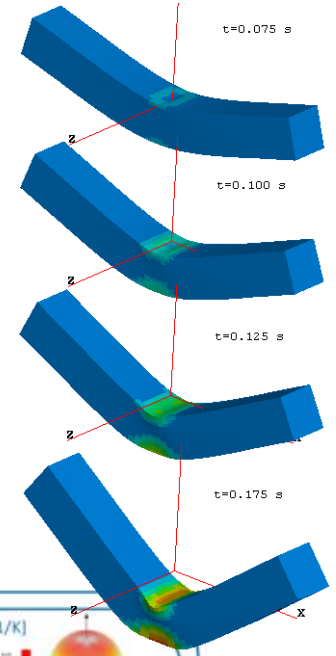
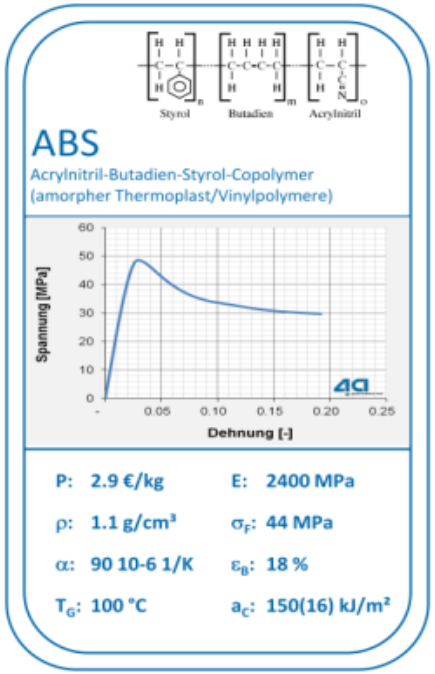


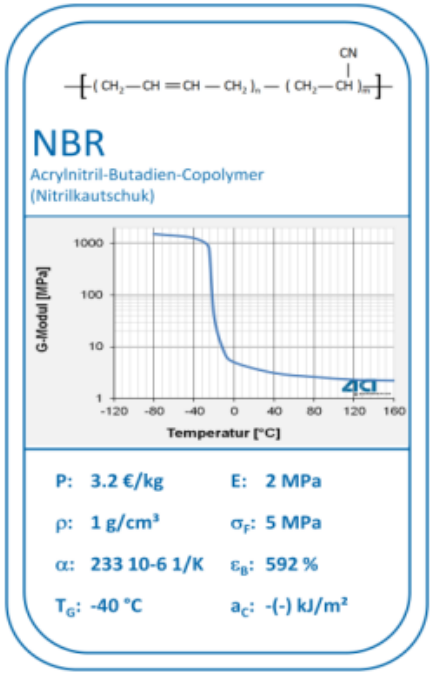
Level
Deformation → Failure
Creep → Static → Crash
ISOTROPIC → ANISOTROPIC

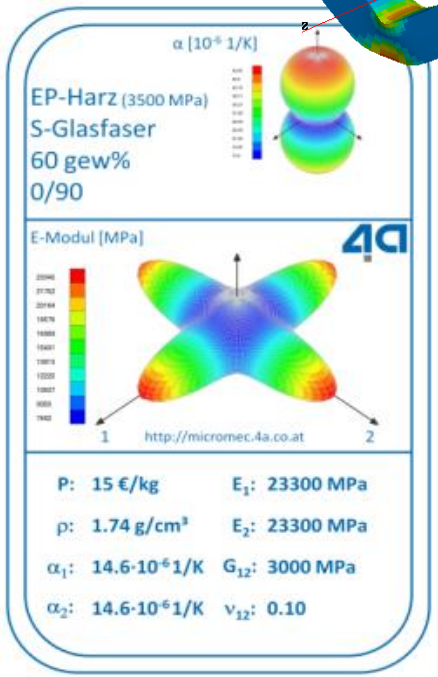
LSTC Livermore Software Technology Corp.
LS-DYNA®

Virtual Performance Solution

SIMULIA

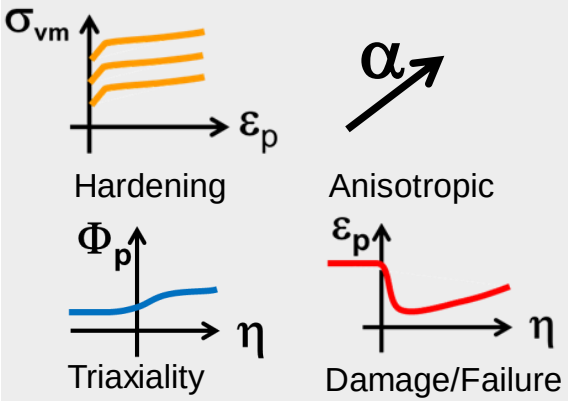






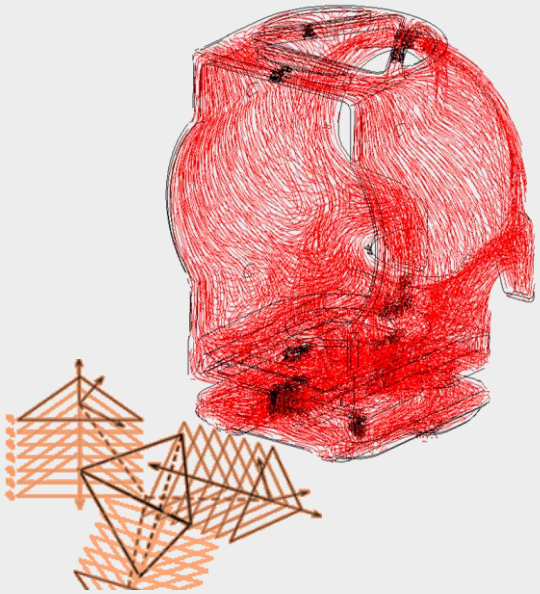
intelligent reliable solutions for plastics, composites, metals, foams, ...

VALIMAT



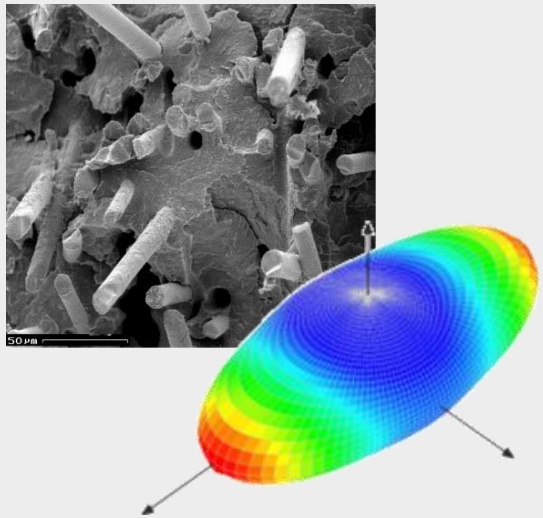
from test to validated material cards

FIBERMAP



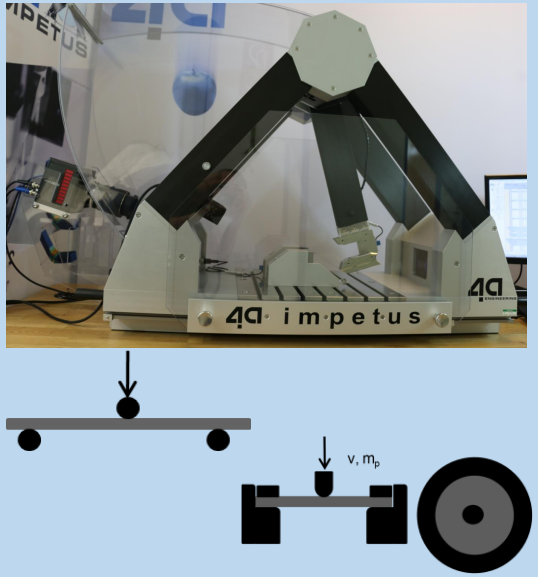
individual mapping process information

MICROMEC



3D anisotropic material cards

IMPETUS



efficient dynamic testing

efficient dynamic testing

IMPETUS

plastics

engineering

production

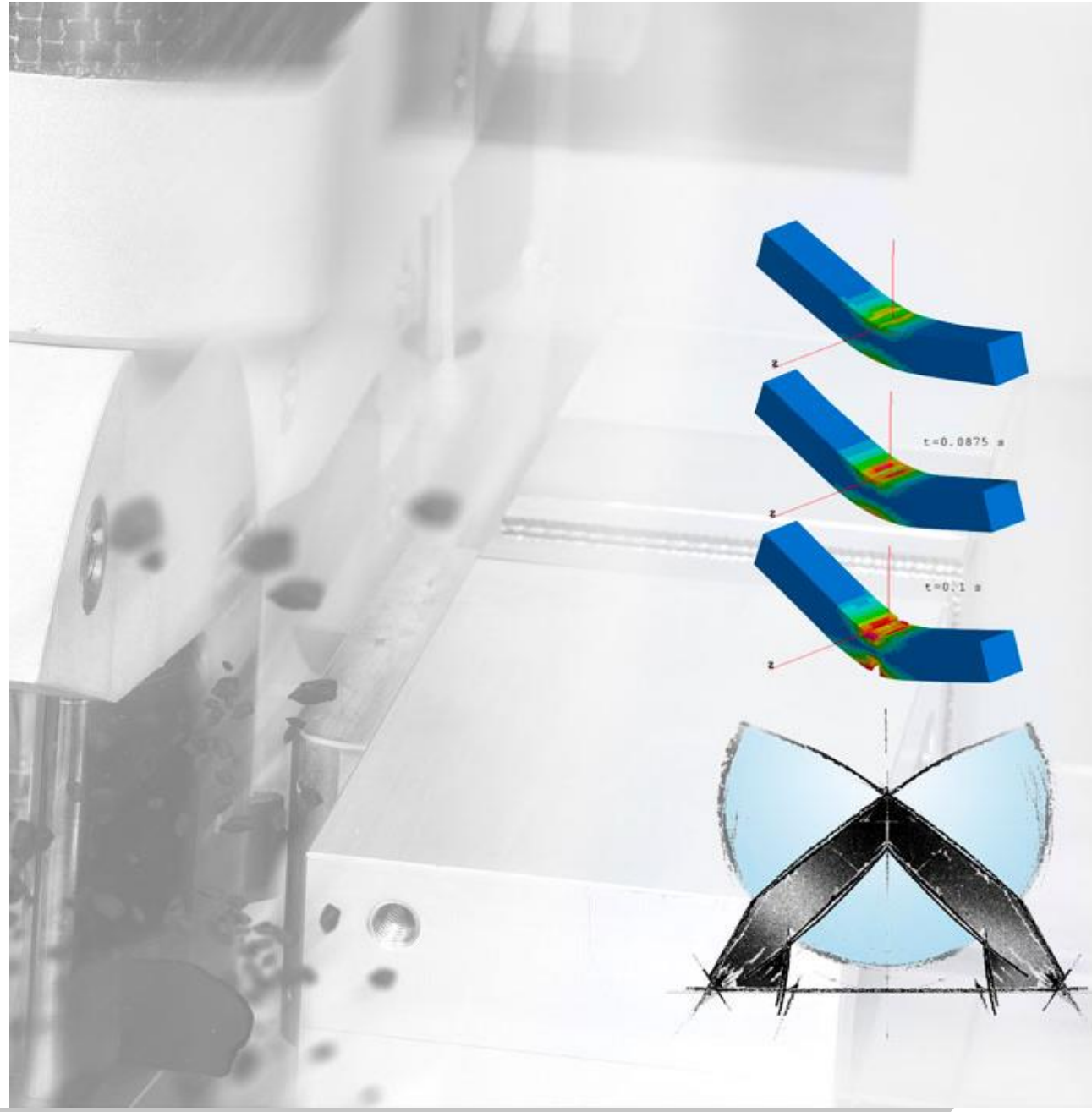
excellence in testing

concepts

simulation

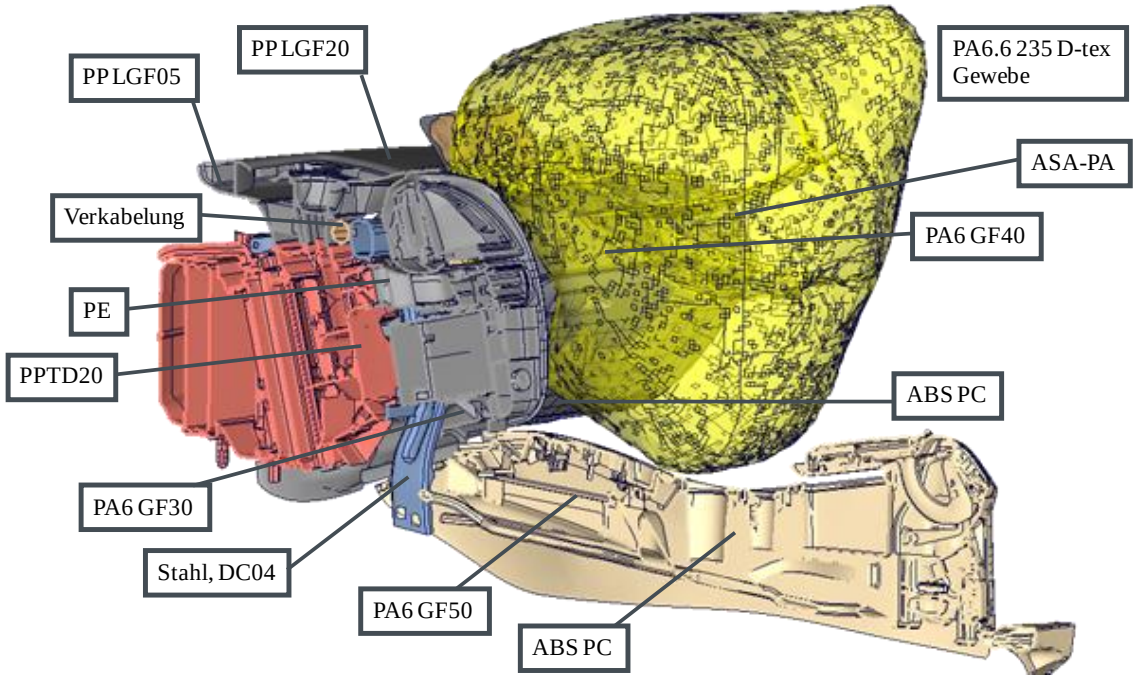
lightweight

prototypes

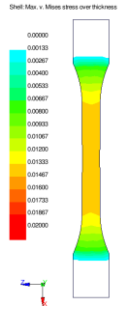


2004 - motivation

material variety

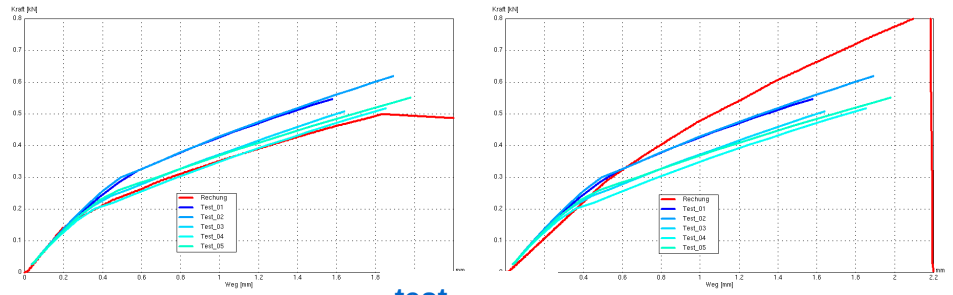


bending load case



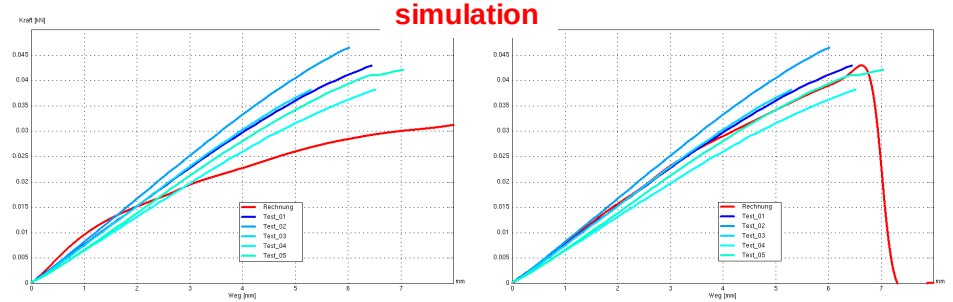
original test curve tension

scaling 1.25



test

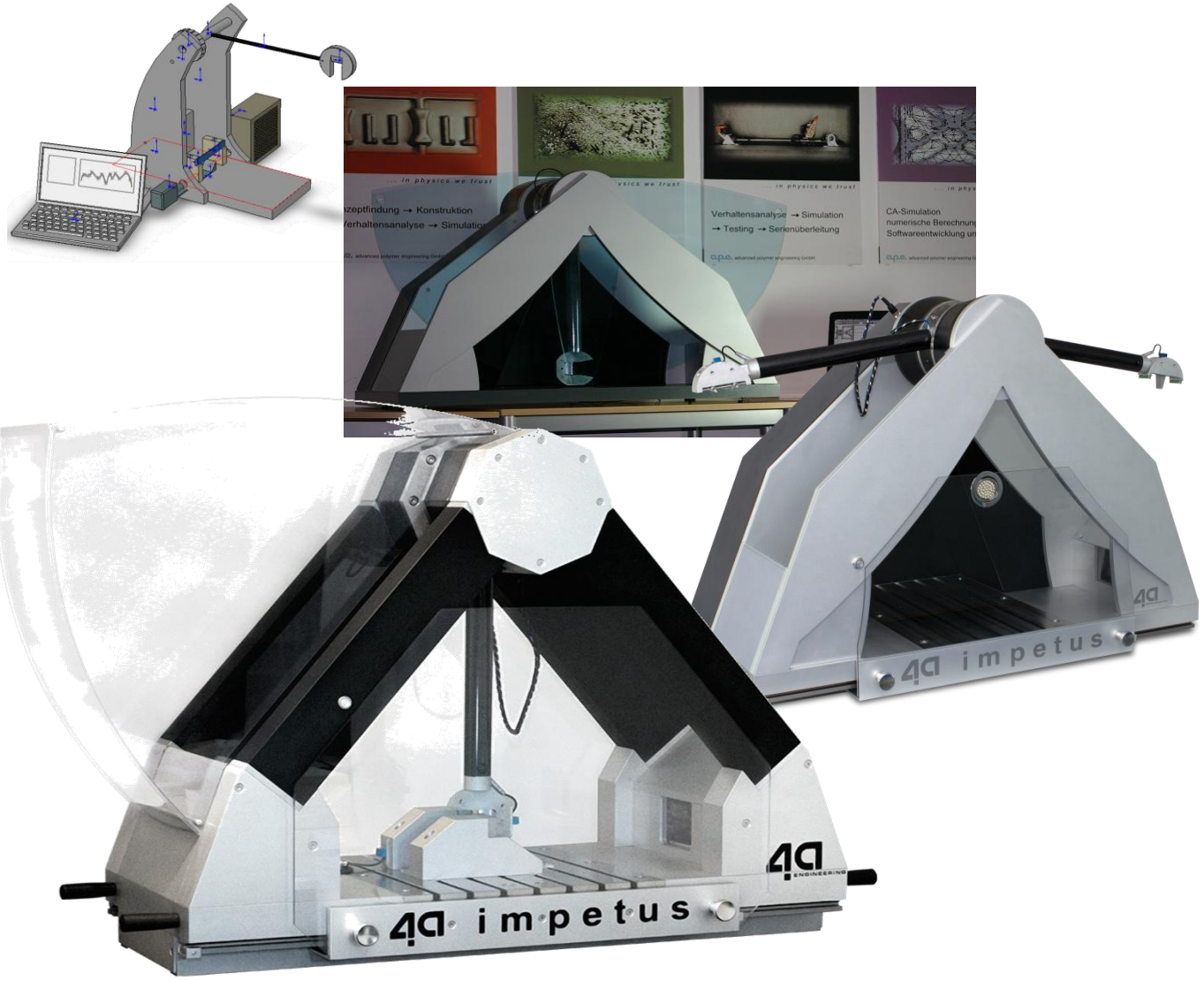
simulation



Source: R. Luijkx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG,* 4a Technologietag 2010

efficient dynamic testing

- desktop testing device
- instrumented high speed testing
  - acceleration → force / displacement
- impact velocity 0.5 – 4.5 m/s
- maximum energy 25 J



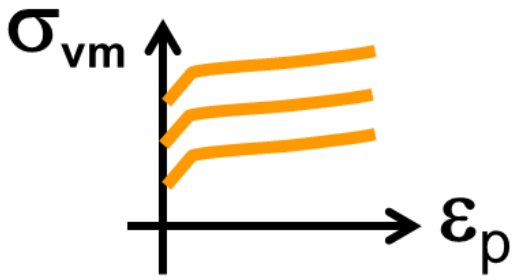
from test to material card

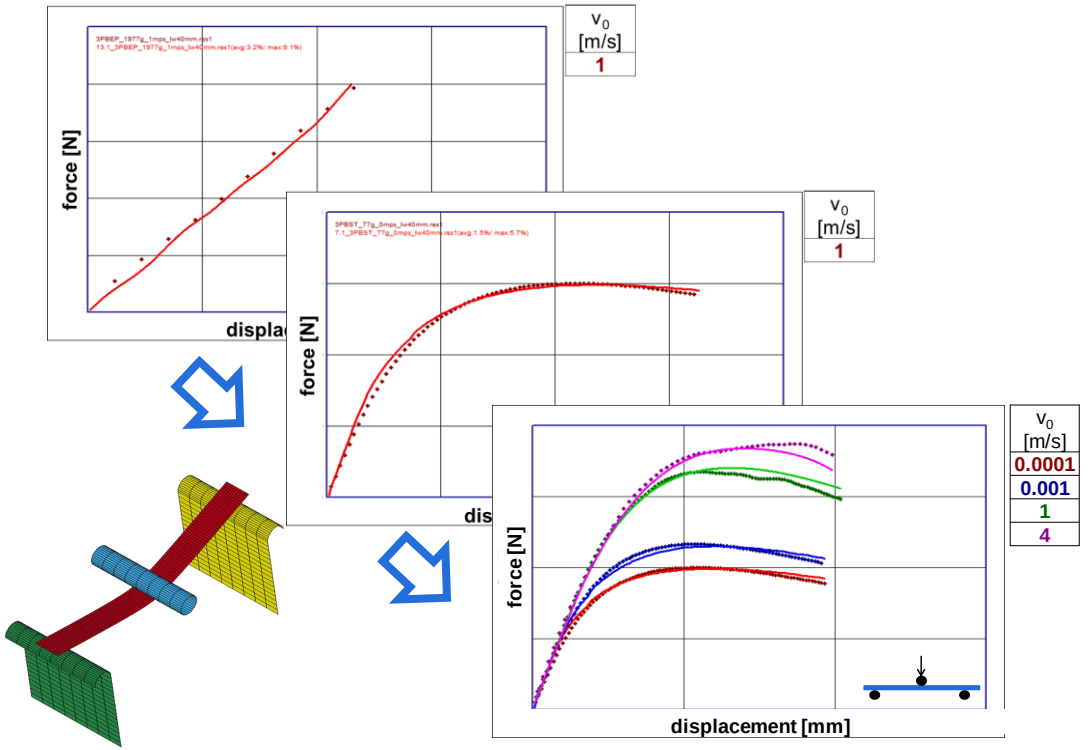
- desktop testing device
- instrumented high speed testing
  - acceleration → force / displacement
- impact velocity 0.5 – 4.5 m/s
- maximum energy 25 J

- easy approach - deformation
  Plastics → Bending → ***MATERIAL_CARD**
  Foams → Compression →***MATERIAL_CARD**

VALIMAT

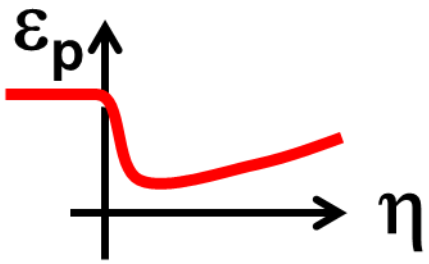
Hardening

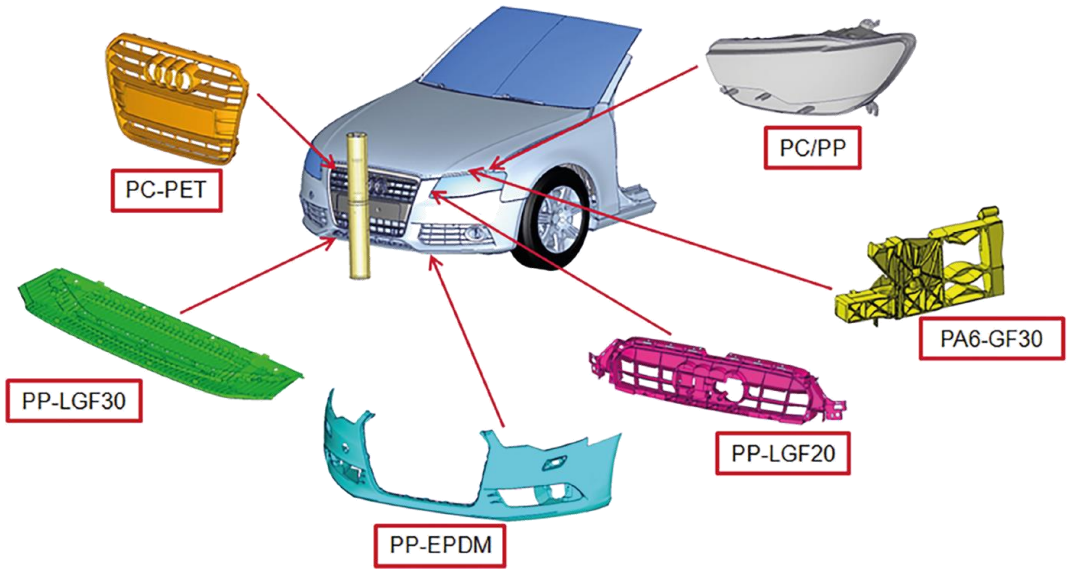


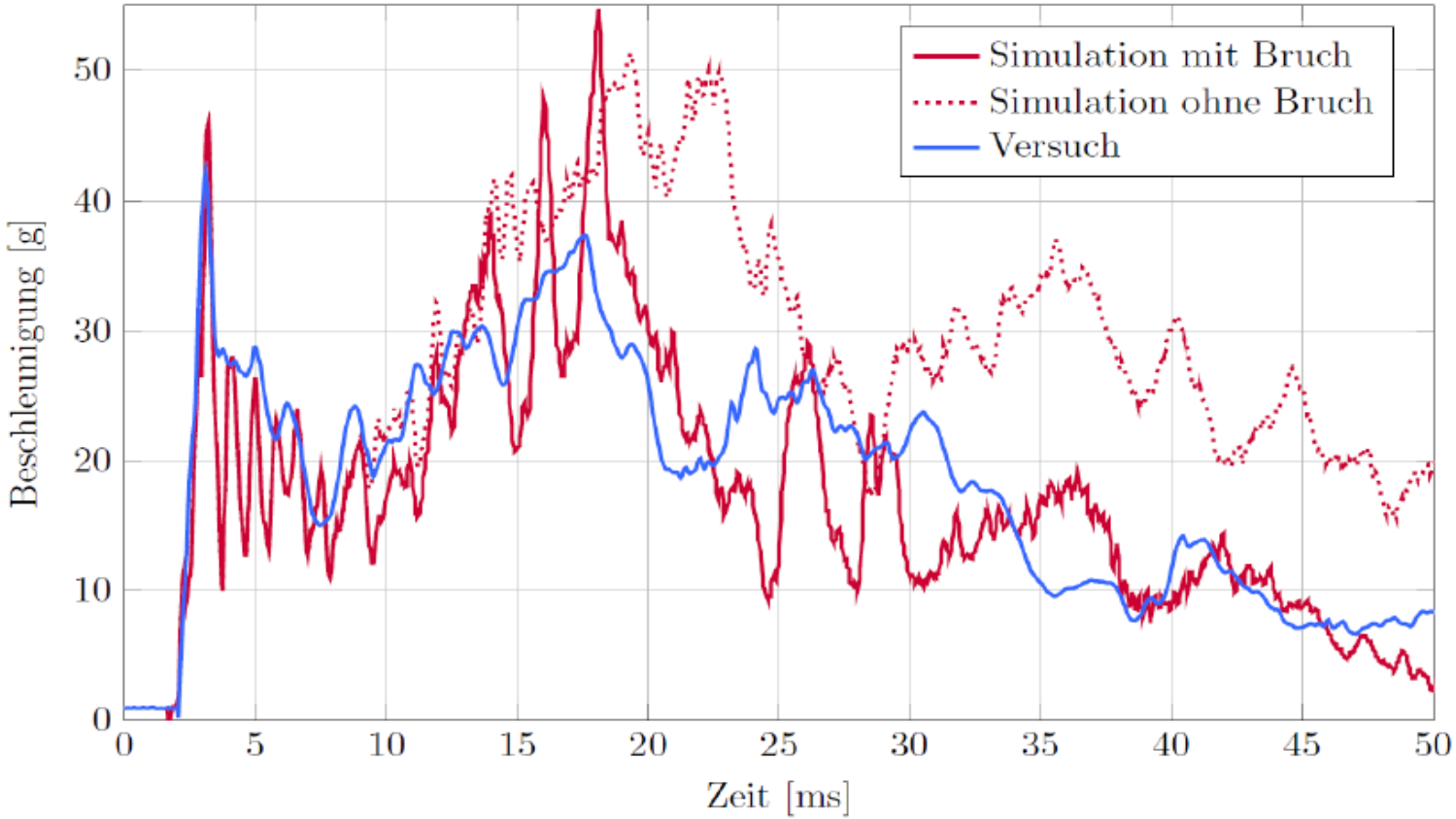


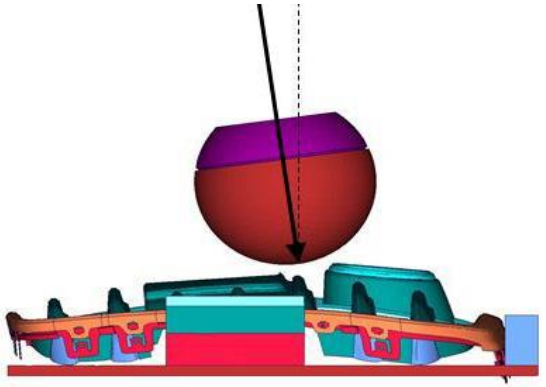
2014 - motivation

Damage/Failure





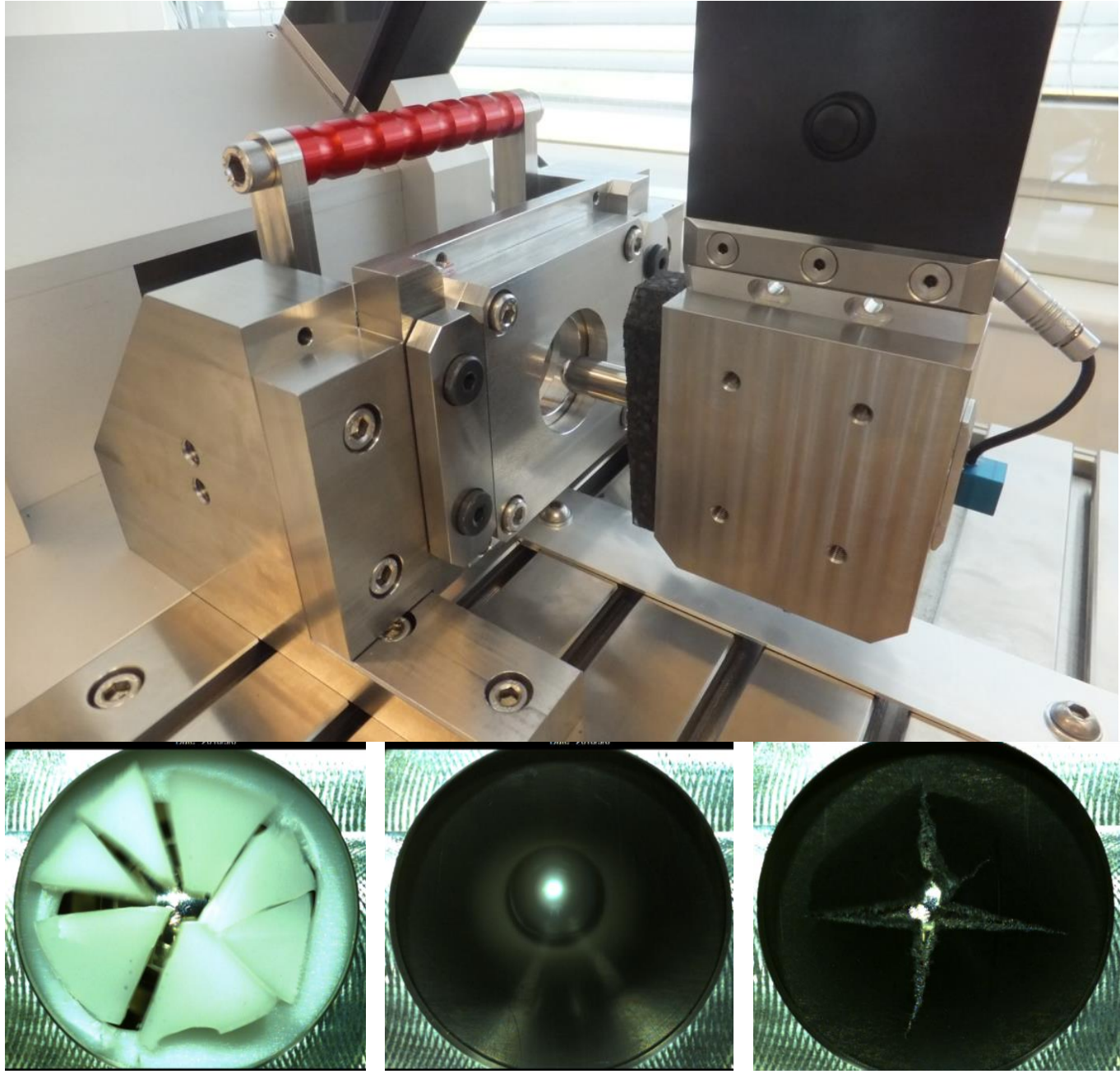




Bildquelle: H. Staack, Audi AG: *Anforderungsgerechte Material- und Bruchmodellierung für die Fahrzeugsicherheit*, TT16 Schladming

efficient dynamic testing

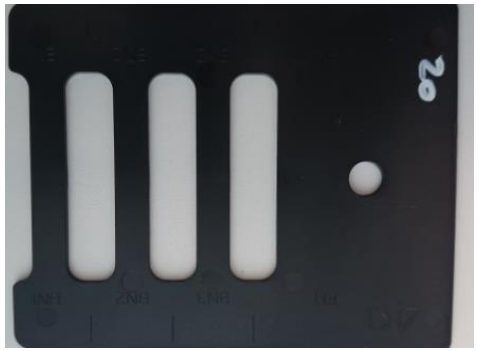
- Different load cases
  - Bending
  - Tension Bending
  - Compression
  - Puncture
  - Component
  - …
- High speed camera
  - Sync. recording
- Maximum energy 50 J
- Material Card
  Deformation → Failure



injection mold for material characterization

DOM & Wall thickness

Melt- & Weldlines



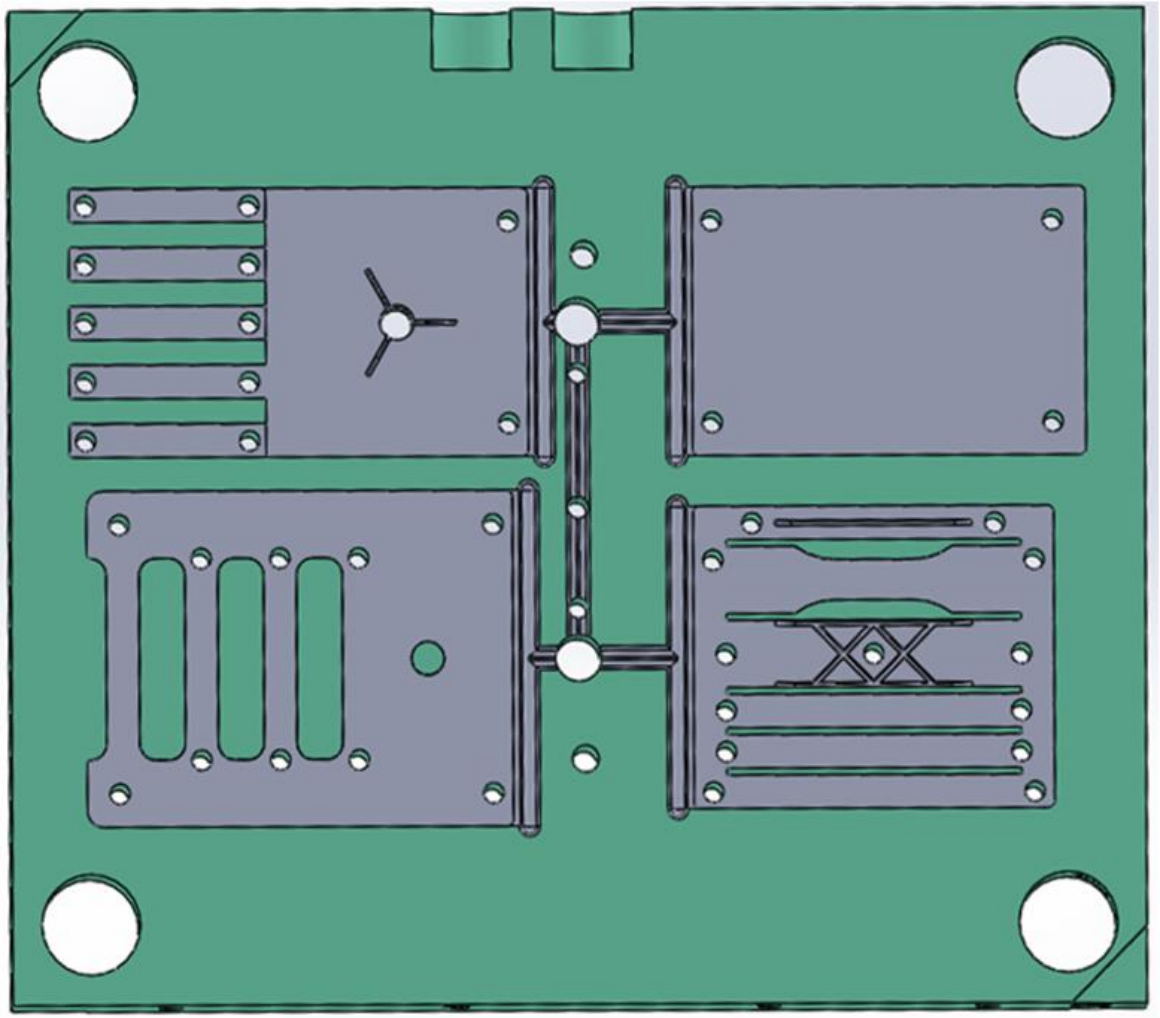
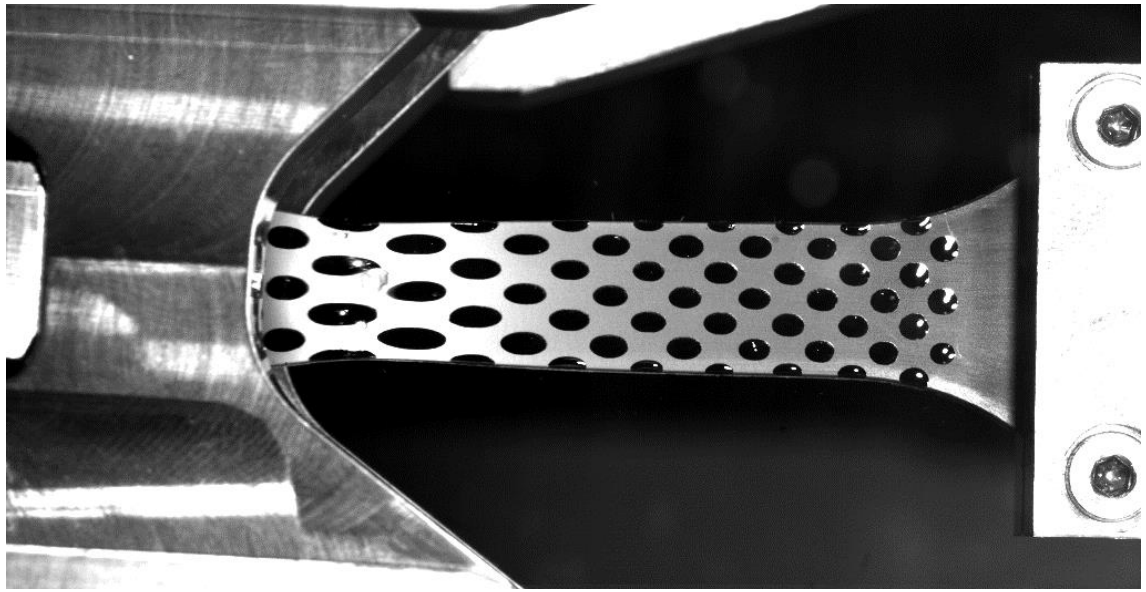


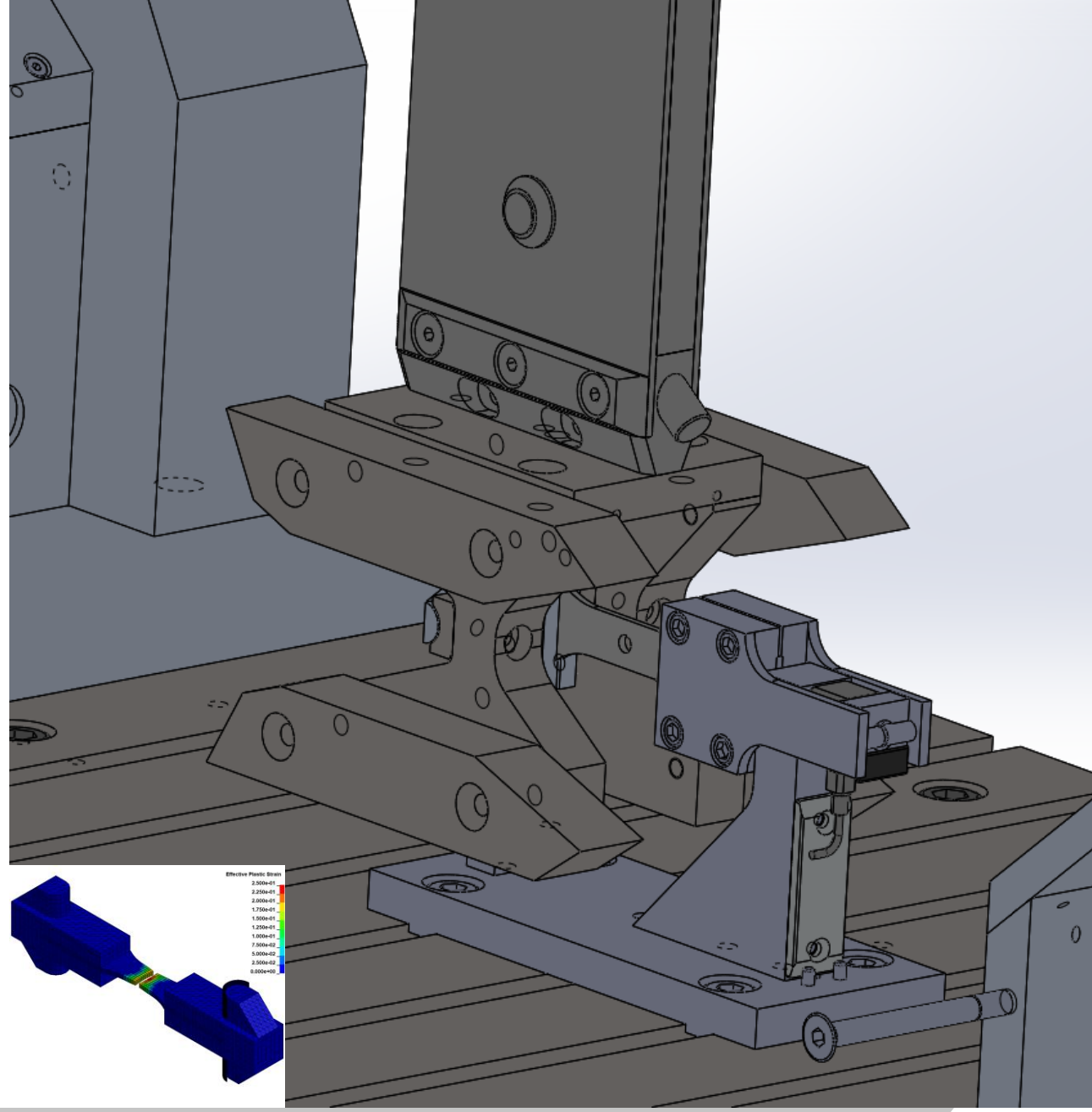
Plate 120 x 80 x 2 mm

Multi-Specimen &
Rib & Component

efficient dynamic testing

- Current Development Dynamic Tensile Test

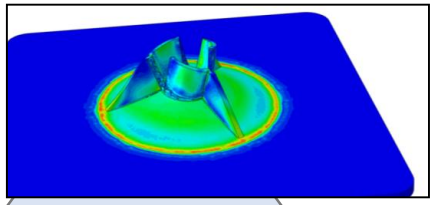


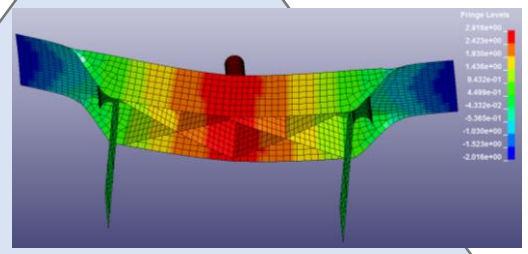


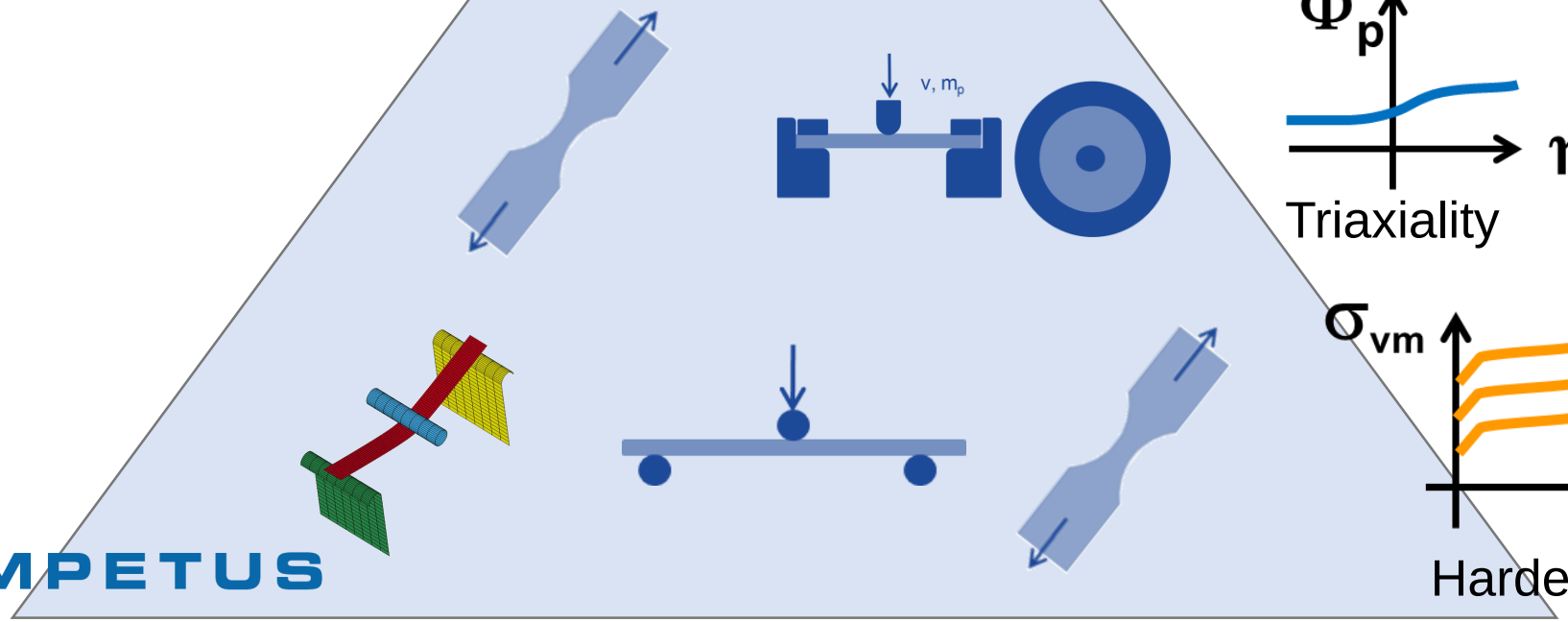
from test to material card

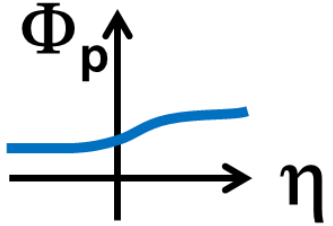
VALIMAT

Deformation → Failure
Creep → Static → Crash
ISOTROPIC → ANISOTROPIC

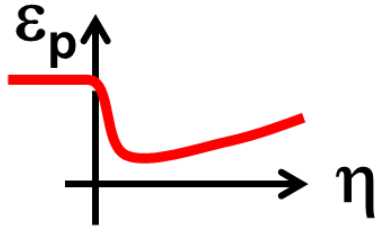




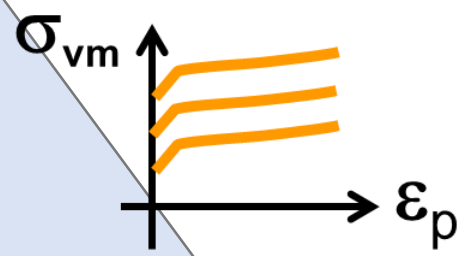




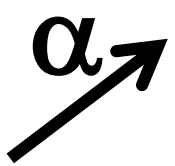
Triaxiality



Damage/Failure



Hardening



Anisotropic

IMPETUS

Short & Long Fiber Reinforced Thermoplastics

plastics

engineering

production

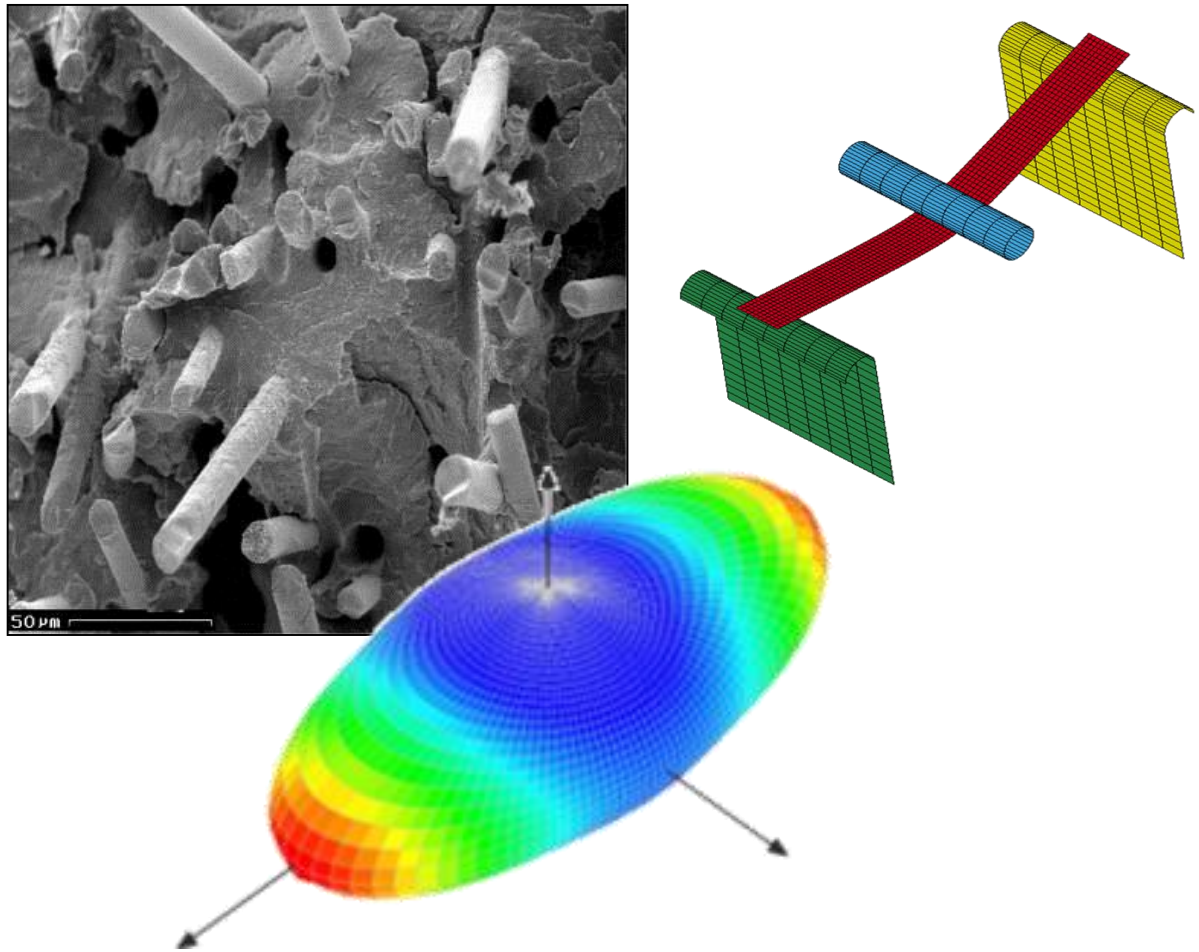
excellence in simulation

concepts

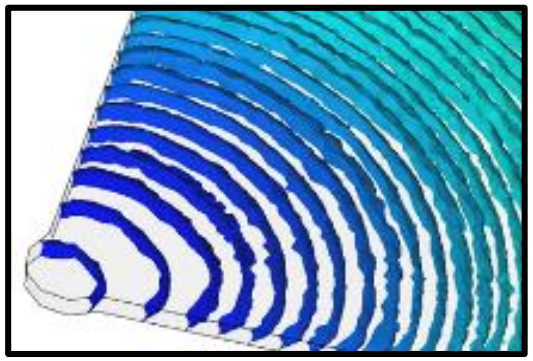
testing

lightweight

prototypes

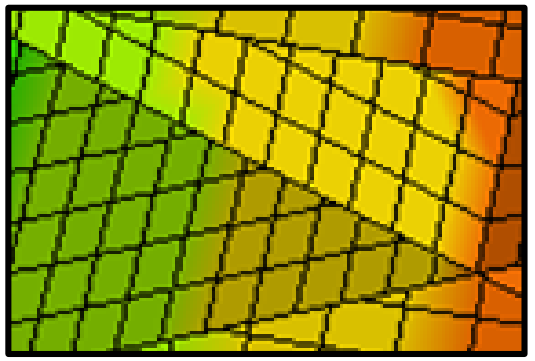


intelligent reliable solutions for plastics, composites, metals, foams, ...



FIBERMAP

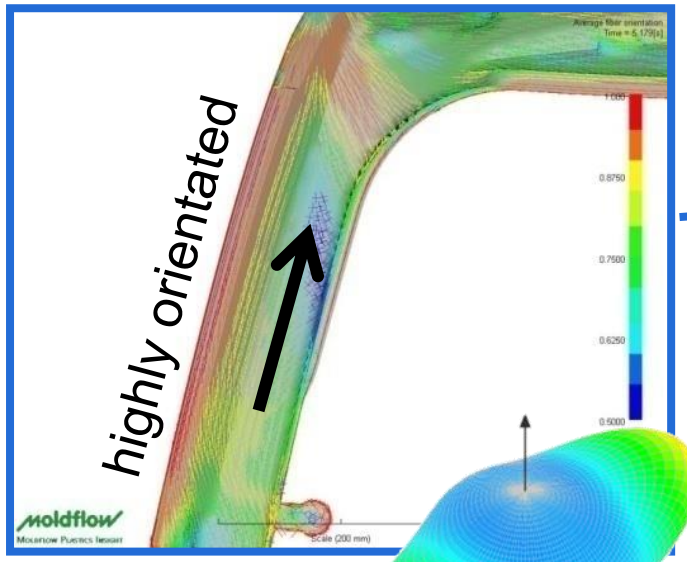
individual mapping
process information



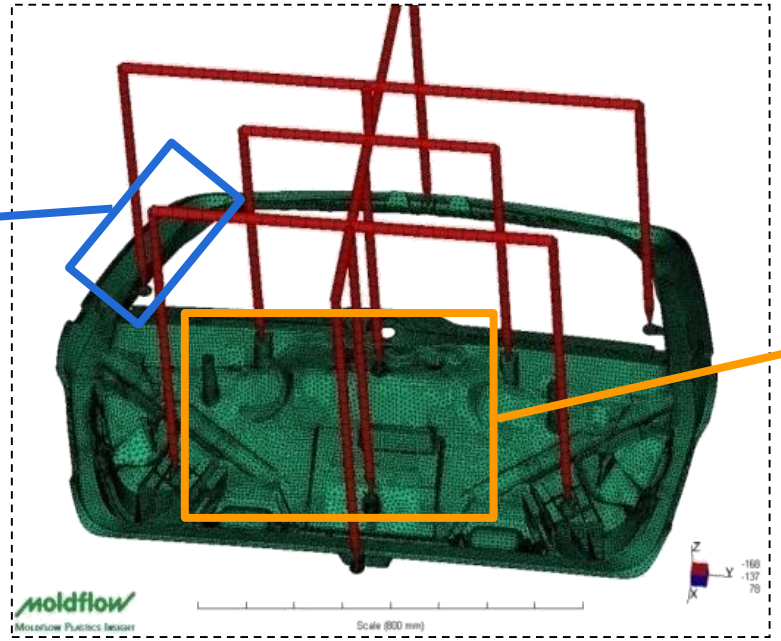
Process

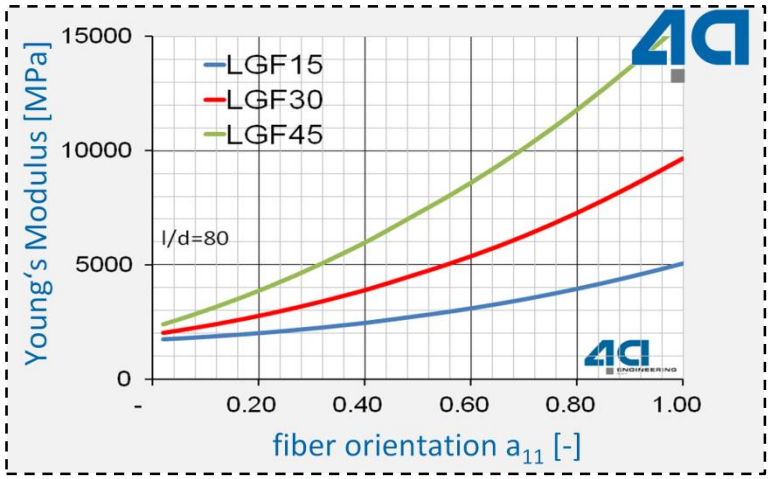
Structural

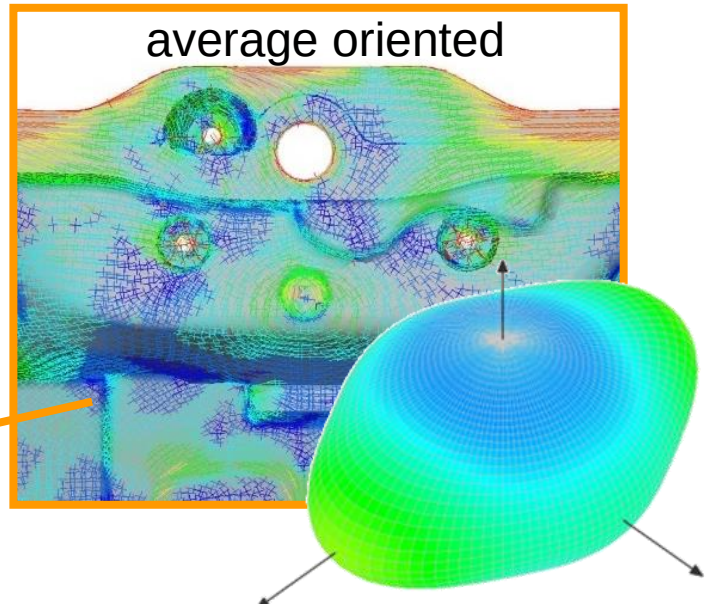
Short & Long Fiber Reinforced Thermoplastics



$$a_{ij} = \begin{bmatrix} 0{,}87 & 0 & 0 \\ 0 & 0{,}11 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$



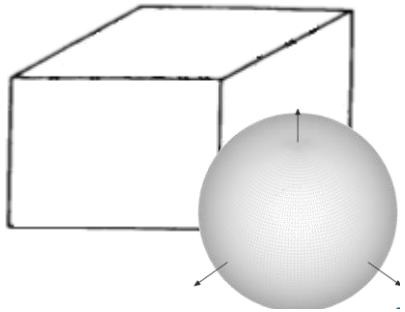


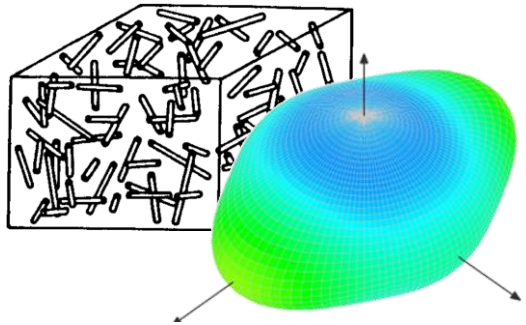


$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

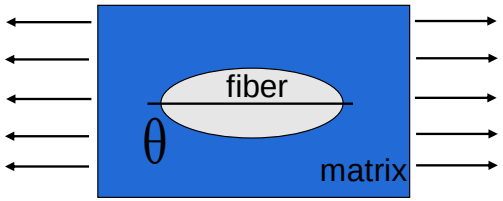
Source: P. Reithofer - *Integrative Simulation – Berücksichtigung der prozessbedingten Anisotropie*, 4a Technologietag 2011

material model - actual approaches





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



Eshelby Tensor

macro scale

constitutiv law → composi

micro scale

homogenizat

Mises plasticity

- quick & d
- criti g
  t
  orientation

elastic

- orthotro
- aniso

elastic tic

- city

M… matrix

- isotropic elas
  viscoplast

F… fiber

- iso tic

*MAT_024

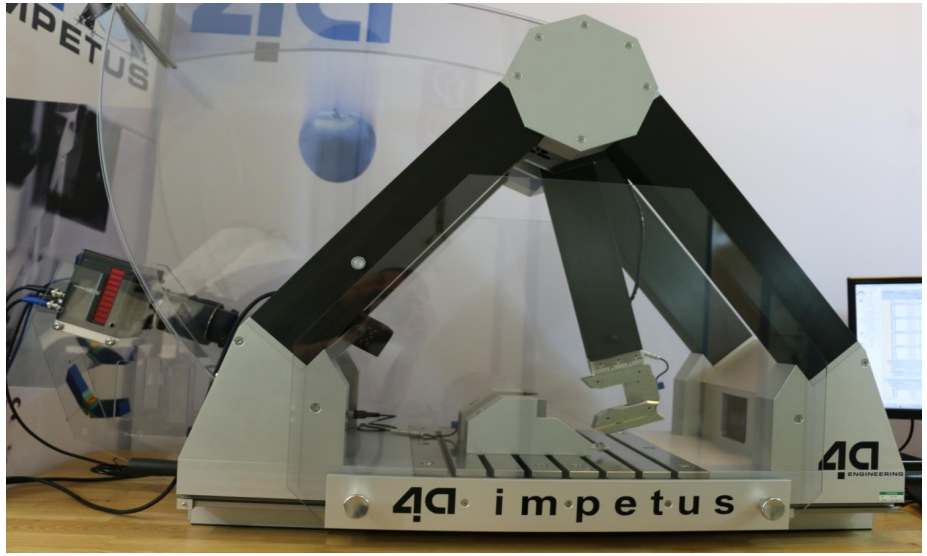
*MAT_157

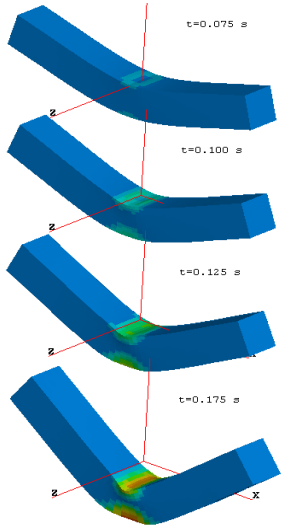
*MAT_215

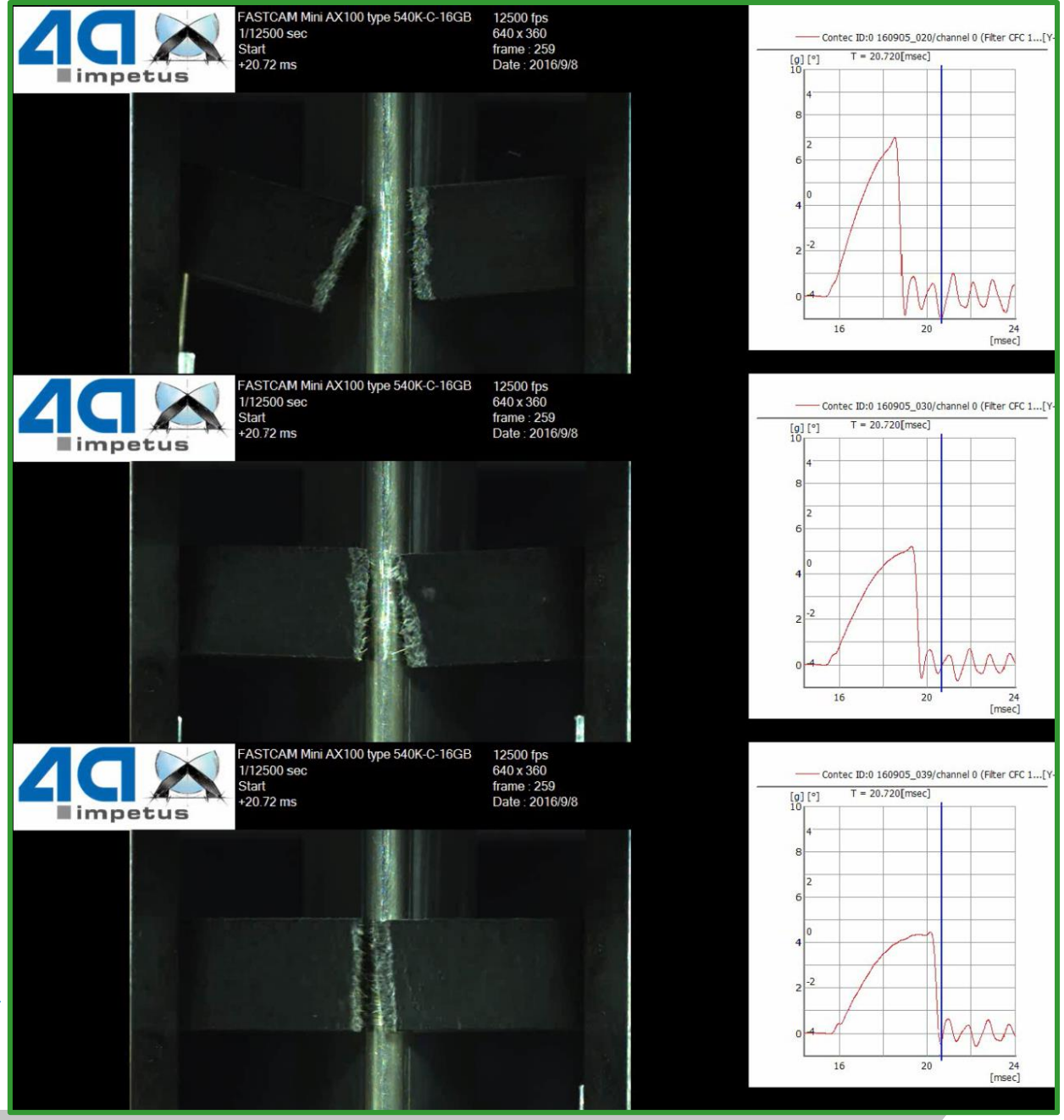
α – orientation dependent

efficient dynamic testing

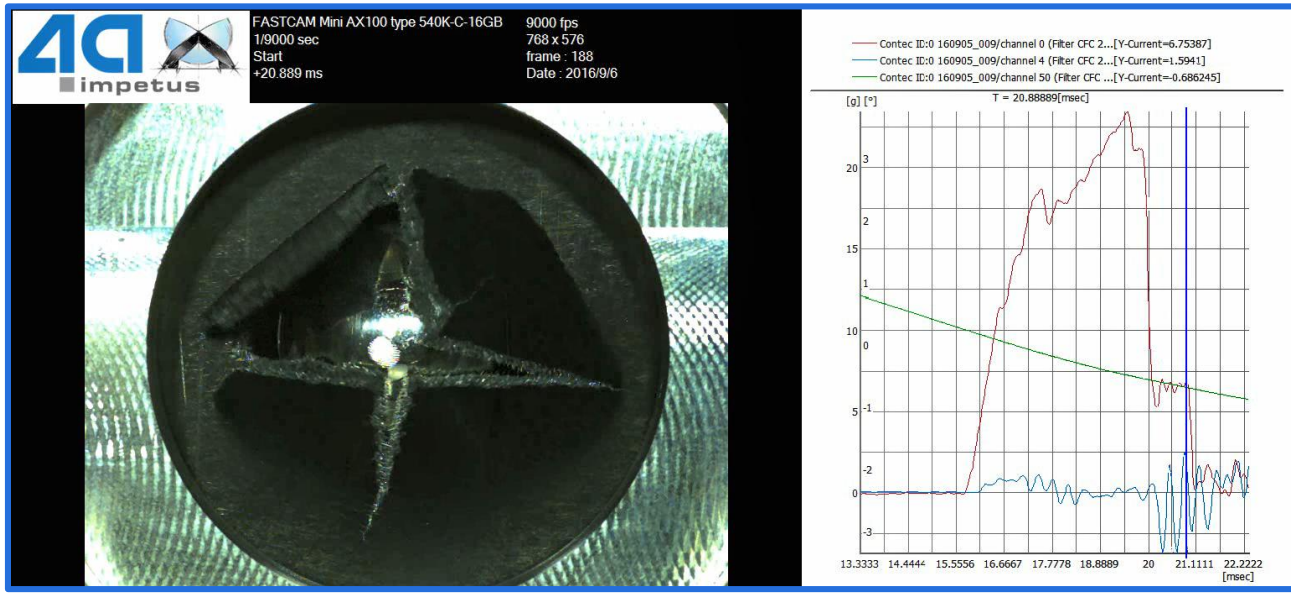
IMPETUS



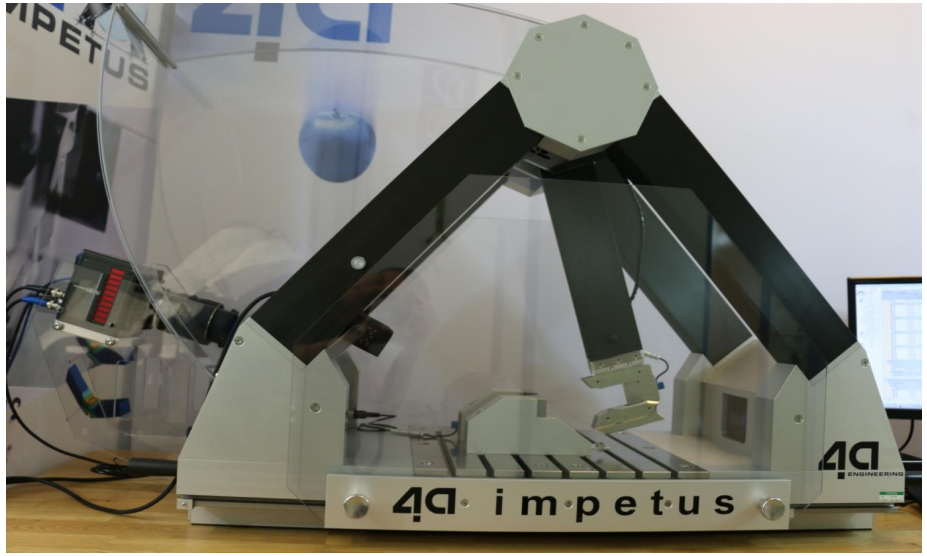


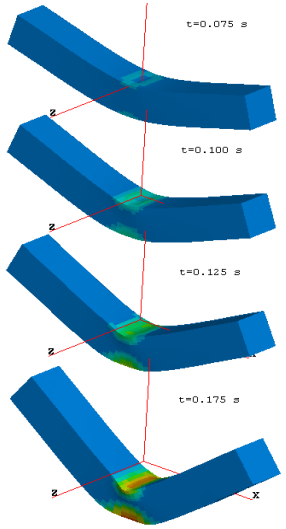


efficient dynamic testing



IMPETUS





from test to material card

Process

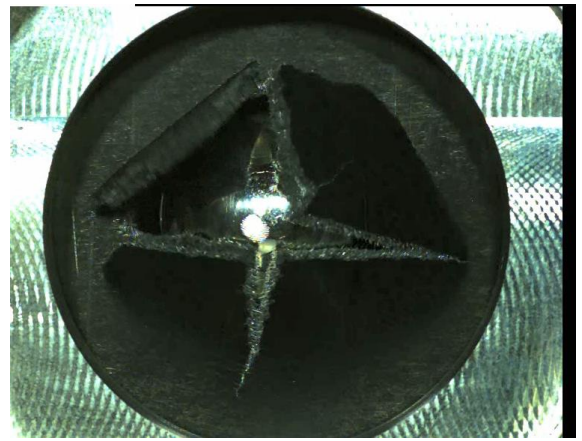
IMPETUS

efficient
dynamic testing

VALIMAT

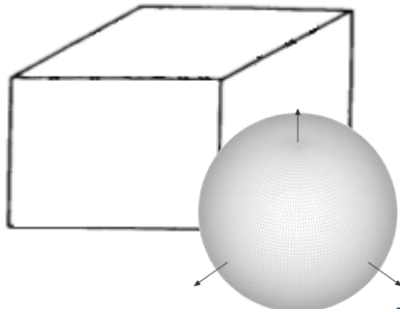
from test to validated material cards

Structural



from test to material card

*MAT_024

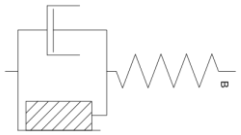


macro scale

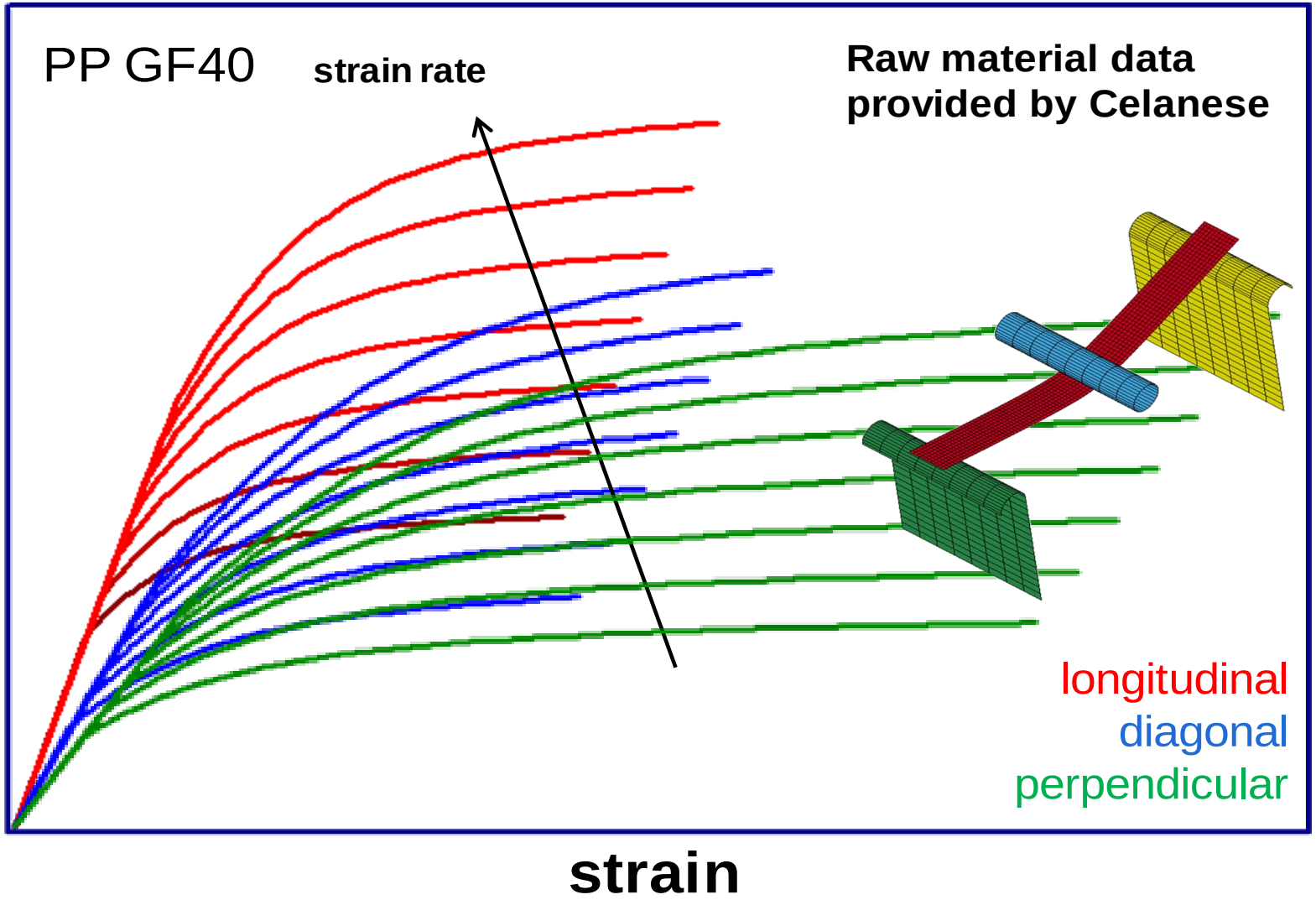
constitutive law

Mises plasticity

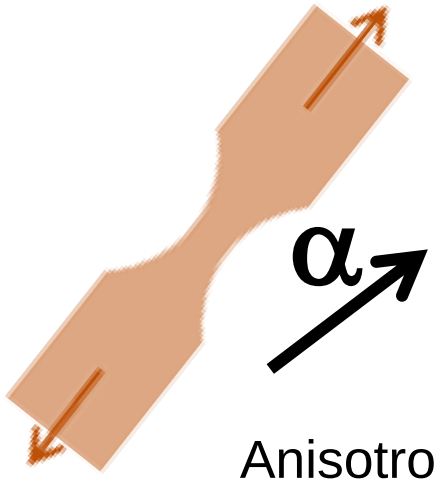
- quick & dirty



- critical loading
  transversal
  to fiber orientation



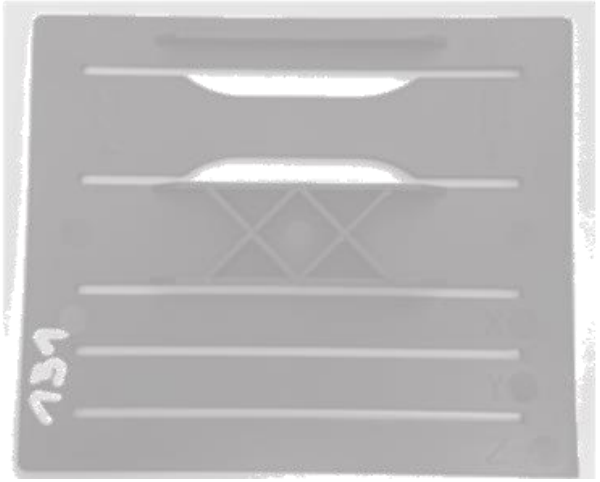
from test to material card



Why not tension (only)?

Anisotropic

Process



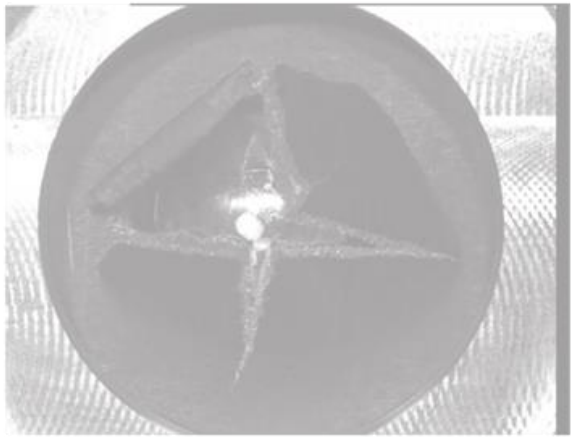
IMPETUS

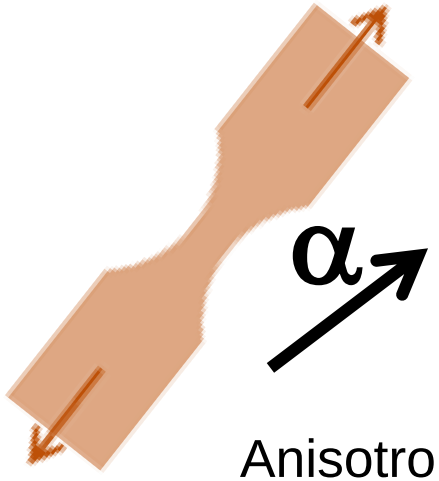
efficient
dynamic testing

VALIMAT

from test to validated
material cards

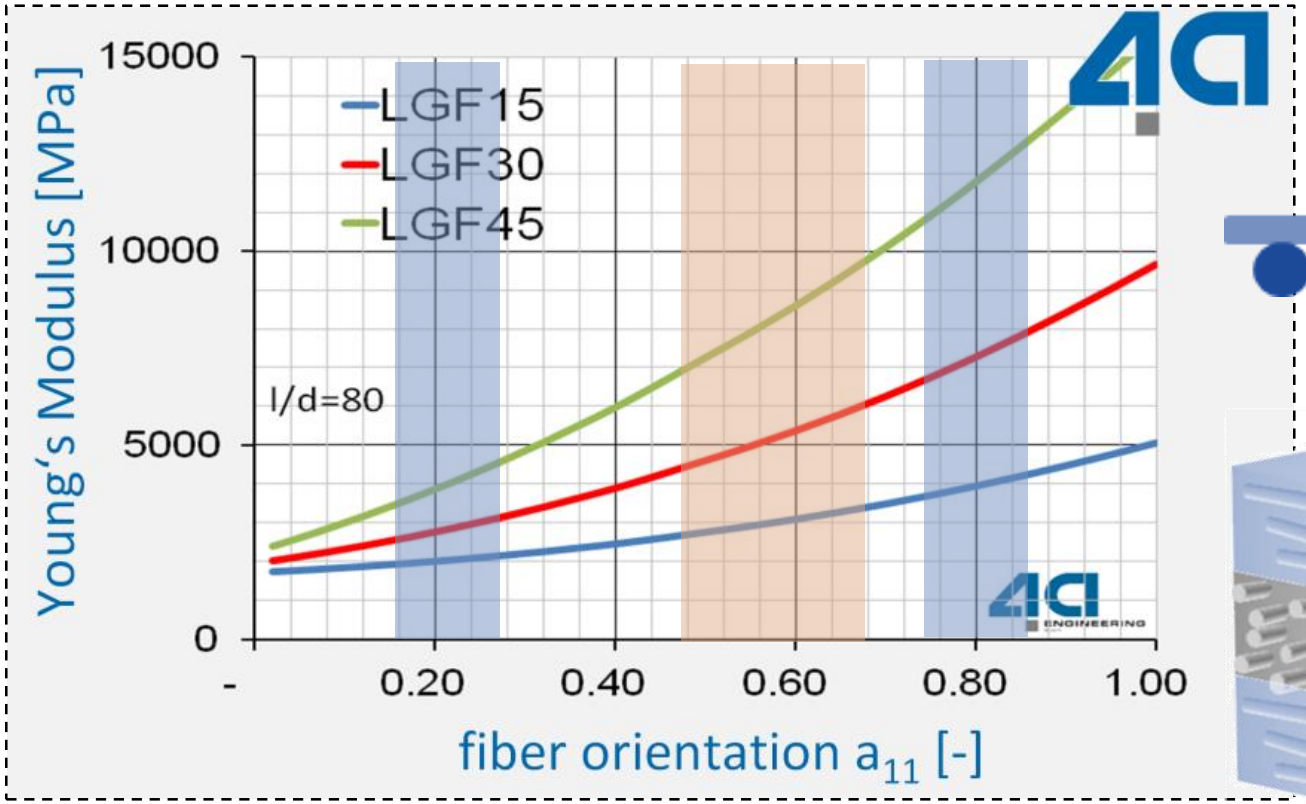
Structural

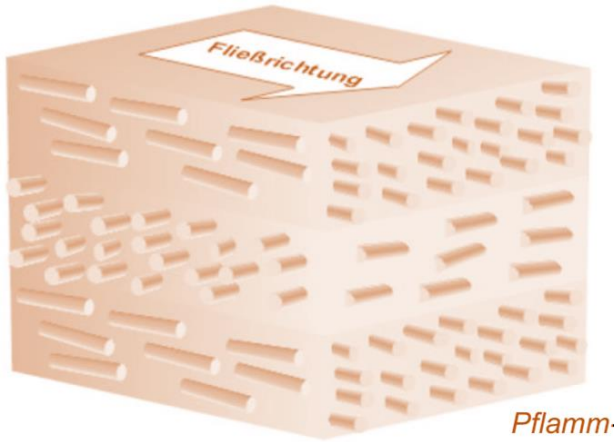


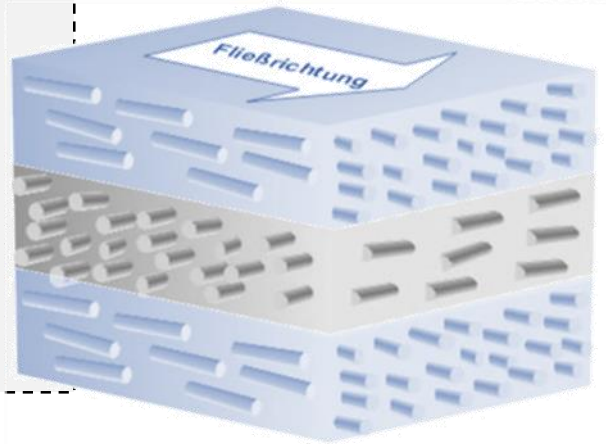


Anisotropic

Why not tension (only)?

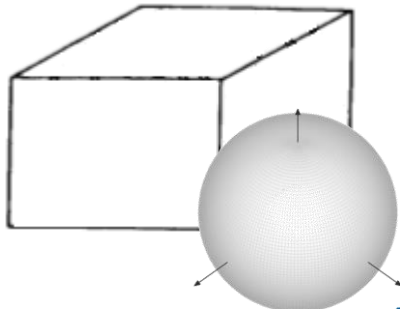


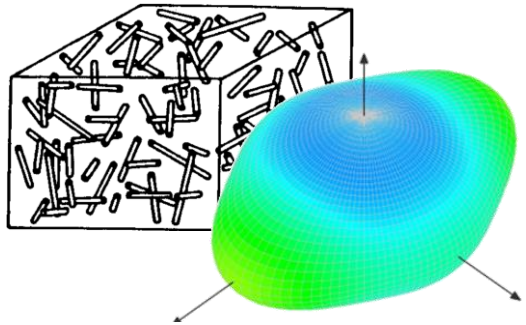




Pflamm-Jonas 2001

material model - actual approaches



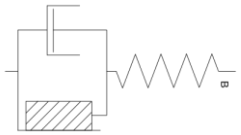


macro scale

constitutive law → composi

Mises plasticity

- quick & dirty



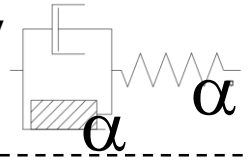
- critical loading transversal to fiber orientation

elastic

- orthotro
- aniso

elasti tic

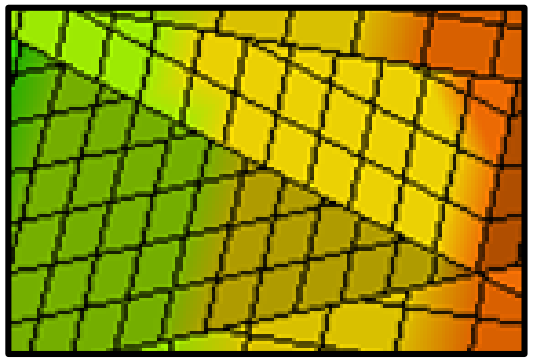
- city



*MAT_157

α – orientation dependent

from test to material card

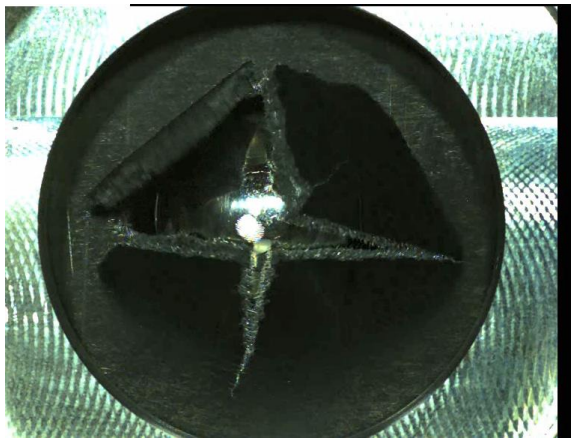


Process

MICROMEC

fully 3D anisotropic material cards

Structural

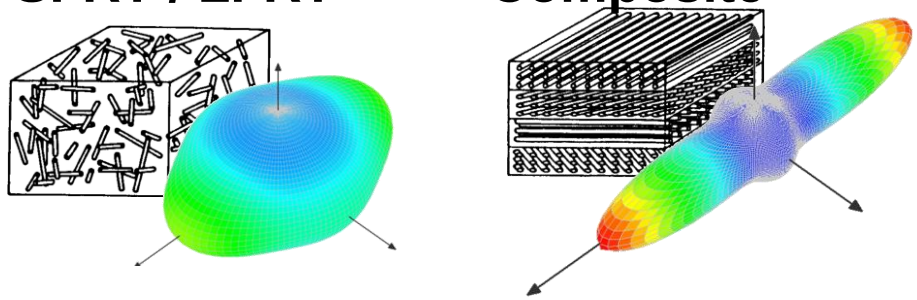


IMPETUS

VALIMAT

MICROMEC

SFRT / LFRT **Composite**

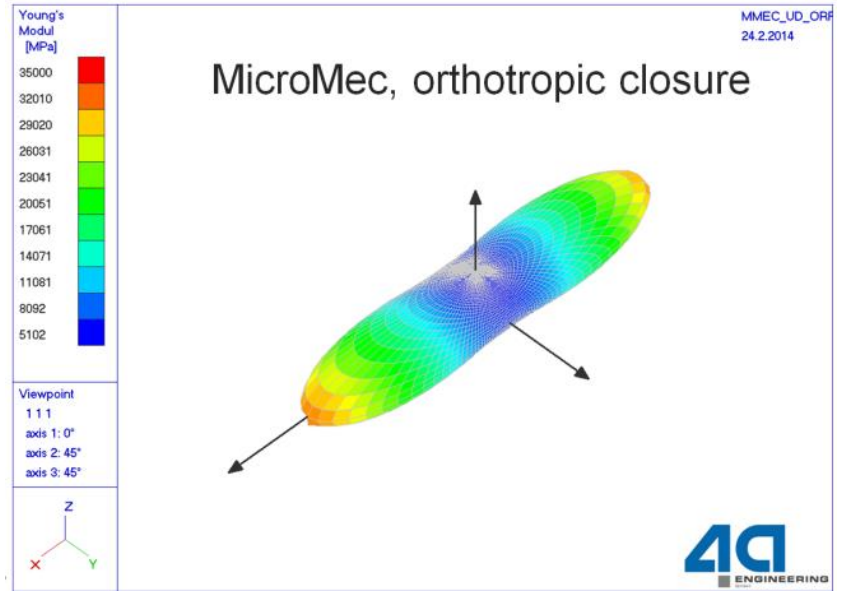


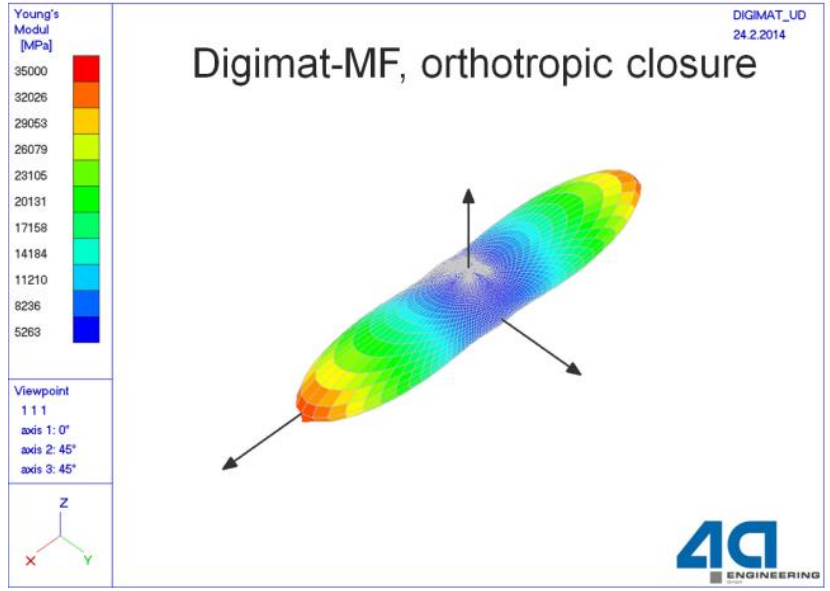
$$\bar{\sigma}^{C} = \varphi\bar{\sigma}^{F} + (1-\varphi)\bar{\sigma}^{M}$$

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

- **Standalone product (2001)**
- **Usermaterial (2007)**
- **Library→4a impetus (2015)**
- **in LSDYNA R10.1 (2018)**

`*MAT_4A_MICROMEC`

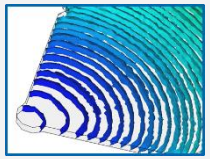




Comparison by University of Leoben [Bodor2014]

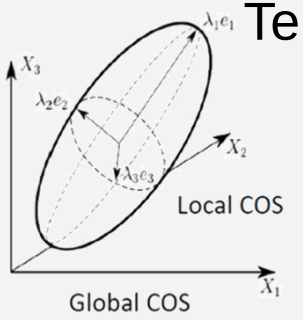
Material models – actual approaches

Process simulation



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

Tensor 2nd order



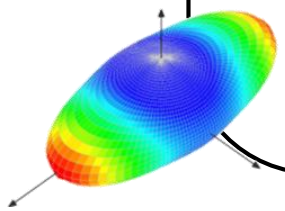
CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

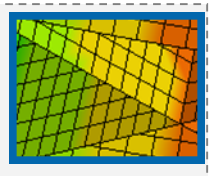
FIBERMAP

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



MICROMEC

Structural simulation

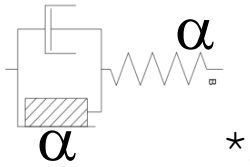


Homogenization (Micro Scale)
Mean Field Theory

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

*MAT_215

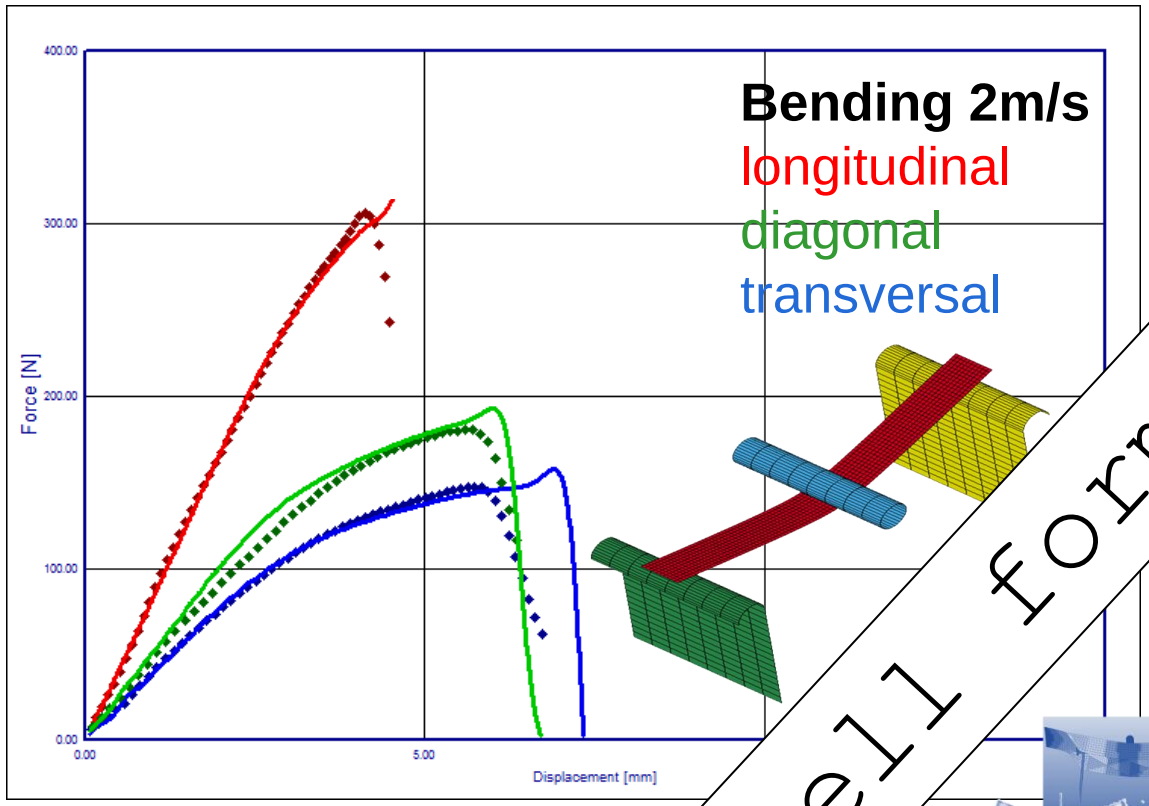
Composite (Macro Scale)
Hill Plasticity

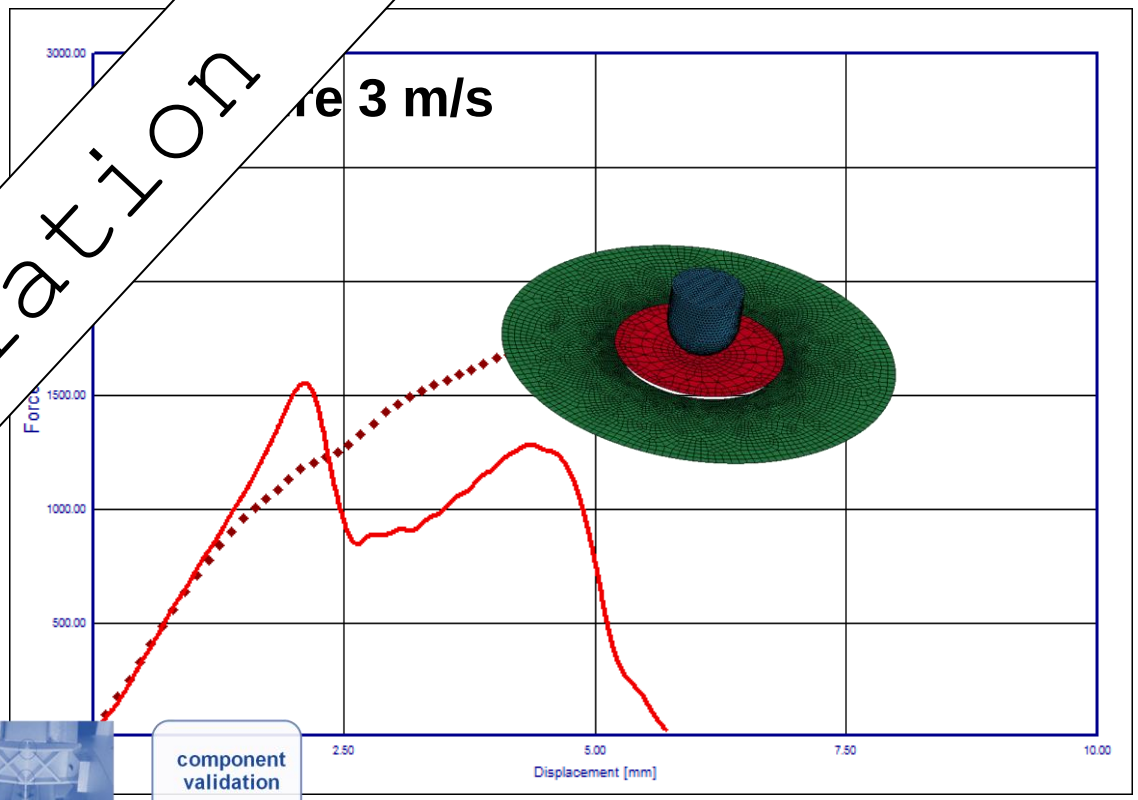


*MAT_157

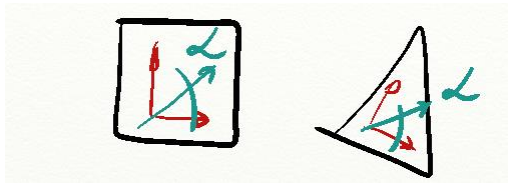
LSTC Livermore Software Technology Corp.
LS-DYNA®

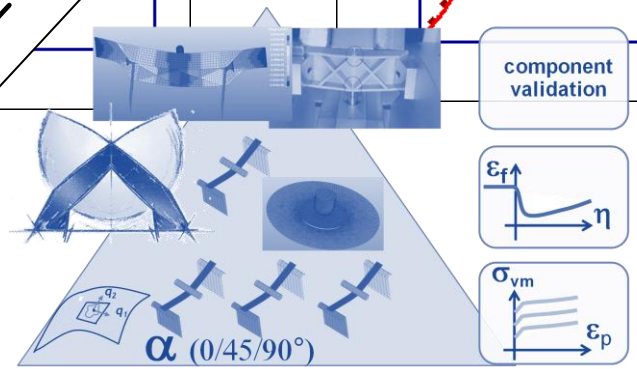
CASESTUDY PP LGF30 - *MAT_157/215





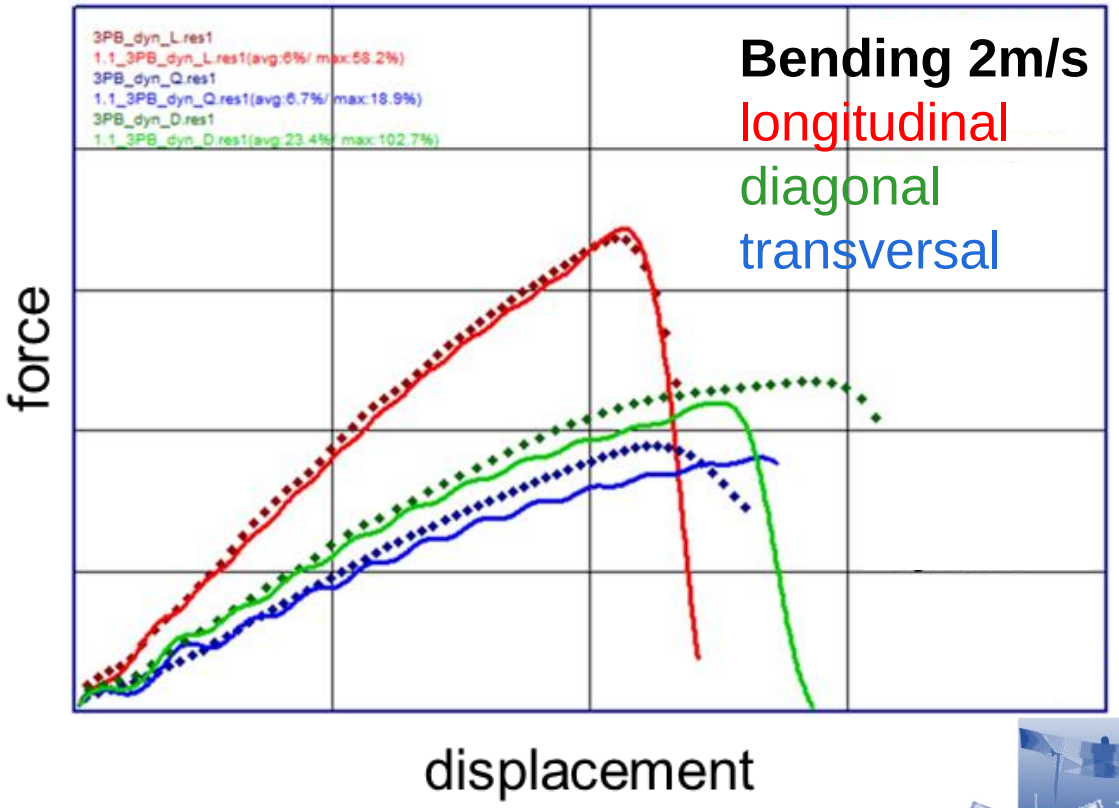
Shell formulation 2.

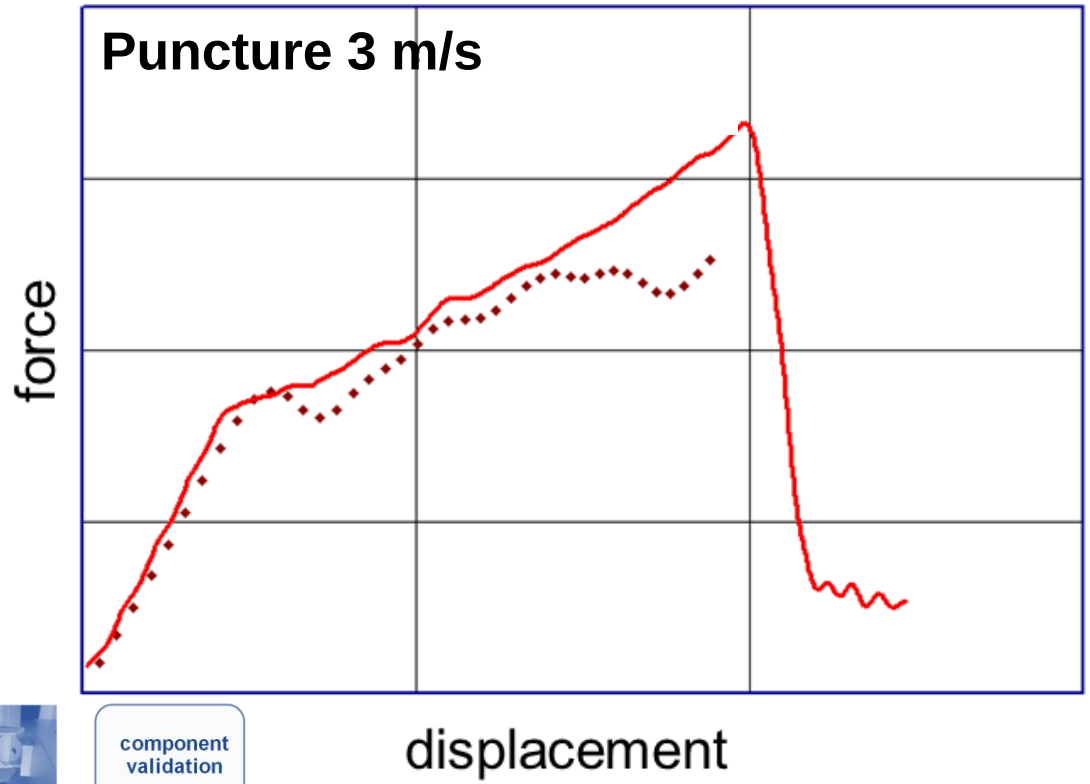


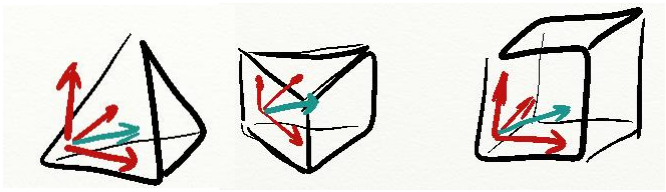


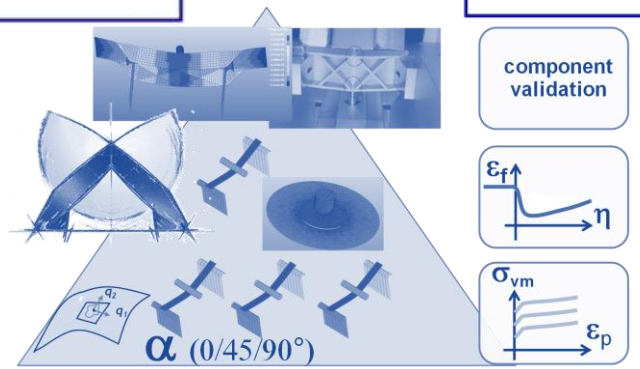
···· averaged test curves
— result of simulation

CASESTUDY PBT GF30 - *MAT_215



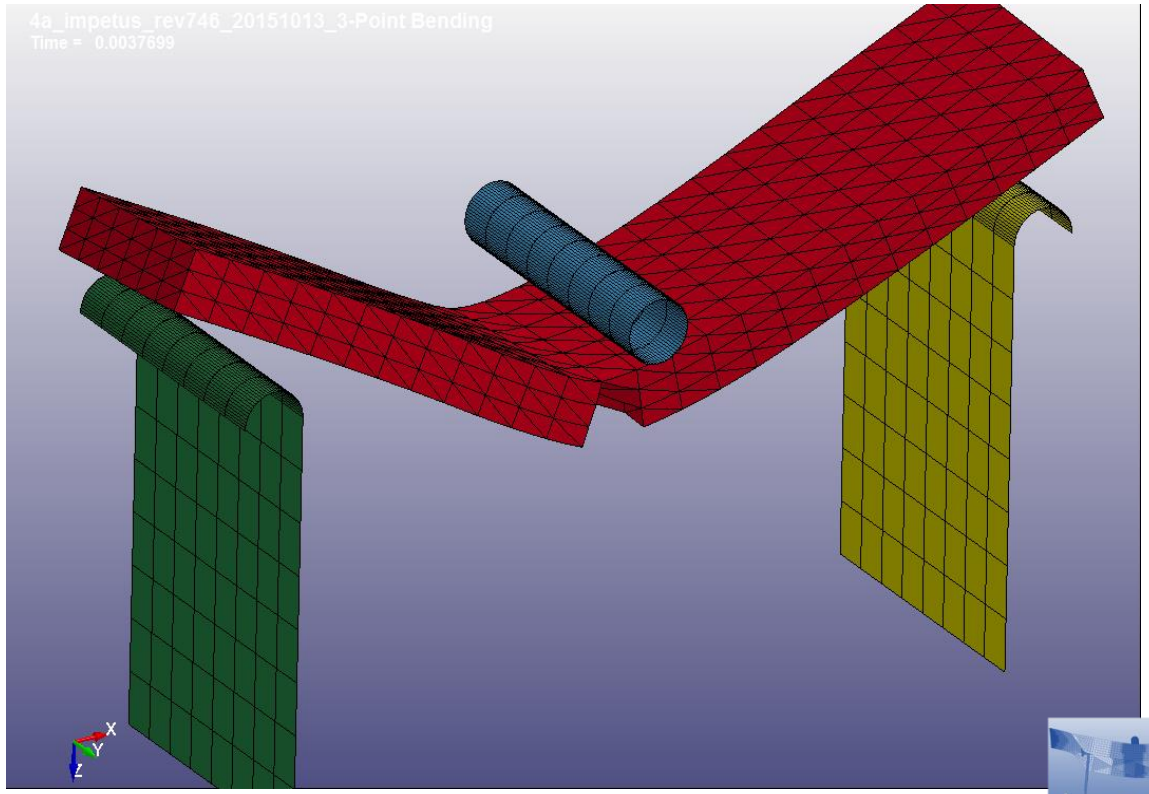


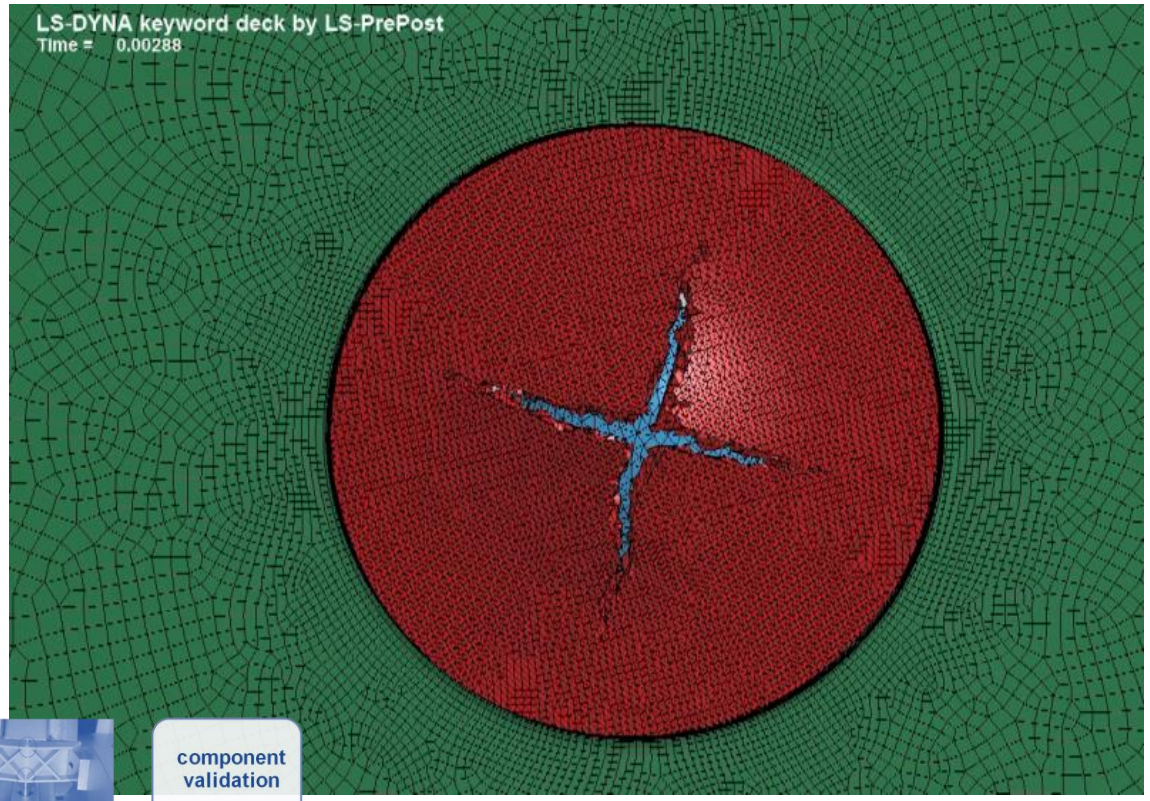


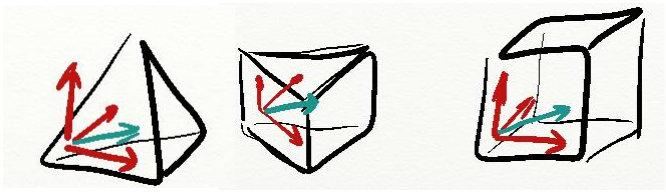


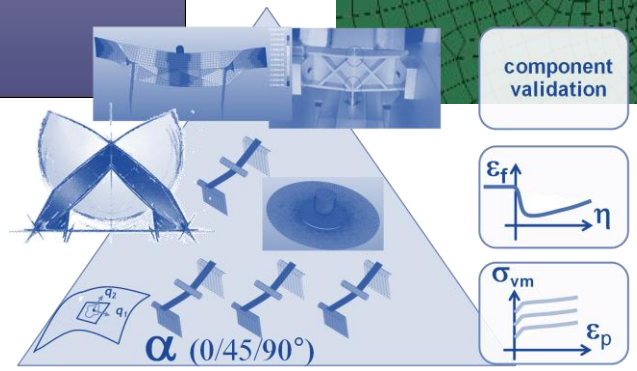
···· averaged test curves
— result of simulation

CASESTUDY PBT GF30 - *MAT_215

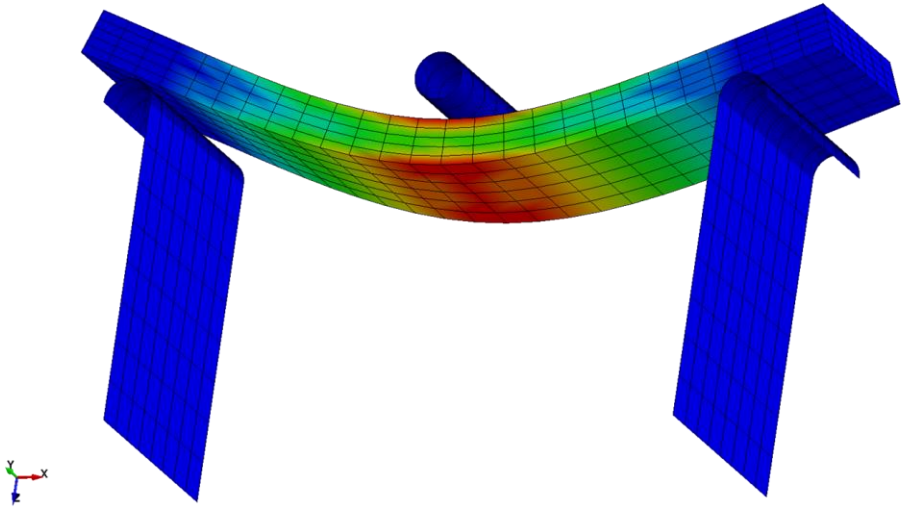






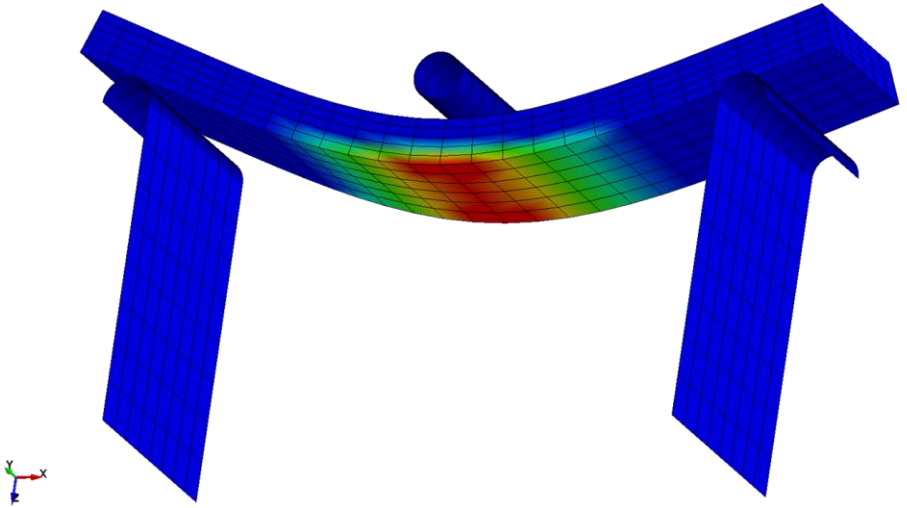


CASESTUDY PBT GF30 - *MAT_215



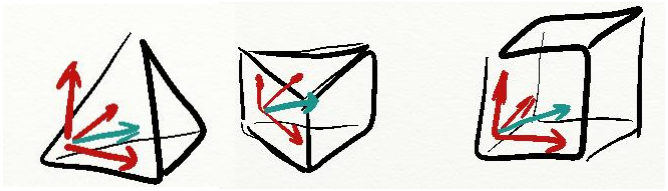
History#6 (step8: 0-0.13):

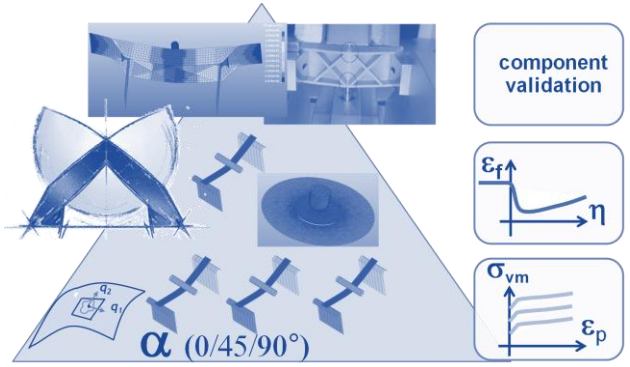
Fiber damage init.



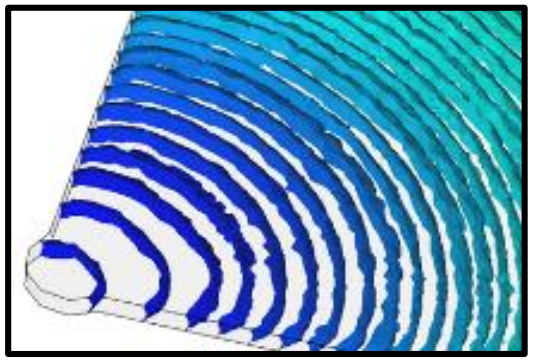
History#4 (step8: 0-0.81):

dm - matrix damage init.

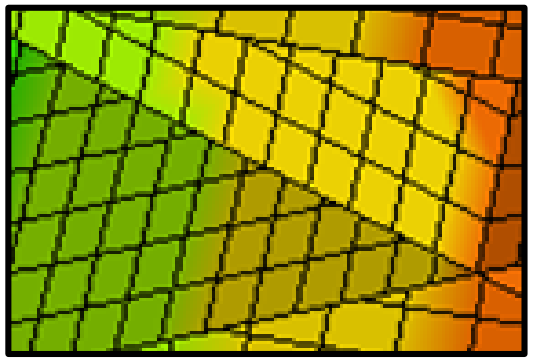




intelligent reliable solutions for plastics, composites, metals, foams, ...



FIBERMAP

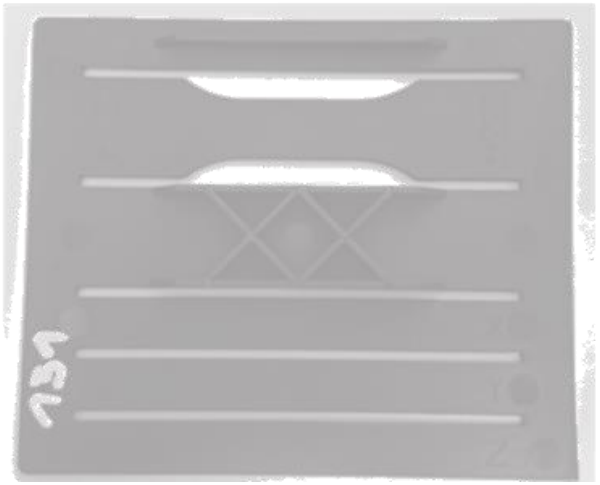


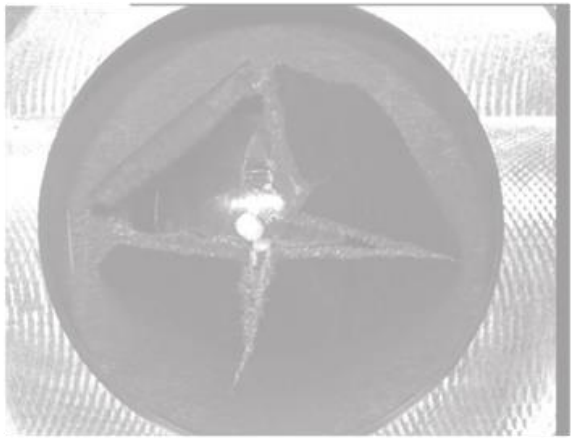
Process

MICROMEC

fully 3D anisotropic material cards

Structural

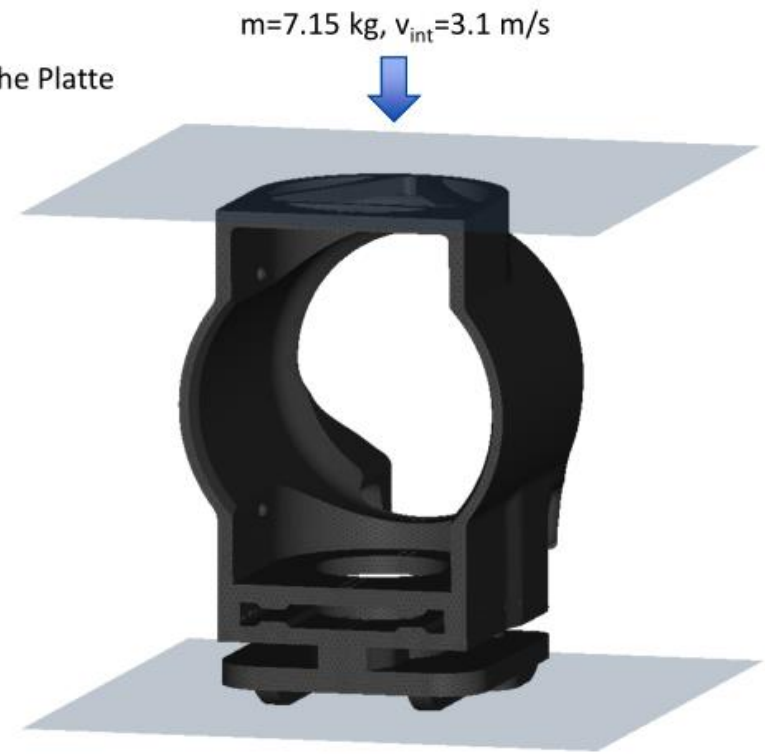




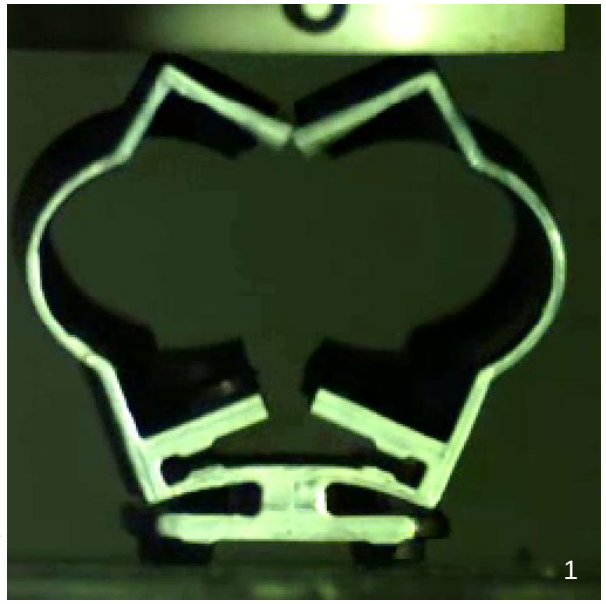
IMPETUS

VALIMAT

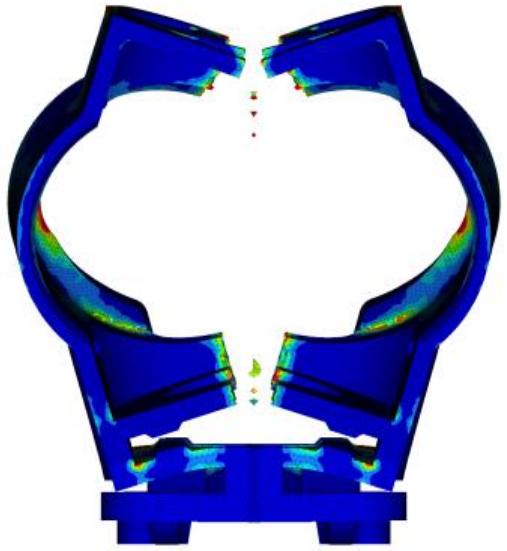
CASESTUDY - SLEEVE



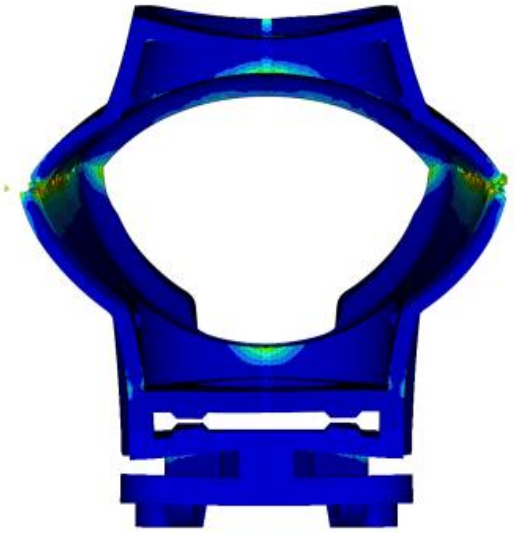
test



****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*