Modeling plastics in LS-DYNA

Part 1 - isotropic Modeling of Thermoplastics

Part 2 - anisotropic Modeling of Fiber-reinforced Thermoplastics

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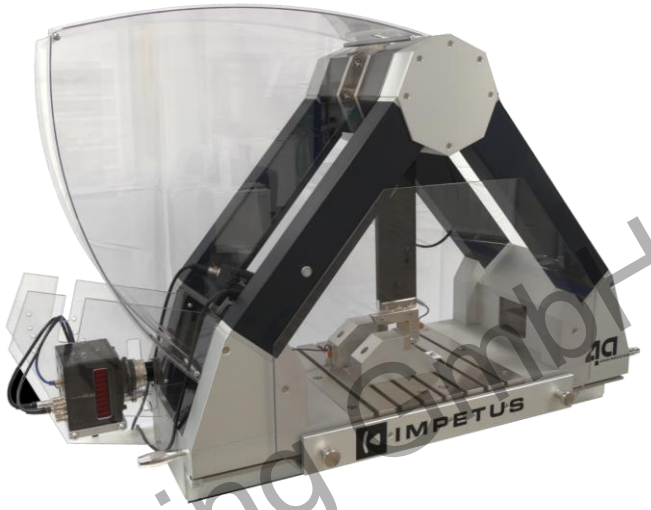
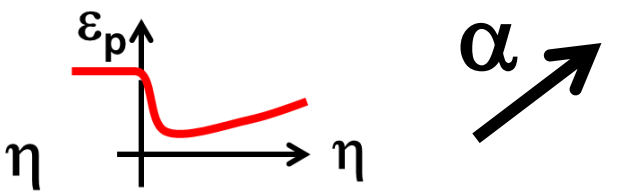
contact: peter.reithofer@4a.at

DYNAmore Express *19th & 26th June 2020*

Outline



IMPETUS VALIMAT



Hardening Triaxiality Damage/Failure Anisotropic

TECHNOLOGY
GmbH

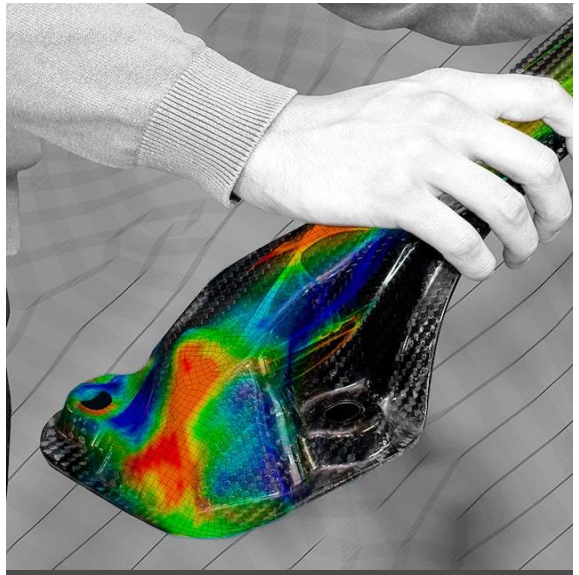
excellence in

plastics&simulation

testing equipment

lightweight products

4a business units

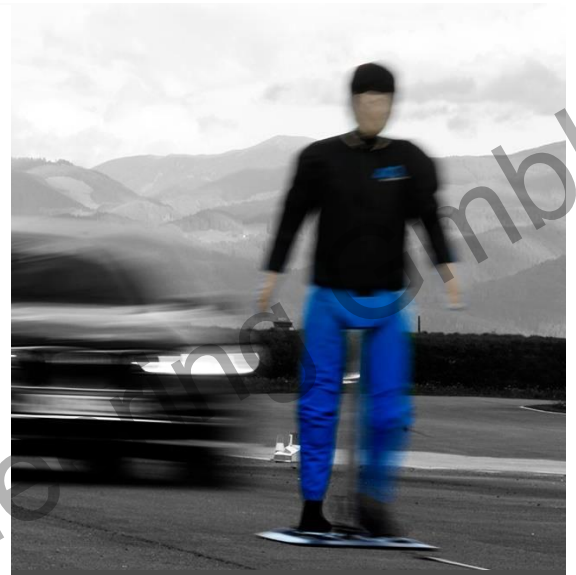


4a engineering

Engineering and simulation for plastic products and composites

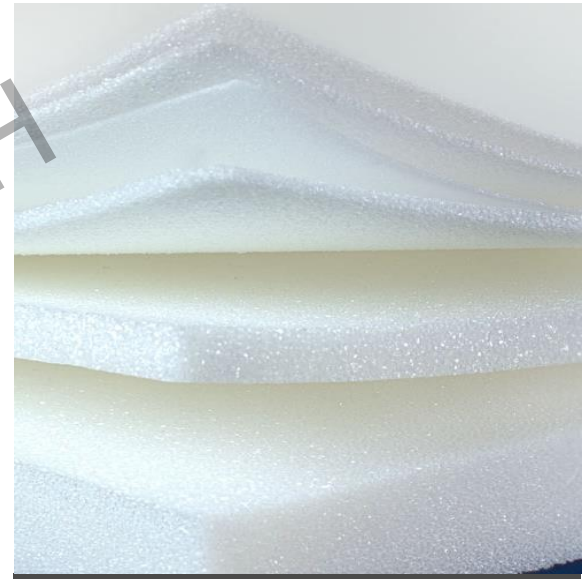
Impetus

Testing equipment generating material data for the dynamic simulation of plastics



4activeSystems

Dummies and testing facilities for active vehicle safety

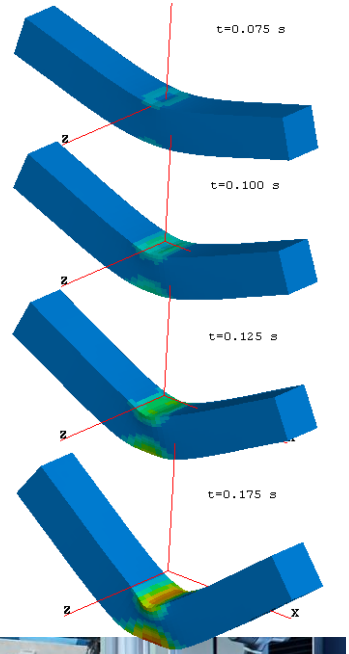


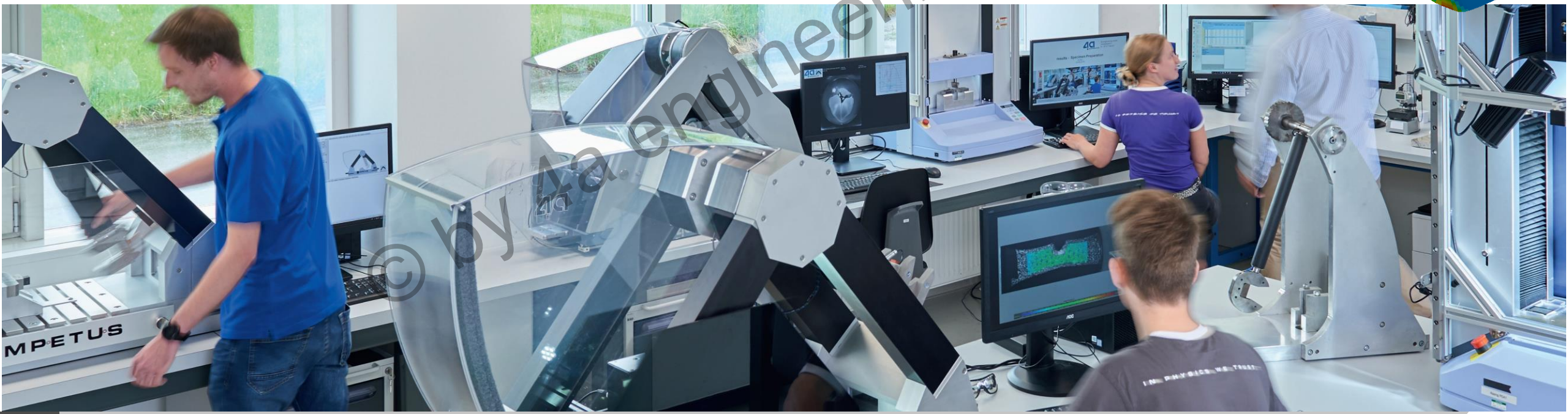
4a manufacturing

Specialized thin foams and multi layer materials

Material characterization - services

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



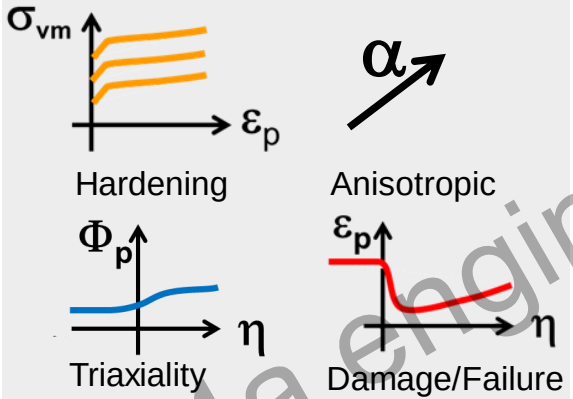


Intelligent reliable solutions for plastics, composites, metals, foams, ...

IMPETUS

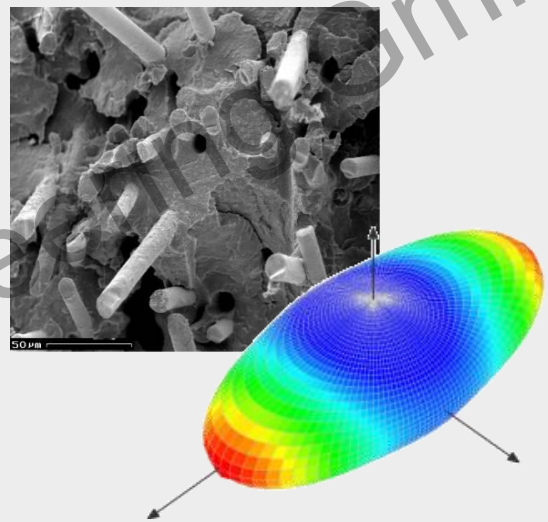
efficient
dynamic testing

VALIMAT



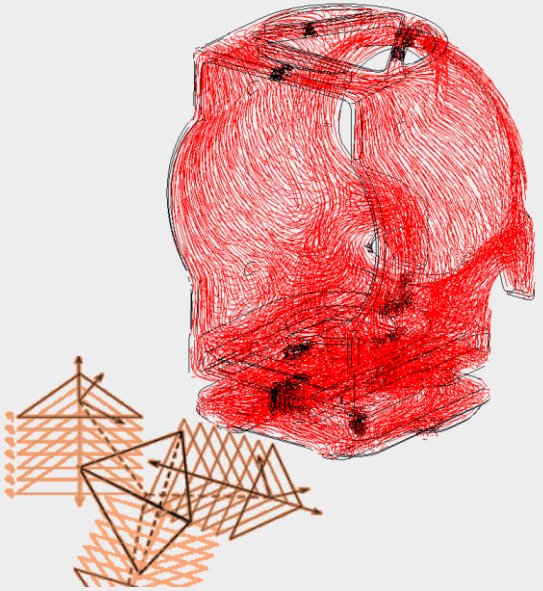
from test to validated
material cards

MICROMEC



3D anisotropic
material cards

FIBERMAP



individual mapping
process information

4a summer-school - webinar and training
Material characterization with VALIMAT® and IMPETUS®

SAVE THE DATE

The webinars will be completely free of charge and will be held from 9 - 11 a.m. CET
https://www.4a-engineering.at/news

1st week - Introduction and outlook

07. July - Introduction to VALIMAT®
from test to material card

08. July - Efficient dynamic testing with IMPETUS®

09. July - Material card generation: vonMises plasticity (**MAT_024*), simple failure, setting up our Autofit

10. July - Summary: Lessons learned, outlook and upcoming feature

2nd week - Advanced topics

14. July - Evaluating and checking test data - interpretation of typical results

15. July - Material card generation: general yield surface (*MAT_187) and other material models, failure approaches and comprehensive Autofit setup

16. July - Material card generation: Fiber reinforced plastics and their modelling approach: an extensive guide

17. July - Python: a powerful tool with VALIMAT®, user defined material cards/specimen,

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

IMPETUS

VALIMAT

MICROMEC

FIBERMAP

Foams

Thermoplastics

Fiber reinforced Plastics (SFRT & LFRT)

Composites (Carbon)

Metals

efficient
dynamic testing

from test to validated
material cards

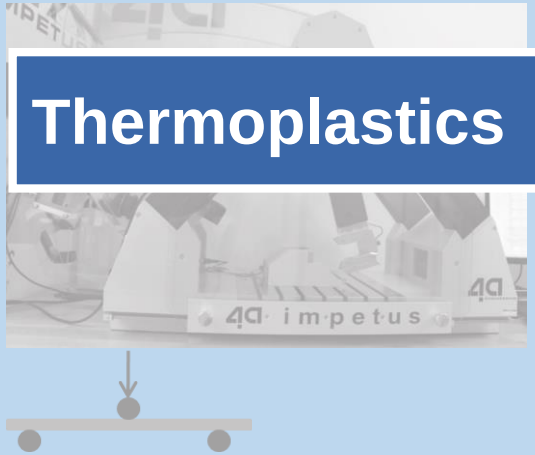
3D anisotropic
material cards

individual mapping
process information

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

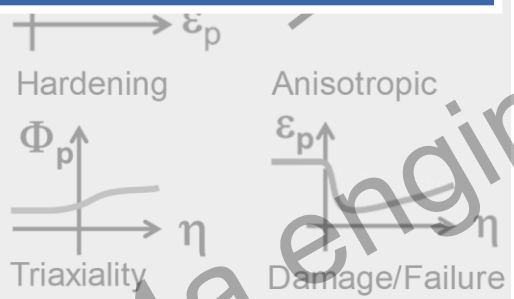
Thermoplastics

IMPETUS



efficient
dynamic testing

VALIMAT

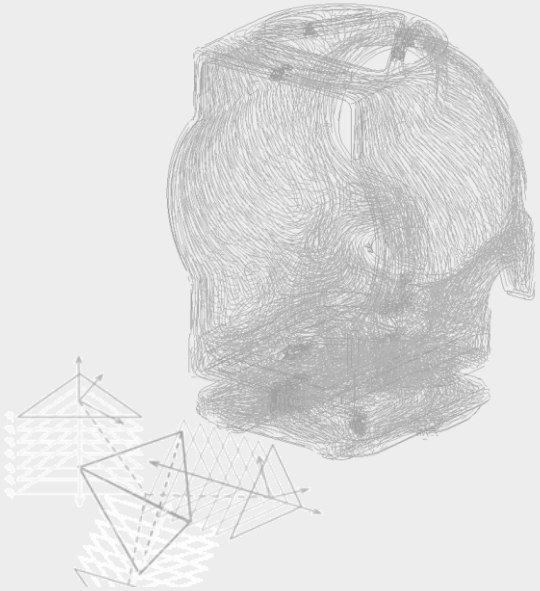


from test to validated
material cards

MICROMEC

3D anisotropic
material cards

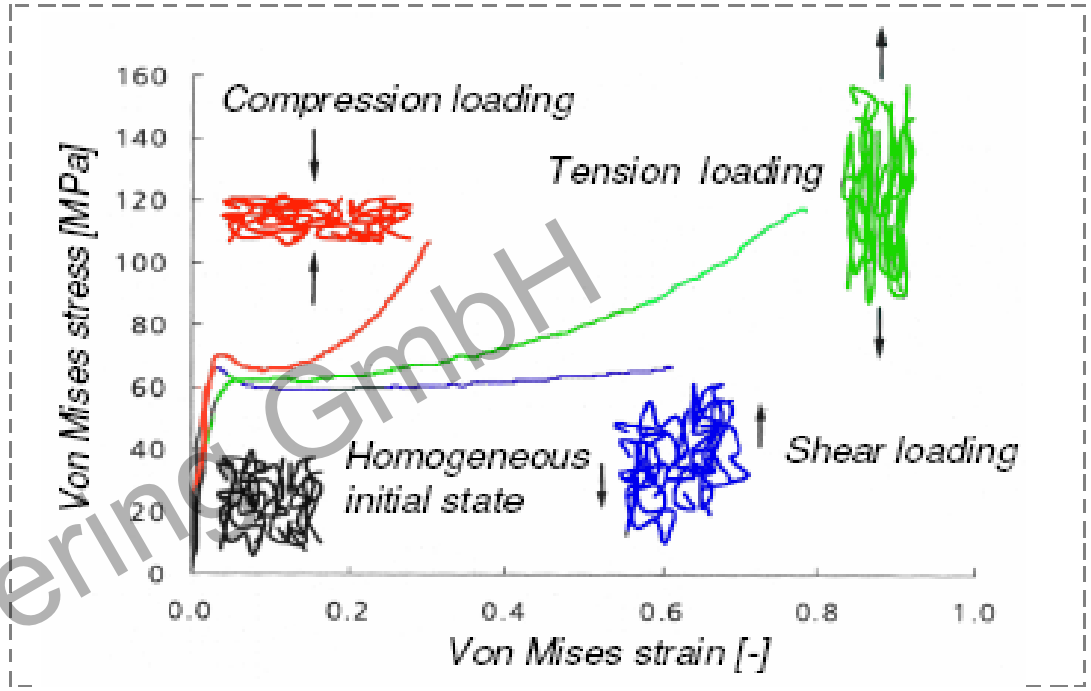
FIBERMAP



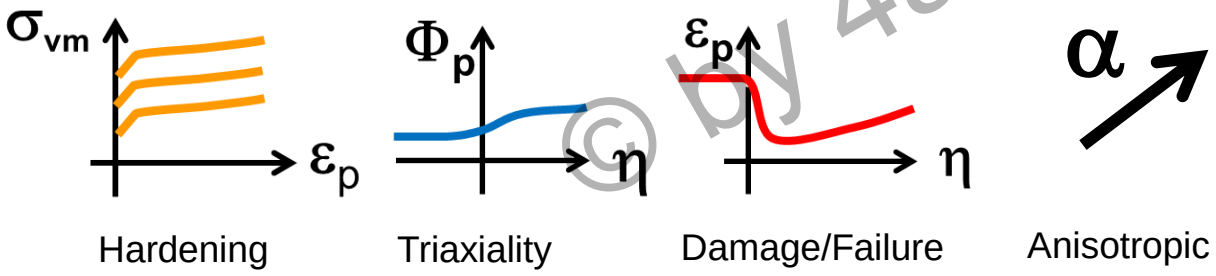
individual mapping
process information

Thermoplastic materials

- Motivation
- Material behavior
- Material characterization
  - IMPETUS™ - dynamic impact tensile testing
  - typical test results PP T10
- Material and failure models
- First validation results



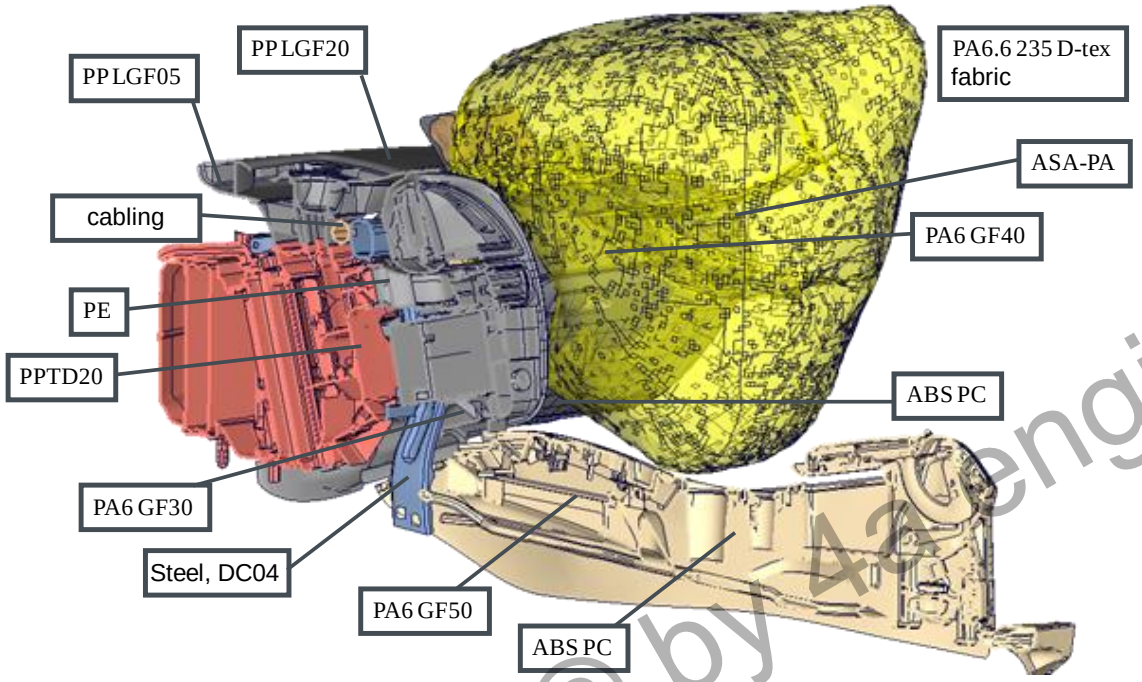
Source: Mechanik der Kunststoffe *W. Retting, Hanser Verlag 1991*



Hardening | Triaxiality | Damage/Failure | Anisotropic

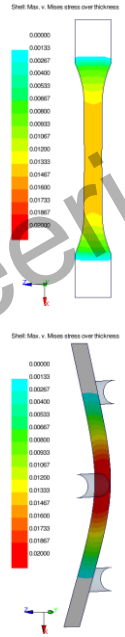
Motivation

material variety

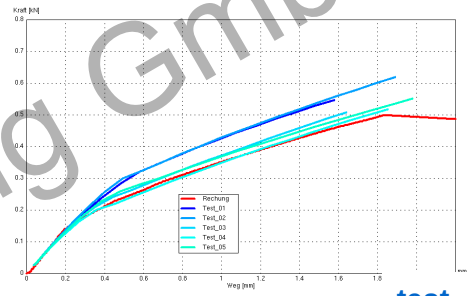


Source: R. Luijkx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG,* 4a Technologietag 2010

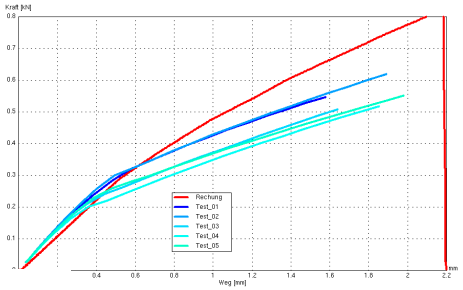
bending load case



original test curve tension

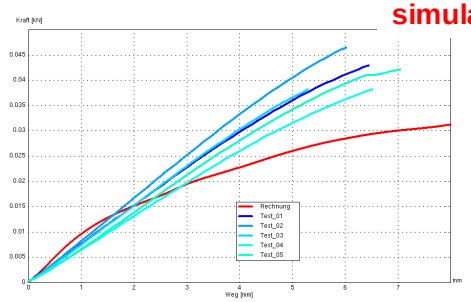


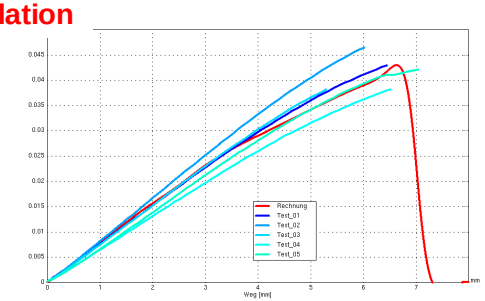
scaling 1.25



test

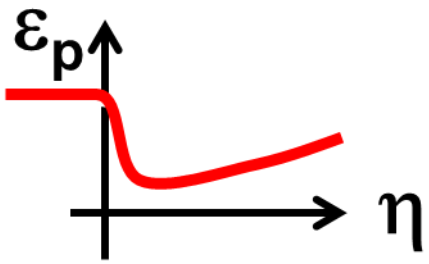
simulation

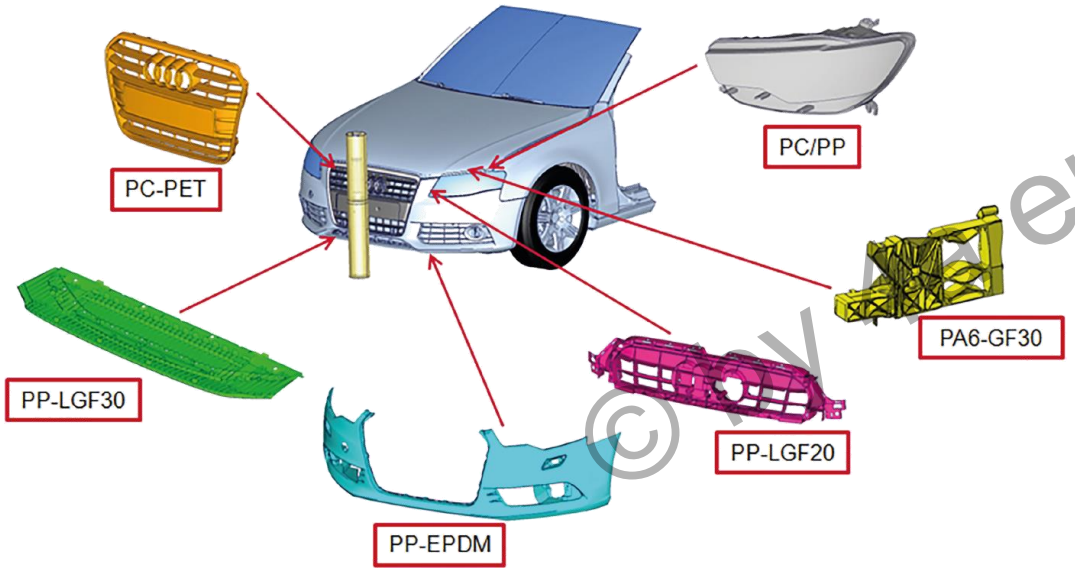


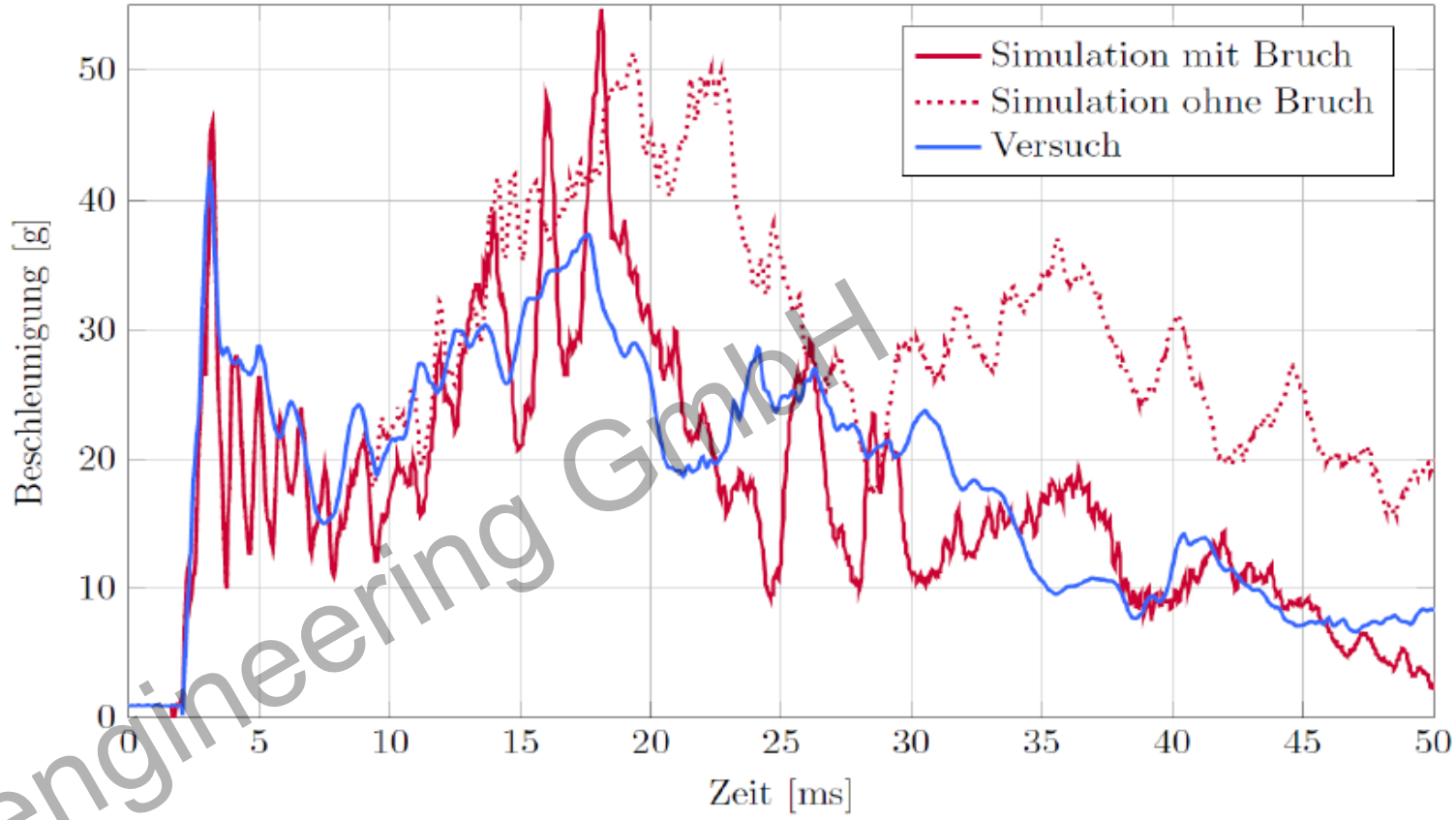


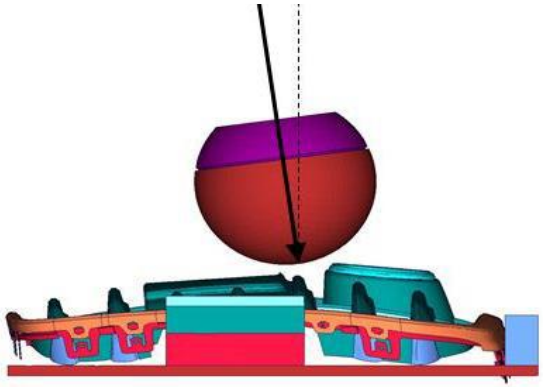
Motivation

Damage/Failure





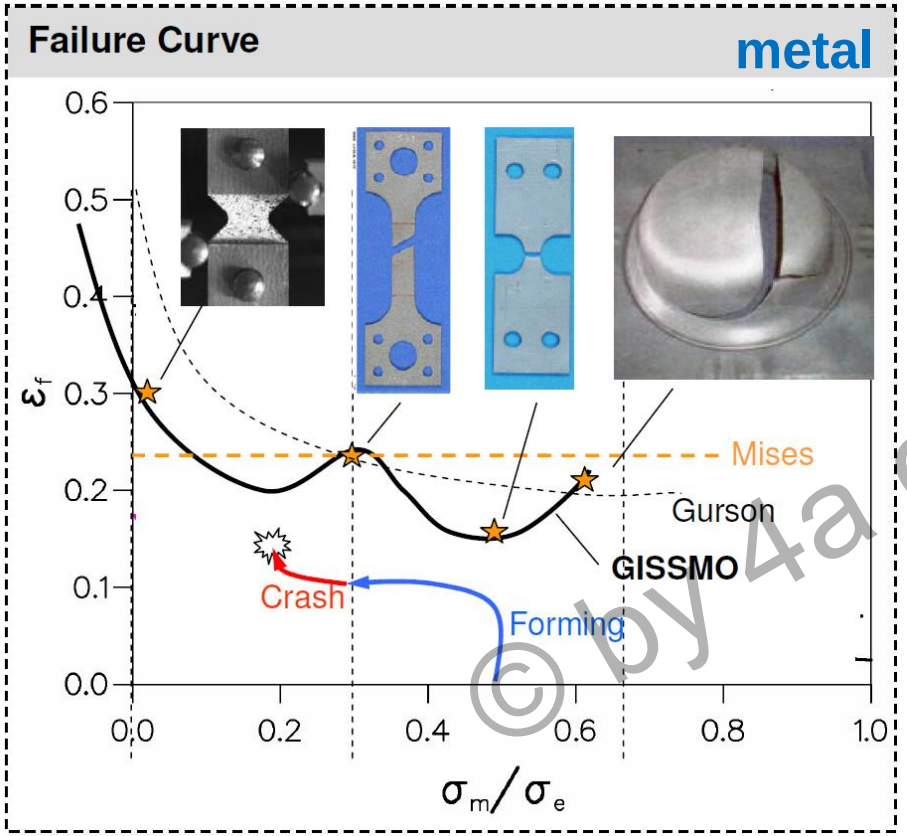




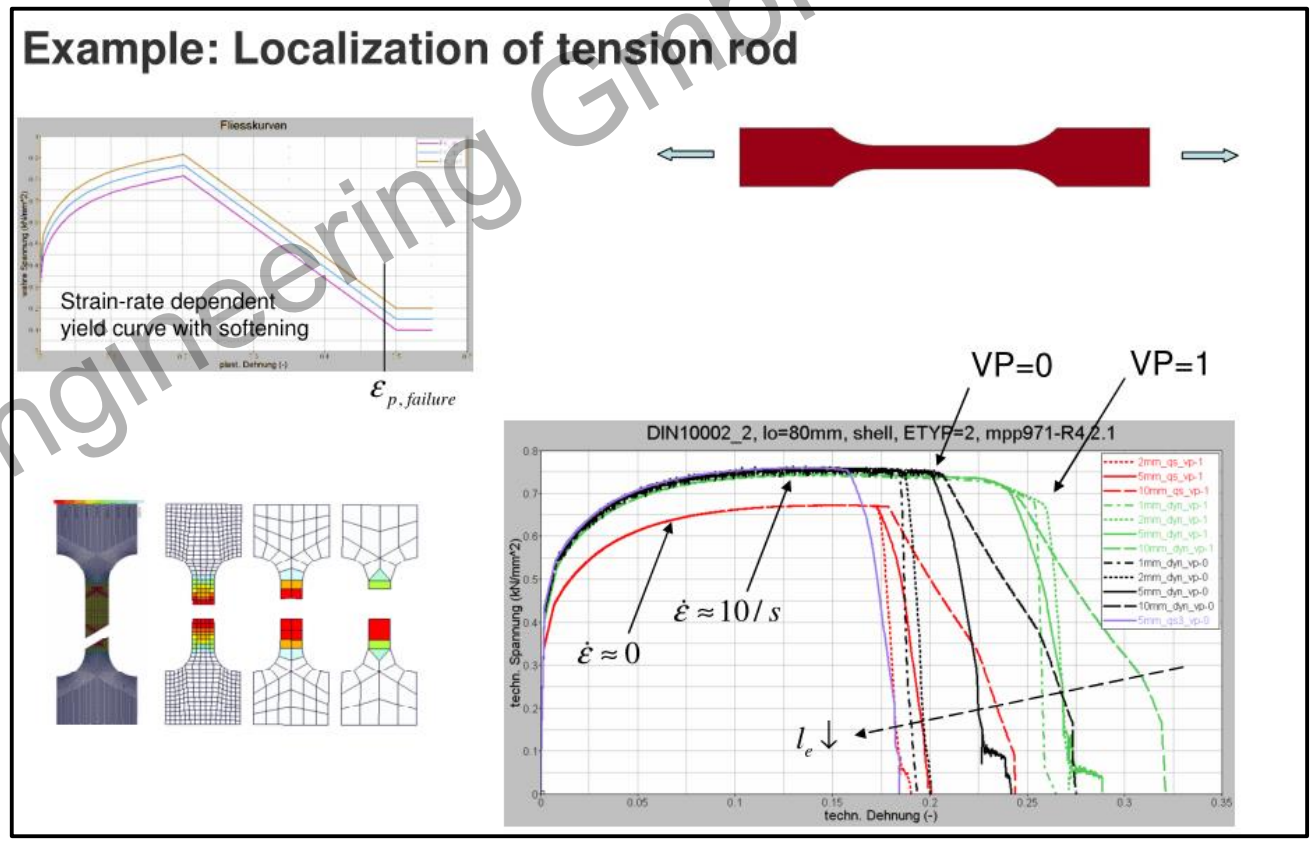
Source: H. Staack, Audi AG: *Anforderungsgerechte Material- und Bruchmodellierung für die Fahrzeugsicherheit*, TT16 Schladming

Motivation

- typical customers request for plastics
  → **GISSMO with *MAT_024**

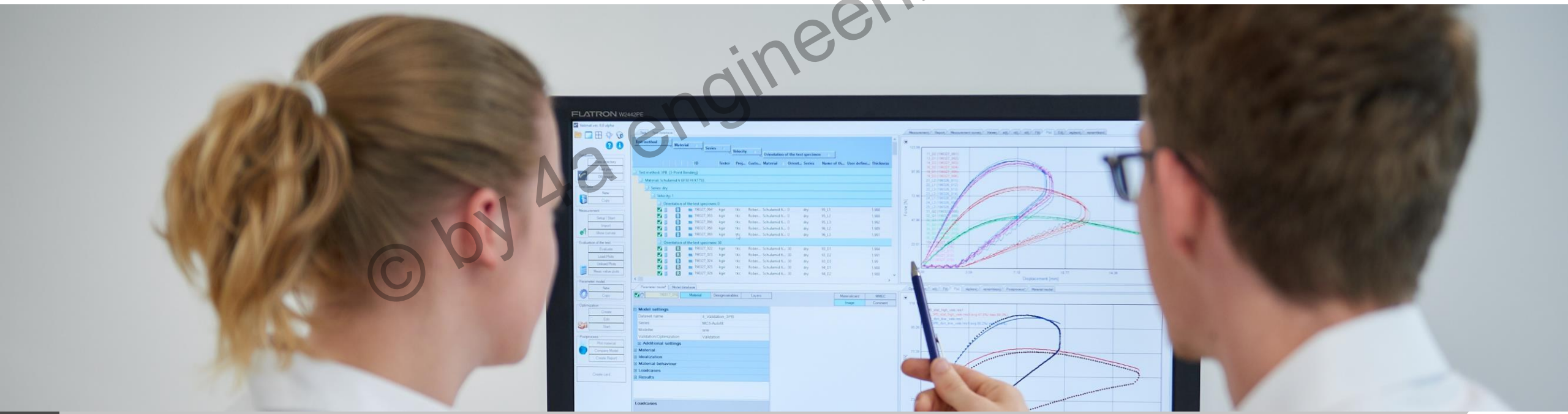


source: F. Neukamm – *GISSMO – Material modeling with a sophisticated failure criteria*, LS-Dyna Developer Forum 2011, Stuttgart



source: Damage and Failure Models in LS-DYNA; M. Feucht; A. Haufe ;(2009)

Available material and failure models!



Material Model Selection

LS-DYNA has many material models implemented
currently 265 materials (01.07.2020)
most of them won't fit in our use case

The most used material model is **`*MAT_024`**.

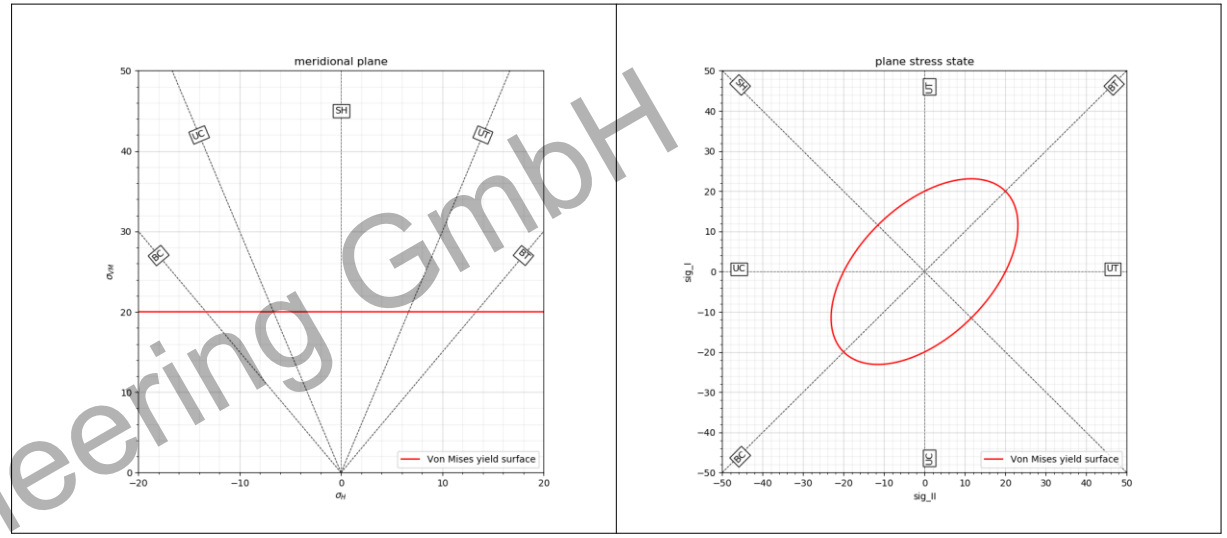
Other interesting material models for thermoplastic polymers are **`*MAT_124`** and **`*MAT_187`**.

Table: number of available material models for subset of filters
http://www.lstc.com/dynamat/ (01.7.2020)

Element	Material family	Nr. of material models
Any element	Any family	265
Shell element	Any family	23
Solid element	Any family	179
Any element	Plastics	33
Shell element	Plastics	23
Solid element	Plastics	29

Commonly Used Material Models For Plastics

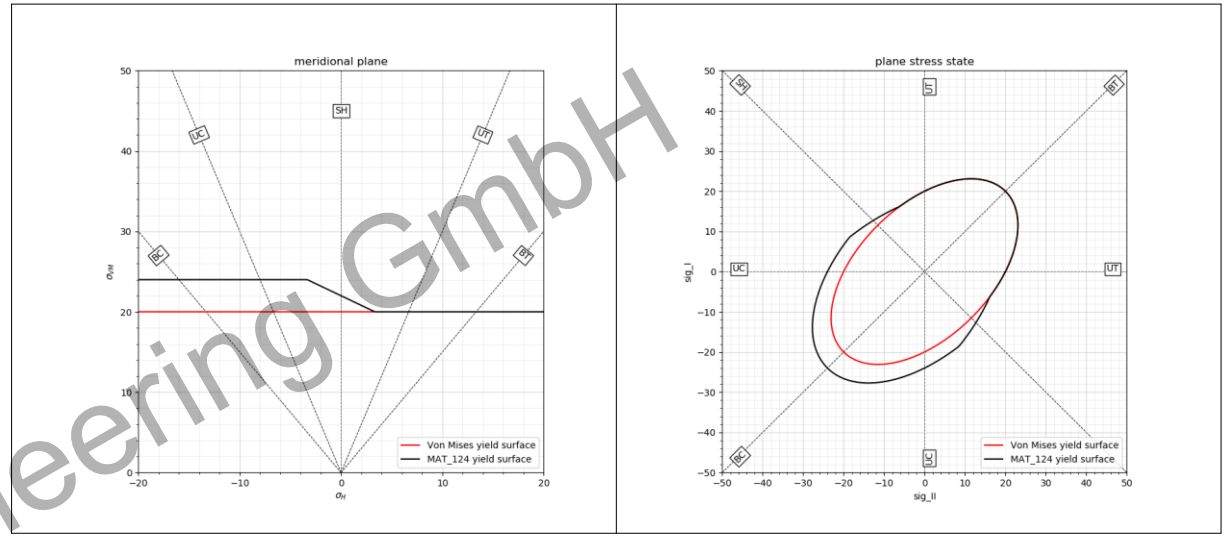
- ****MAT_024*** **- *The workhorse***
  (MAT_081*, **MAT_089*, **MAT_123*, …)**



Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
***MAT_024**	von Mises	✘	✓	✘	0.5

Commonly Used Material Models For Plastics

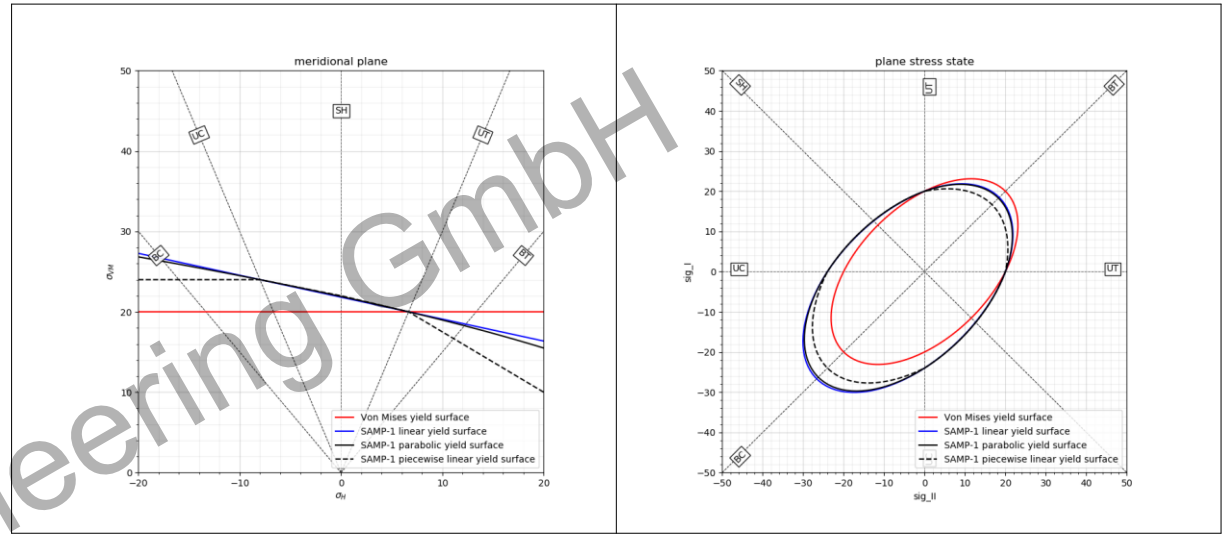
- ****MAT_024*** **- The workhorse**
  (MAT_081*, **MAT_089*, **MAT_123*, …)**
- ****MAT_124*** **- The hidden**



Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
***MAT_024**	von Mises	✘	✓	✘	0.5
***MAT_124**	2x von Mises	✓ Pronyseries	✓	✓	0.5

Commonly Used Material Models For Plastics

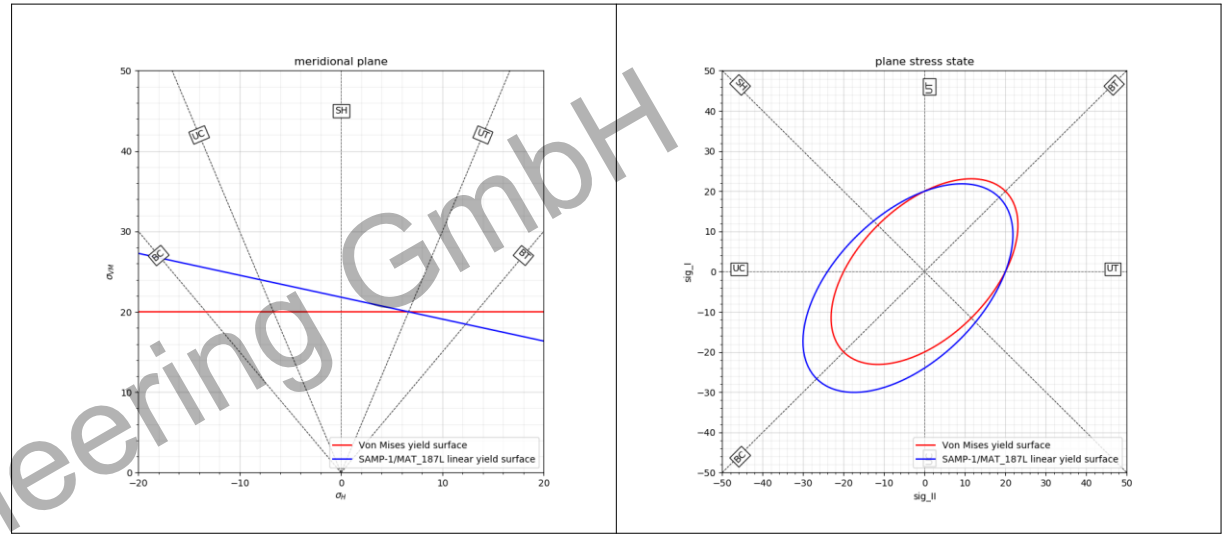
- ***MAT_024** - The workhorse*
  (***MAT_081**, **MAT_089**, **MAT_123**, …)*
- ***MAT_124** - The hidden*
- ***MAT_187** - The plastic expert*



Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
***MAT_024**	von Mises	✗	✓	✗	0.5
***MAT_124**	2x von Mises	✓ Pronyseries	✓	✓	0.5
***MAT_187**	linear; parabolic; piecewise linear	✓ $E(\dot{\varepsilon})$	✓	✓	✓ $\nu_p(\varepsilon)$

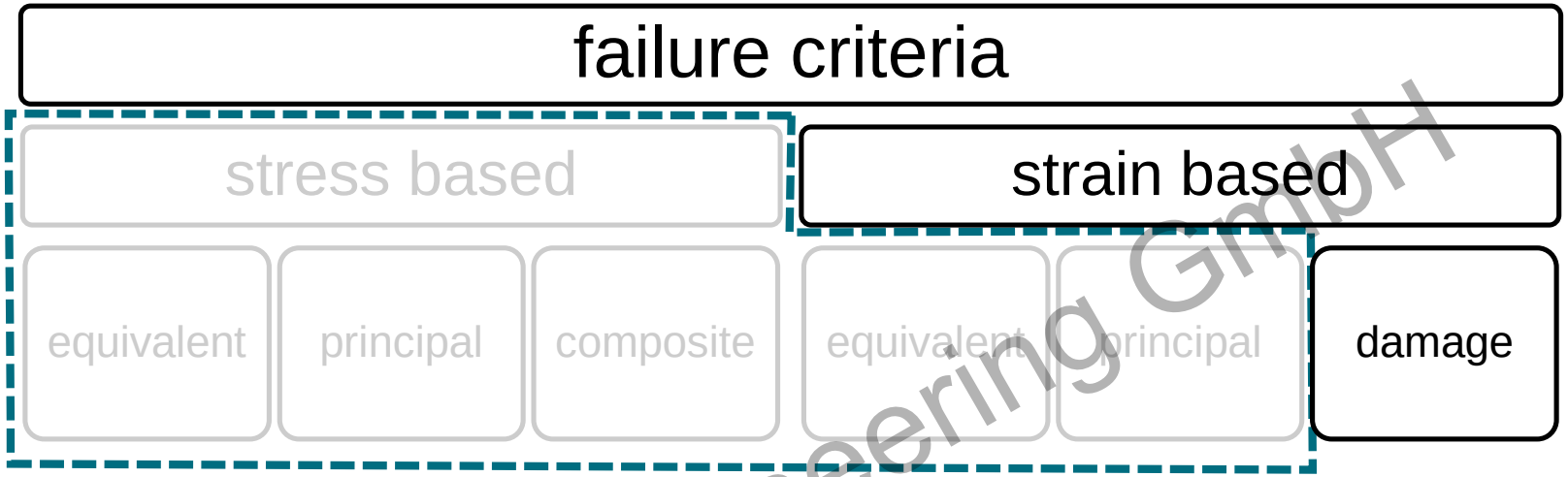
Commonly Used Material Models For Plastics

- ***MAT_024** - The workhorse*
  *(*MAT_081, *MAT_089, *MAT_123, …)*
- ***MAT_124** - The hidden*
- ***MAT_187** - The plastic expert*
- ***MAT_187L** – efficient version (R12)*



Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
***MAT_024**	von Mises	✗	✓	✗	0.5
***MAT_124**	2x von Mises	✓ Pronyseries	✓	✓	0.5
***MAT_187**	linear; parabolic; piecewise linear	✓ $E(\dot{\varepsilon})$	✓	✓	✓ $\nu_p(\varepsilon)$
***MAT_187L**	linear	✓ $E(\dot{\varepsilon})$	✓	✓	✓ $\nu_p(\varepsilon)$

Available failure models in LS-DYNA®



additional failure models

****MAT_ADD_EROSION***

strain damage based

- *before R11 optional DIEM / GISSMO*
- *since R11* ****MAT_ADD_DAMAGE_DIEM***
- *since R11* ****MAT_ADD_DAMAGE_GISSMO***

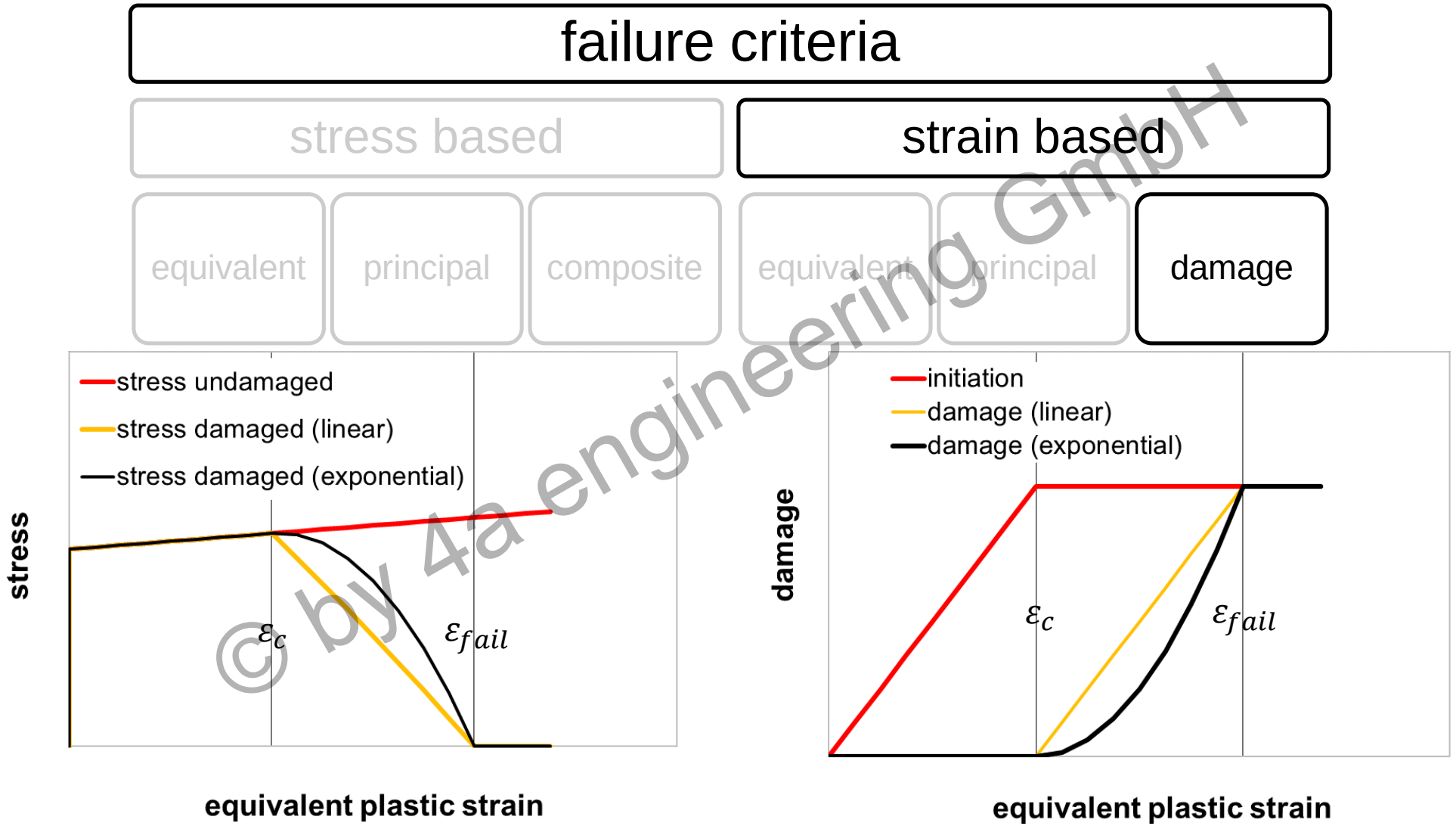
Included eq. pl. strain

****MAT_024***

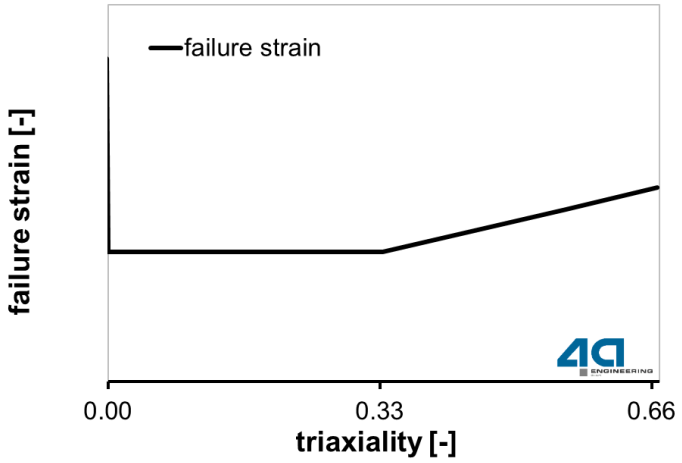
included damage model in

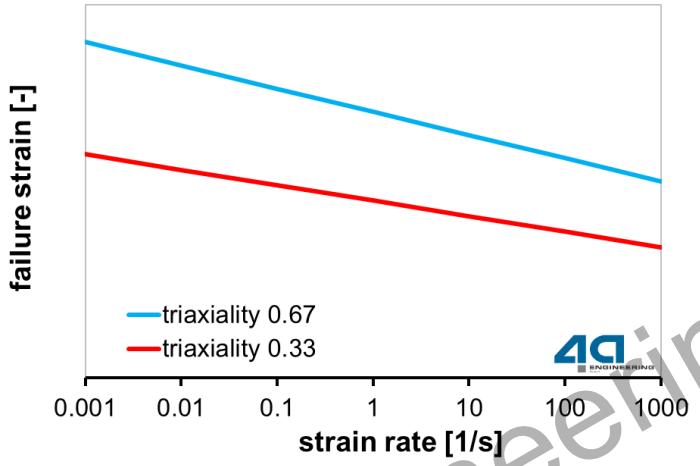
****MAT_SAMP-1(GISSMO like)***

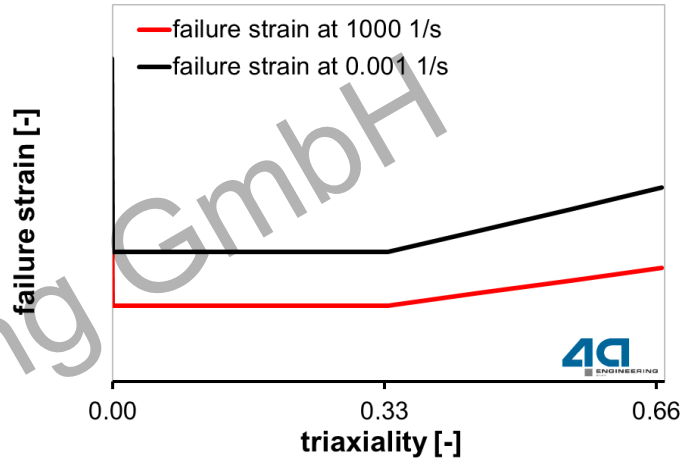
Available failure models – incremental damage formulation



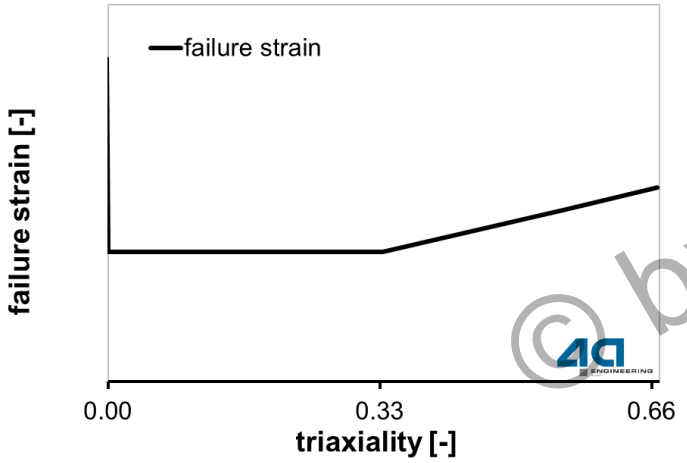
Comparison DIEM-GISSMO visualized

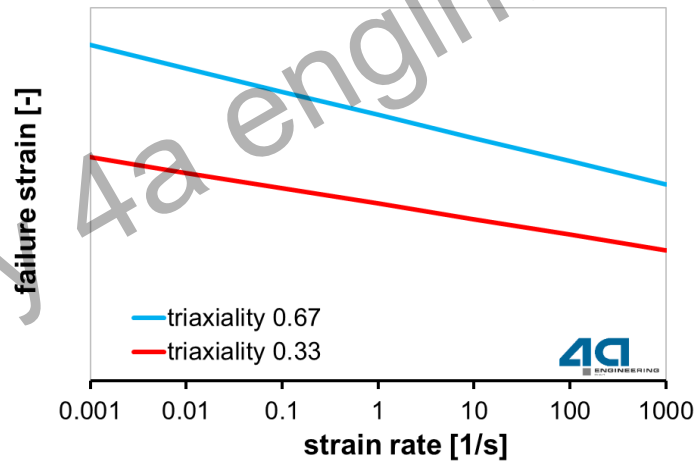


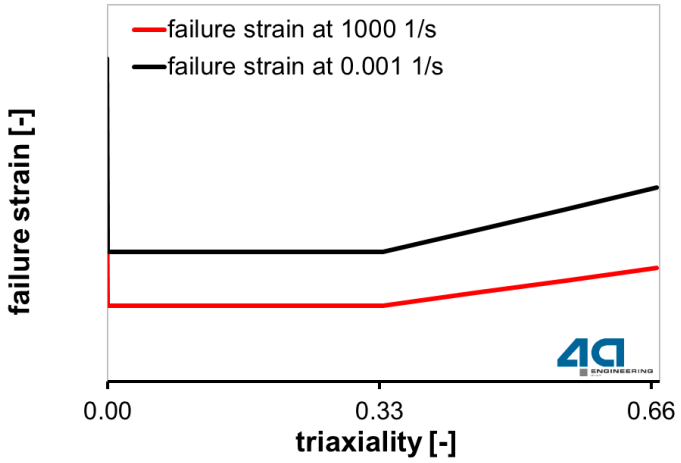




GISSMO

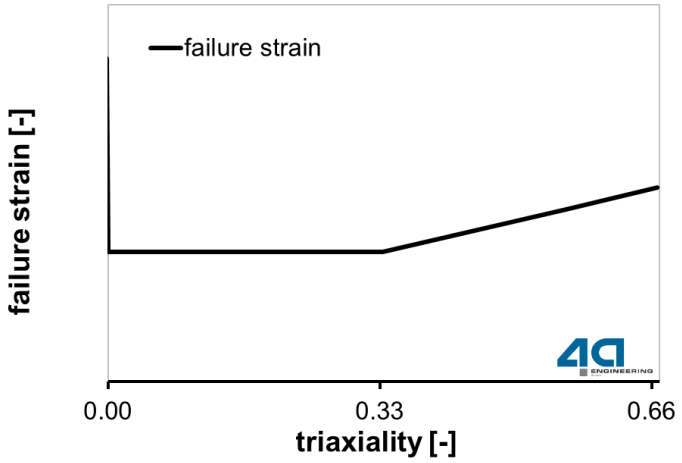


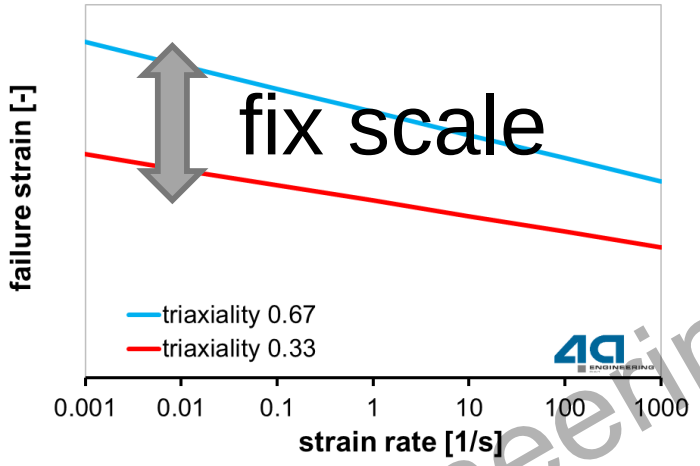


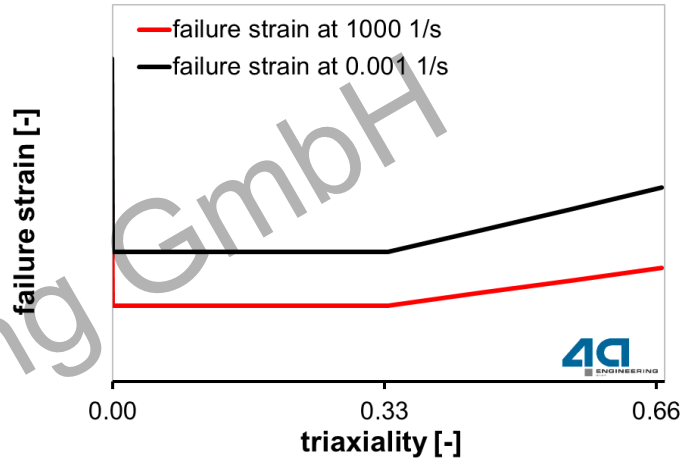


DIEM

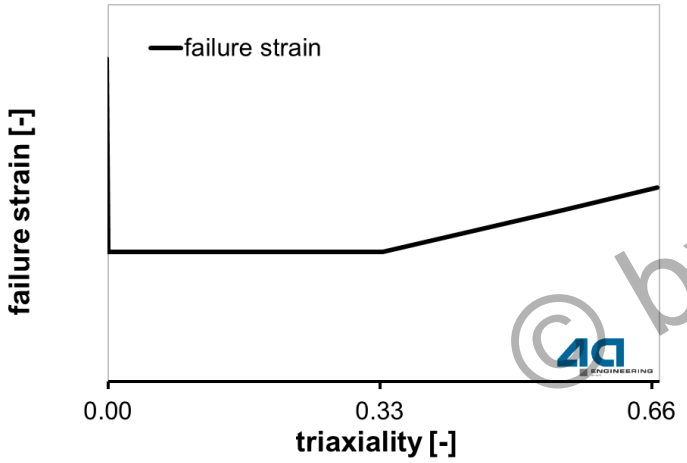
Comparison DIEM-GISSMO visualized

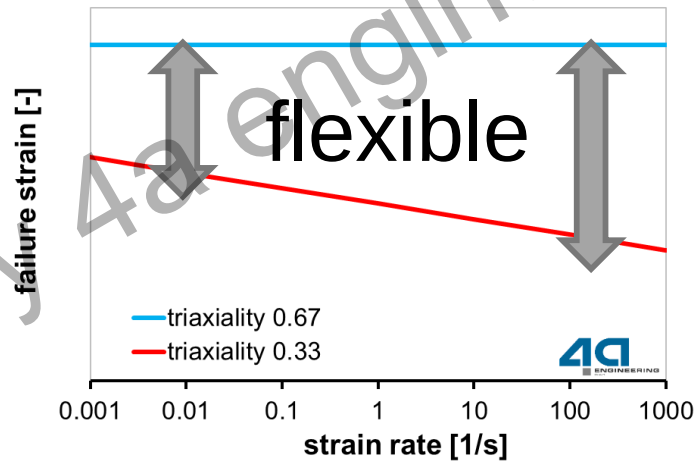


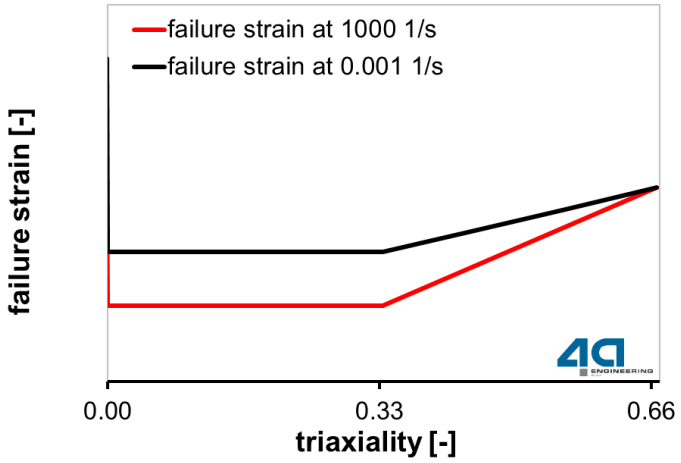




GISSMO







DIEM

Available failure models – typical curves

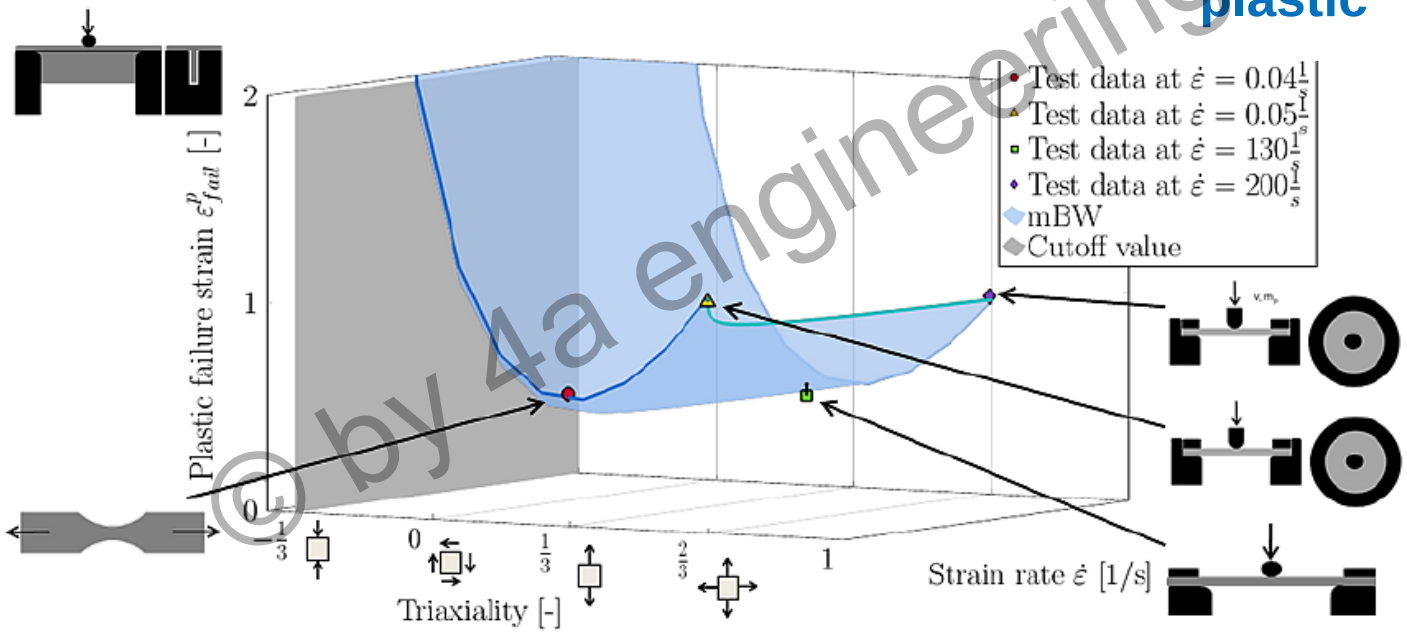
failure criteria

stress based

strain based

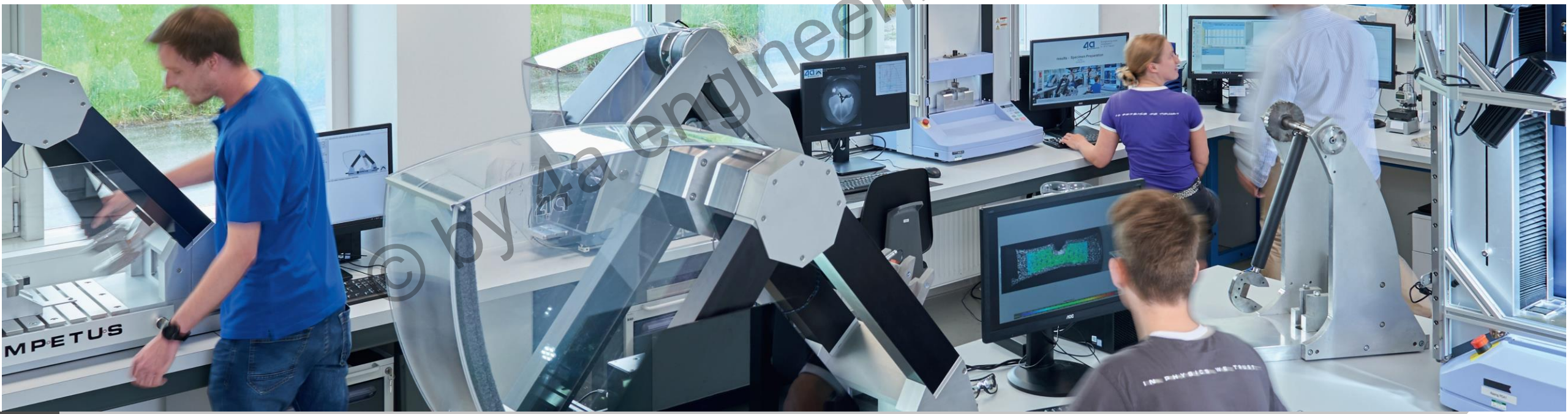
plastic

damage

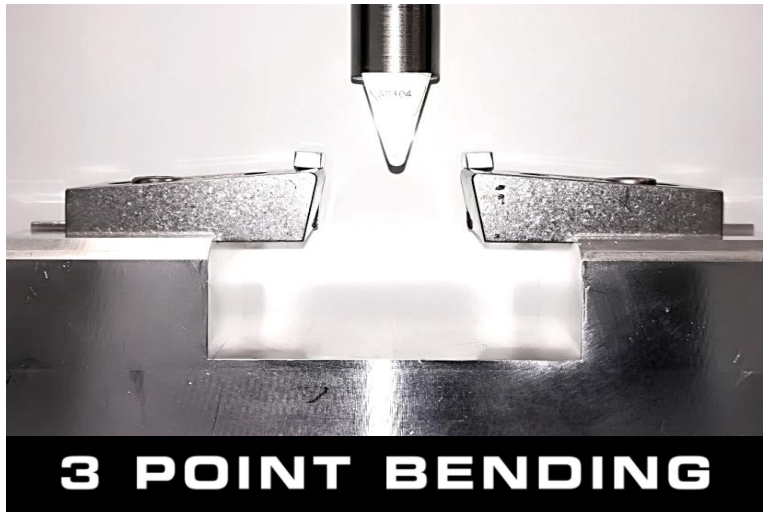


source: H. Staack, - *Application oriented failure modeling and characterization for polymers in automotive pedestrian protection*, COMPLAS 2015, Barcelona

Let‘s take a closer look on the plastic!



Static Testing



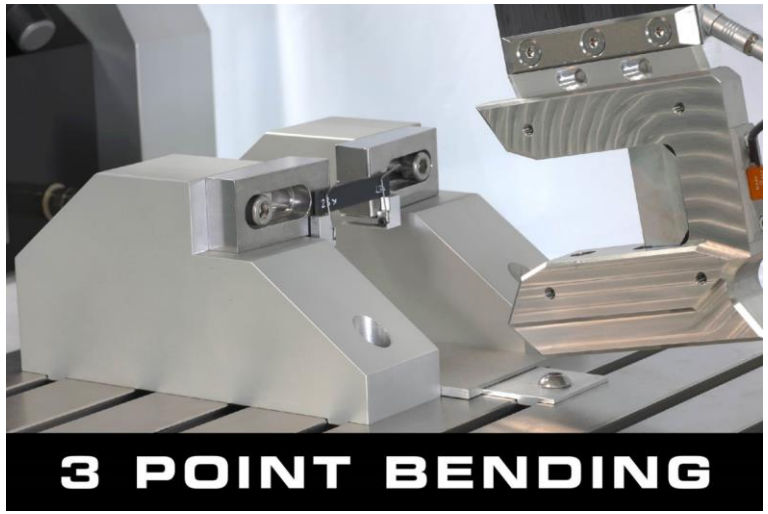
3 POINT BENDING

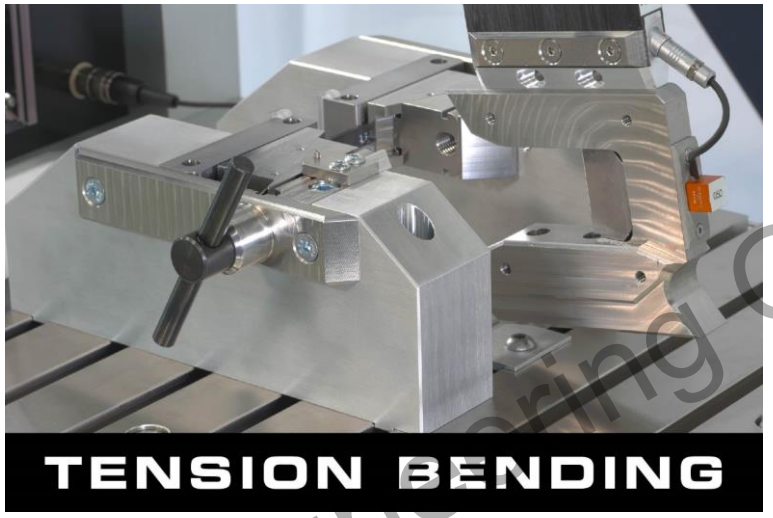
TENSION TEST

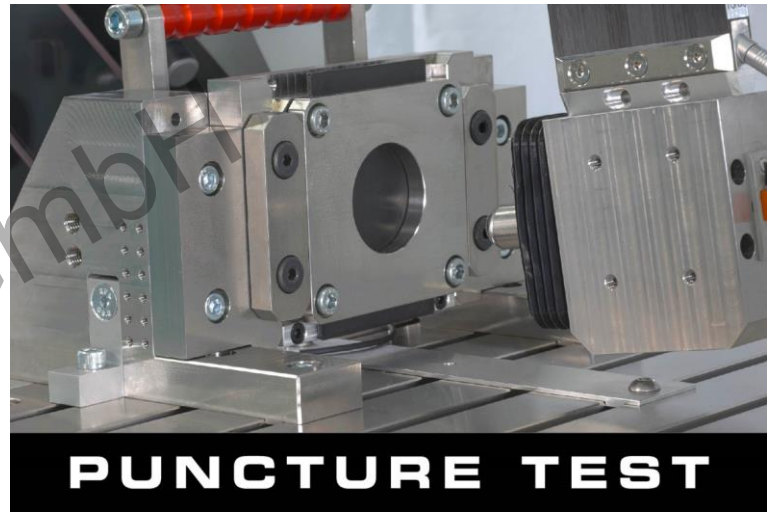
PUNCTURE TEST

static ~ 1mm/s

IMPETUS® - efficient dynamic testing



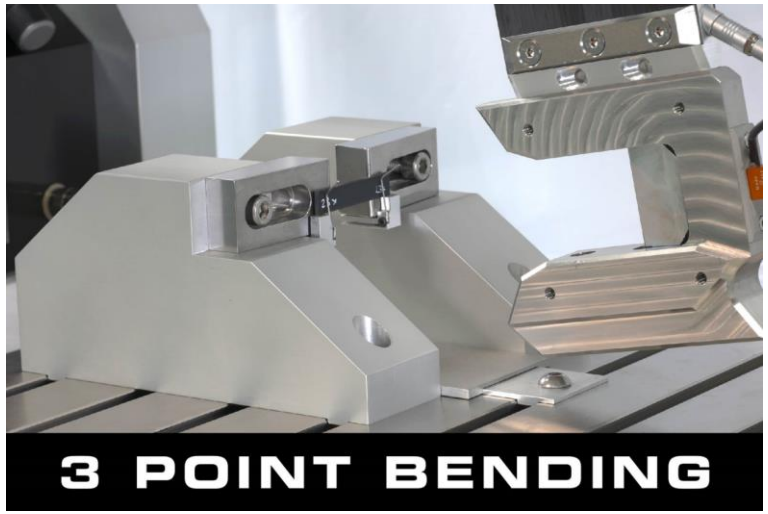


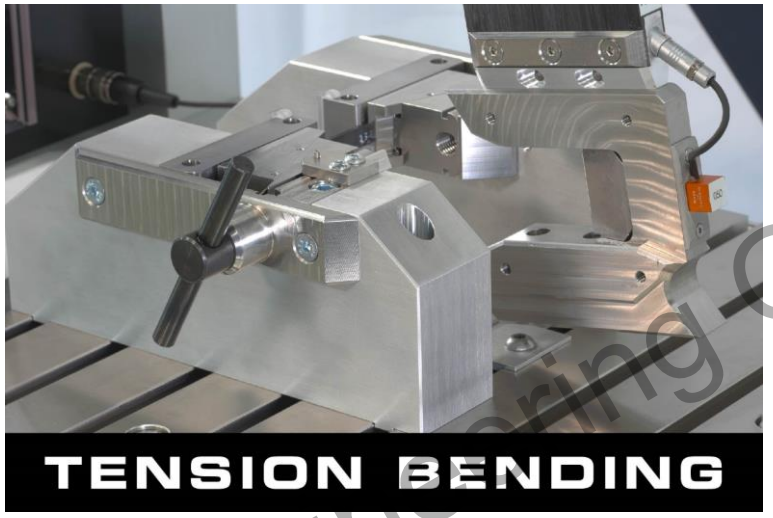


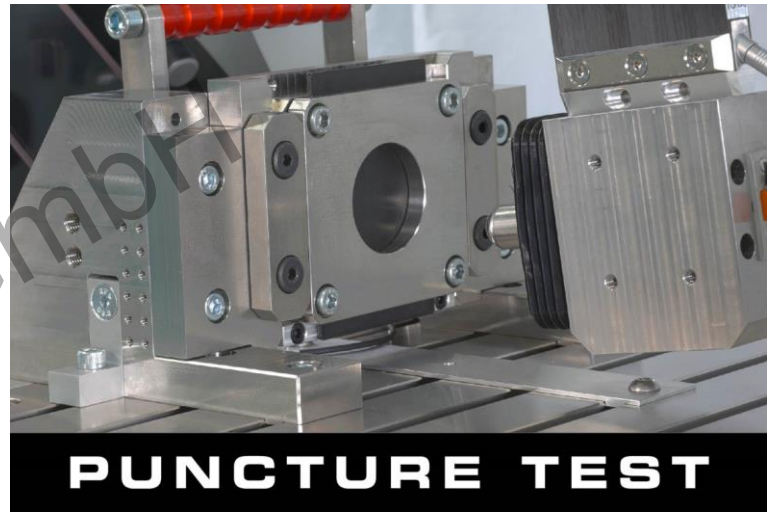
IMPETUS® ~ 3 m/s

YOUTUBE CHANNEL

IMPETUS® - efficient dynamic testing



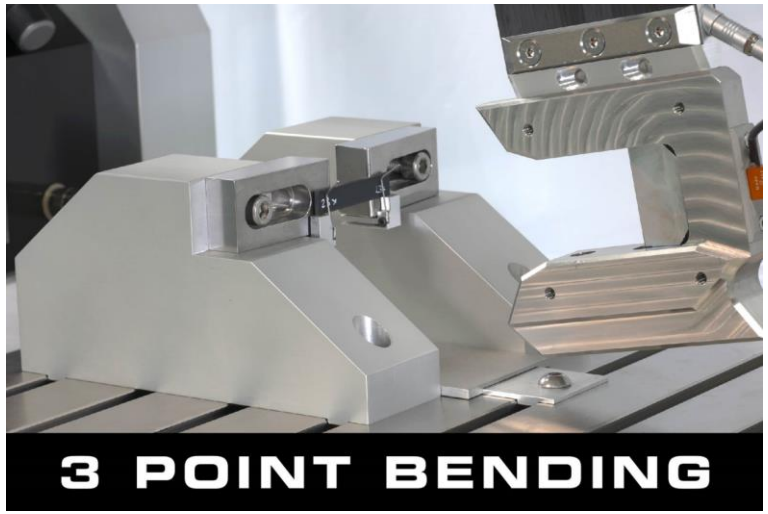


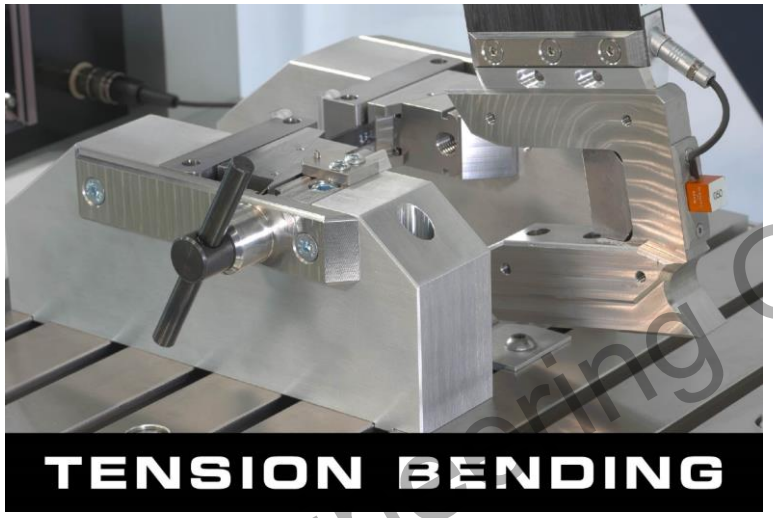


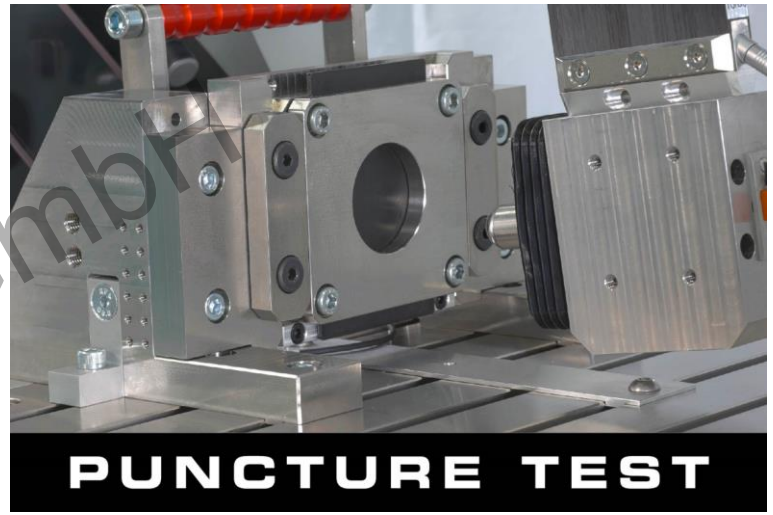
IMPETUS™ ~ 3 m/s

YOUTUBE CHANNEL

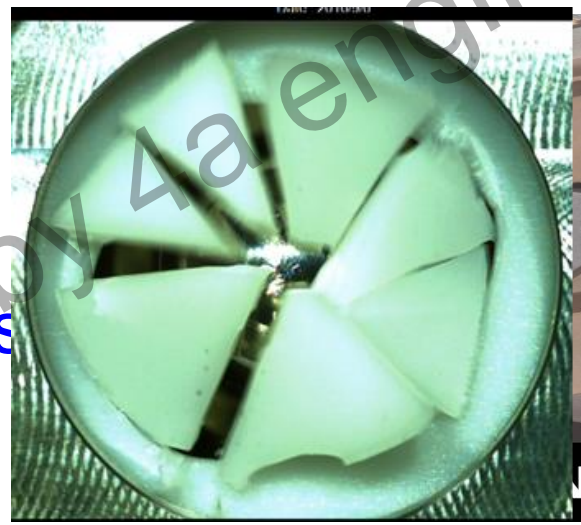
IMPETUS® - efficient dynamic testing

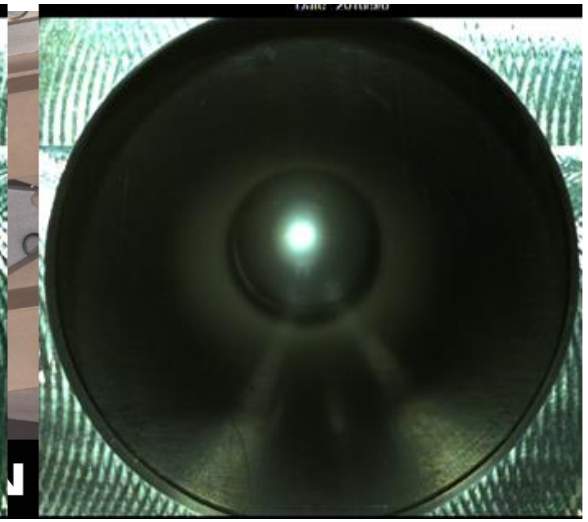


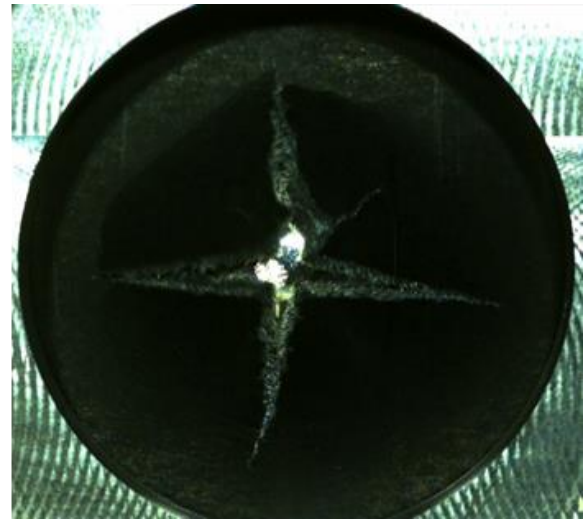




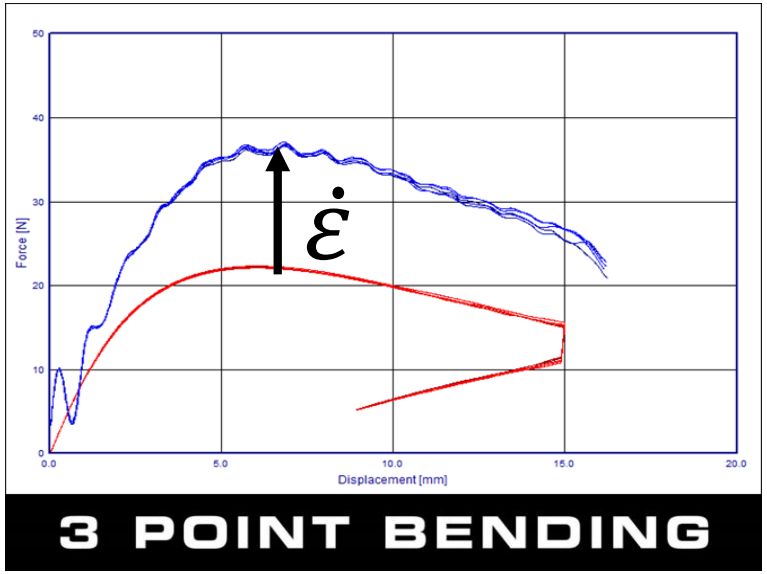
IMPETUS™ ~ 3 m/s



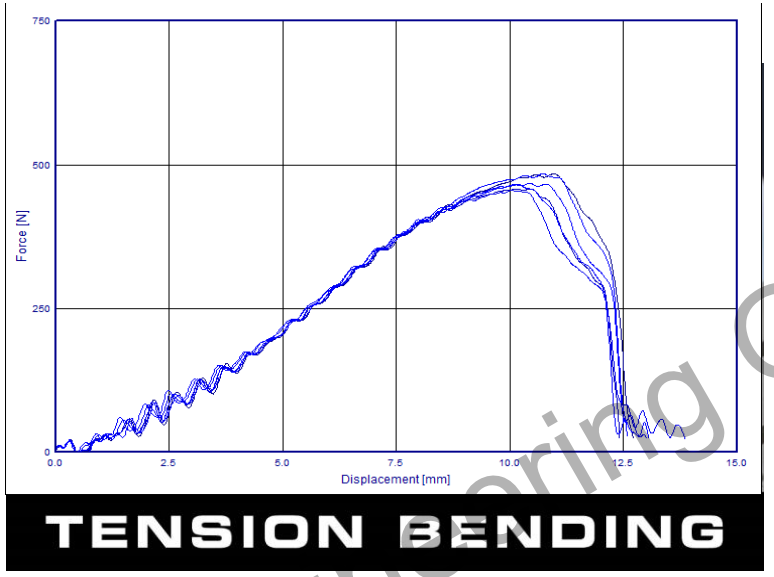




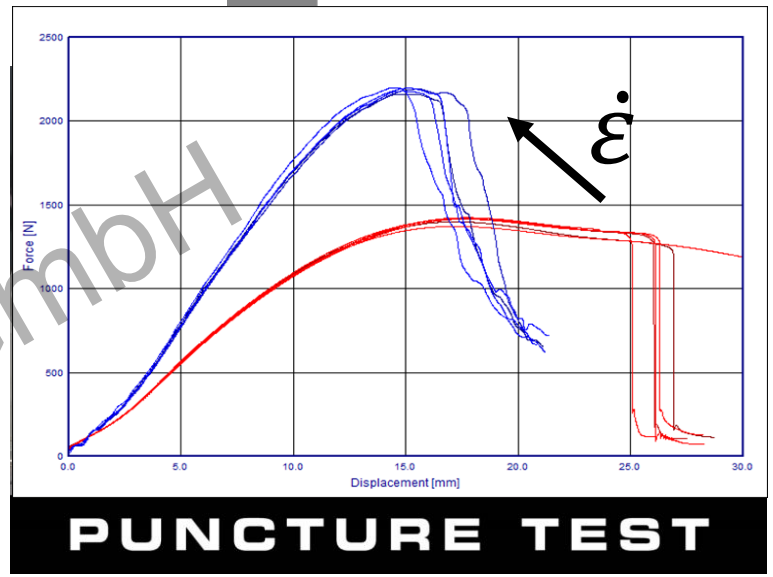
Measurement Results



3 POINT BENDING



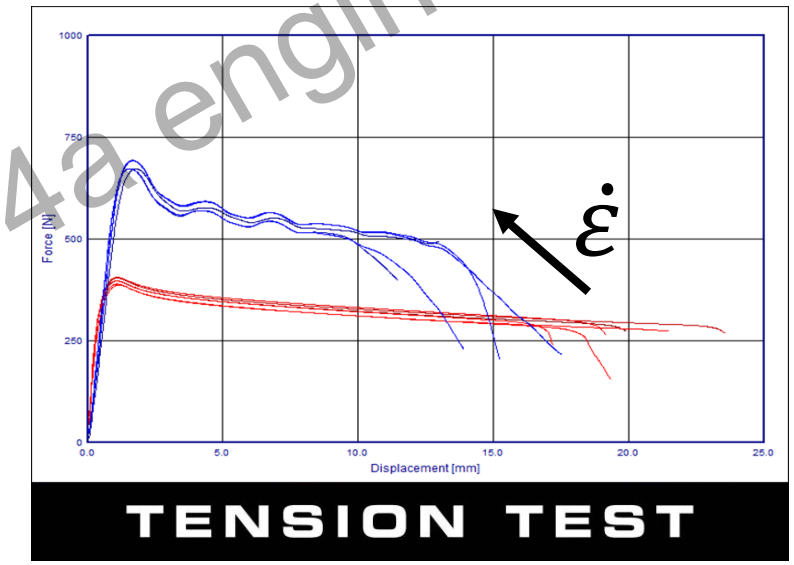
TENSION BENDING



PUNCTURE TEST

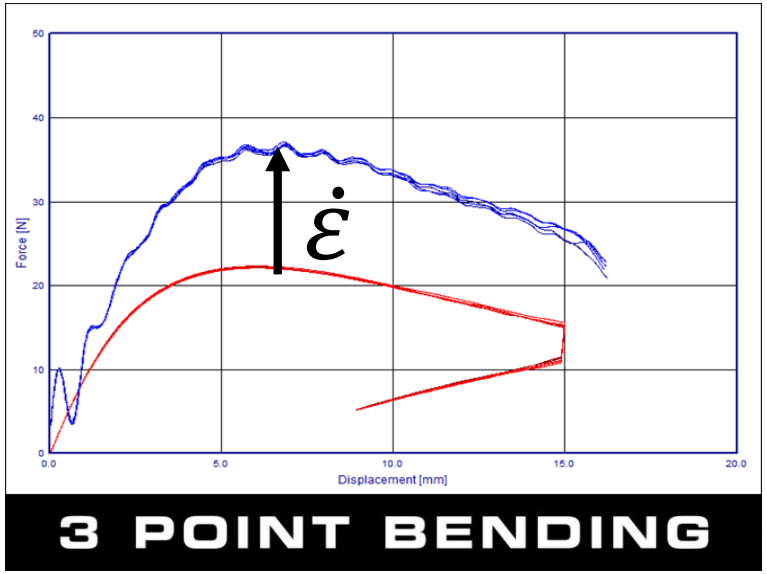
IMPETUS® ~ 3 m/s

static ~ 1mm/s

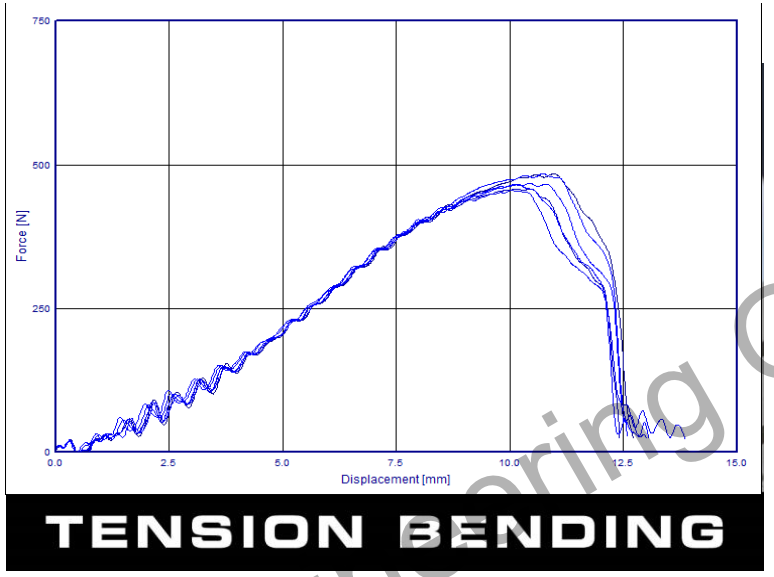


TENSION TEST

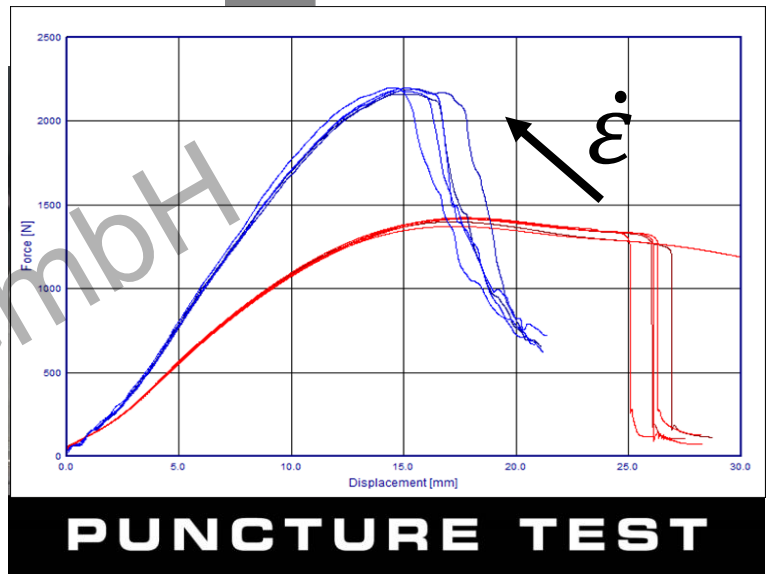
Measurement Results ➔ Material Model



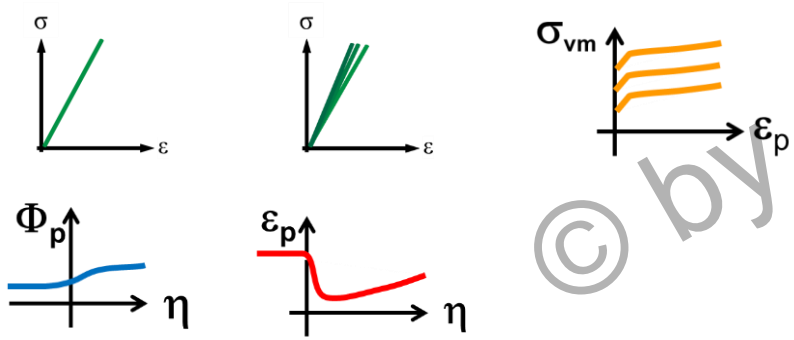
3 POINT BENDING

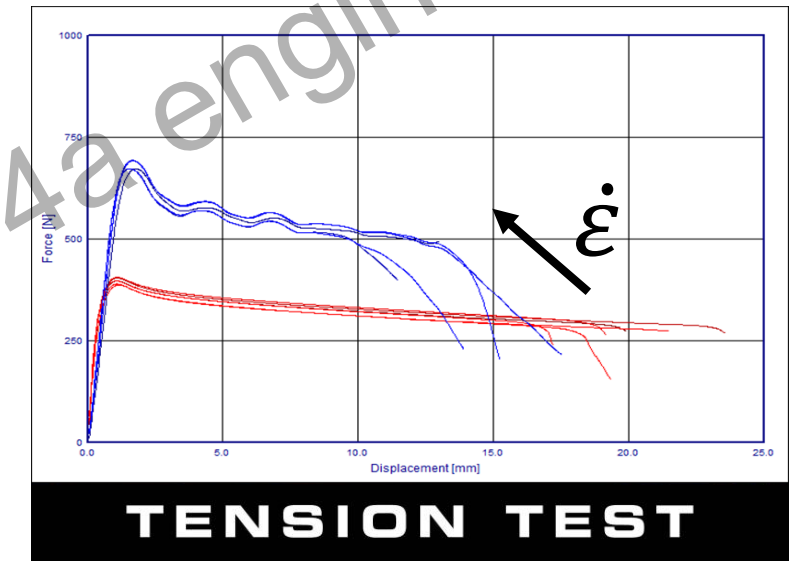


TENSION BENDING

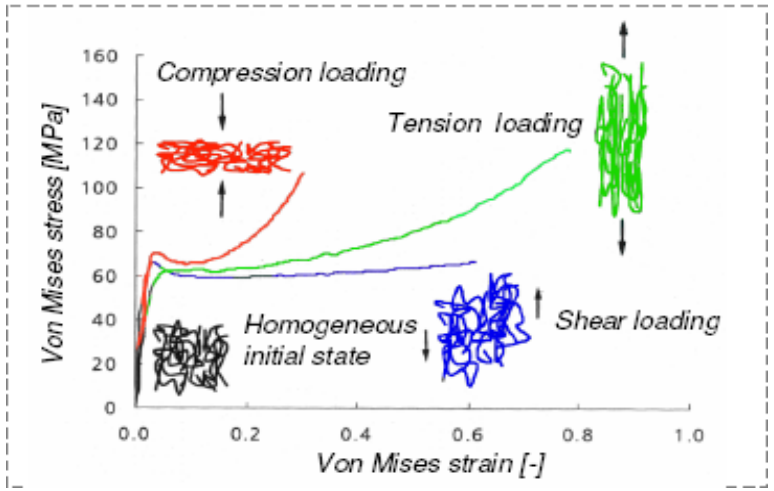


PUNCTURE TEST



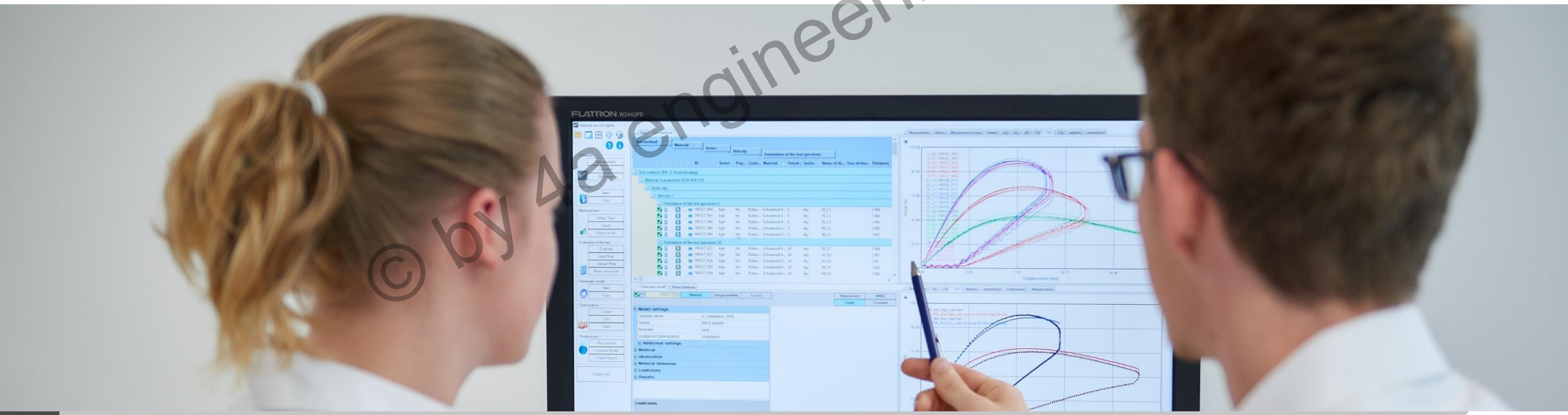


TENSION TEST

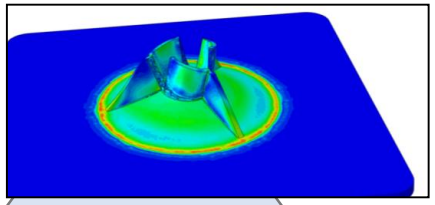


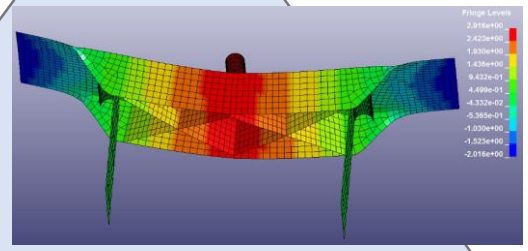
Source: Mechanik der Kunststoffe *W. Retting, Hanser Verlag 1991*

From test to material card



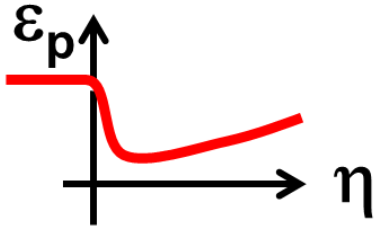
From test to material card





Deformation → Failure
Creep → Static → Crash
ISOTROPIC → ANISOTROPIC

Triaxiality

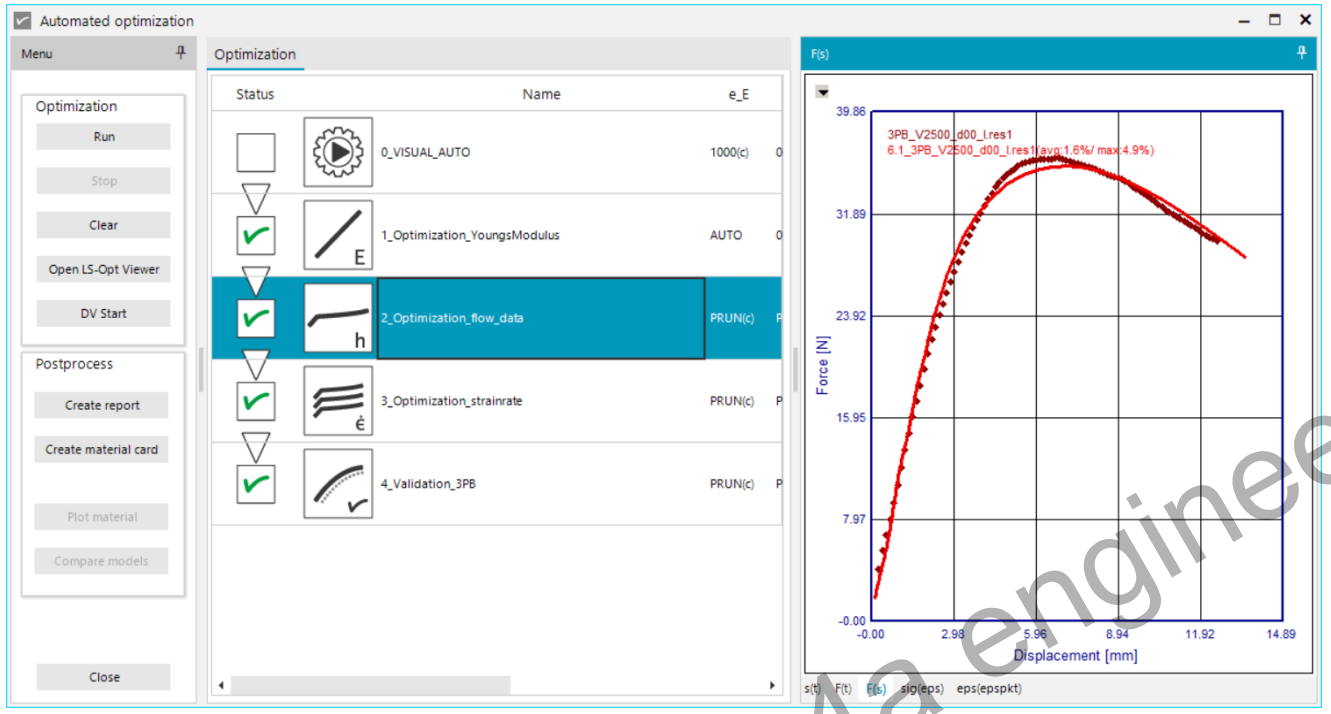


Damage/Failure

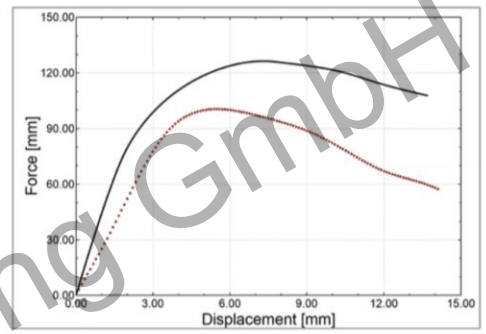
Hardening

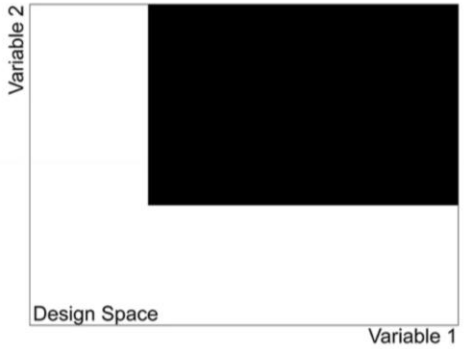
Anisotropic

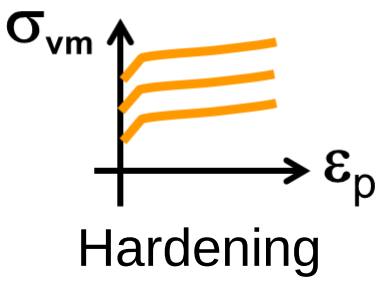
Workflow for Material Card Generation - AUTOFIT



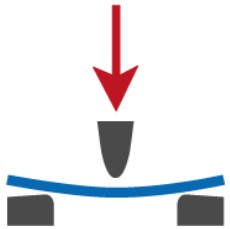
optimization – successive response surface method



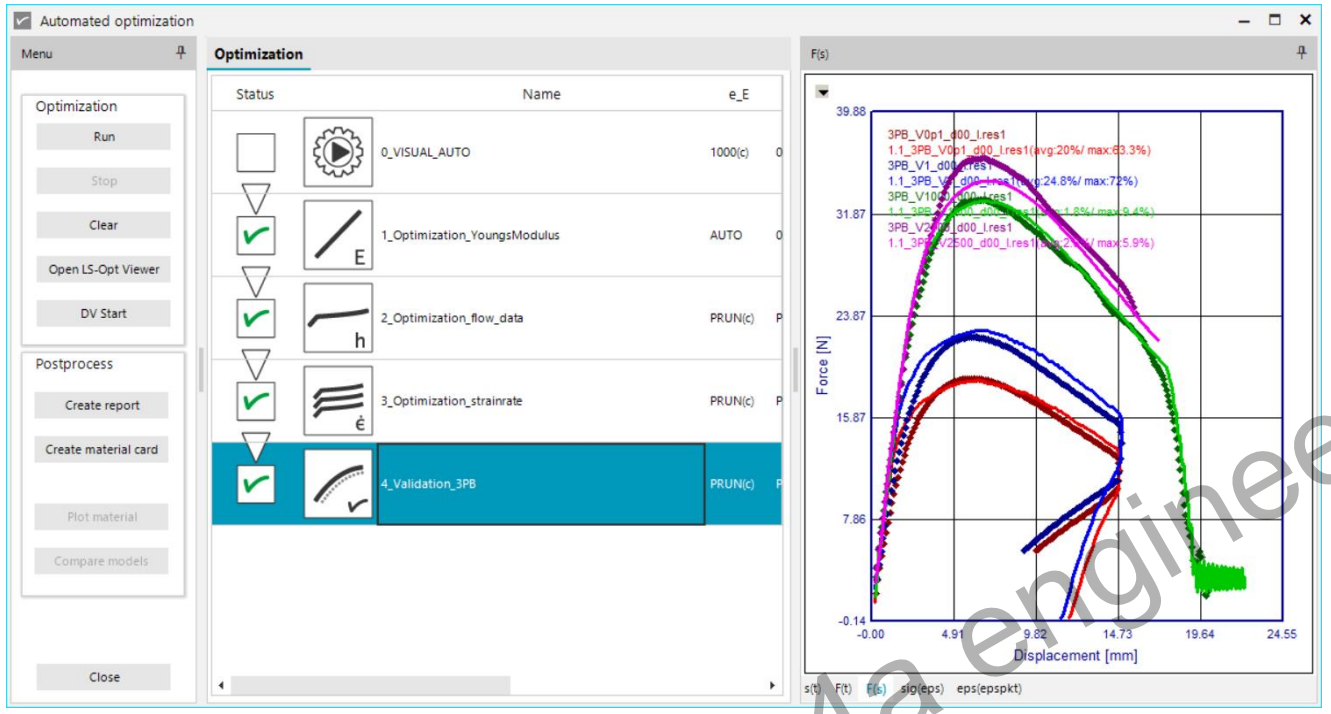




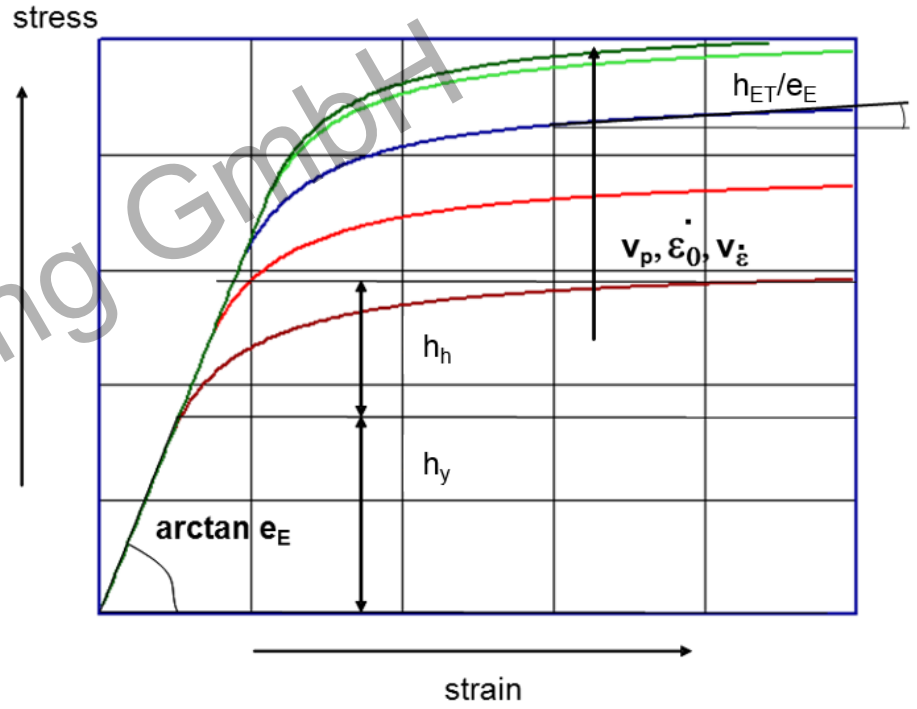
Hardening

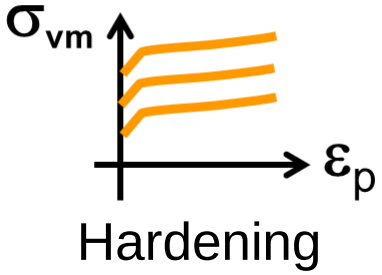


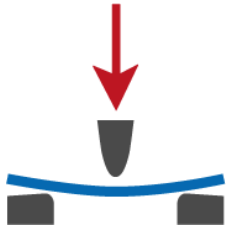
Workflow for Material Card Generation - AUTOFIT



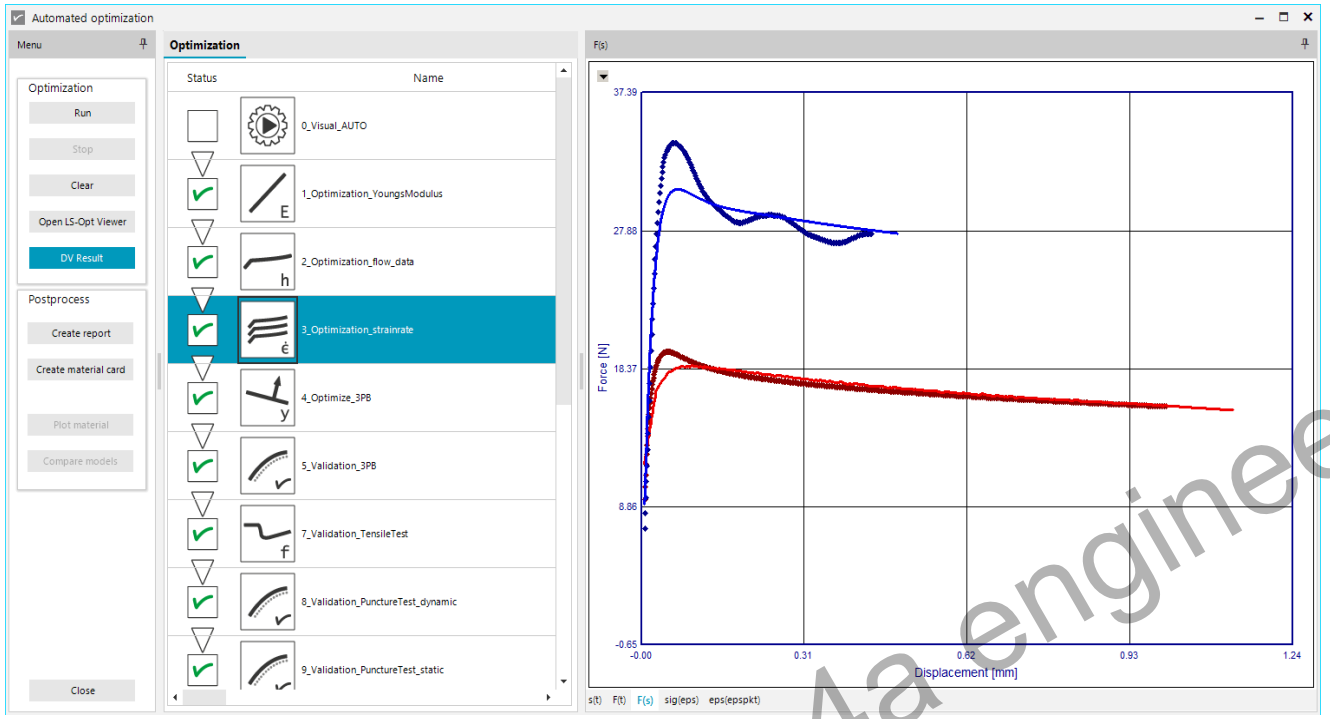
parametrized material card



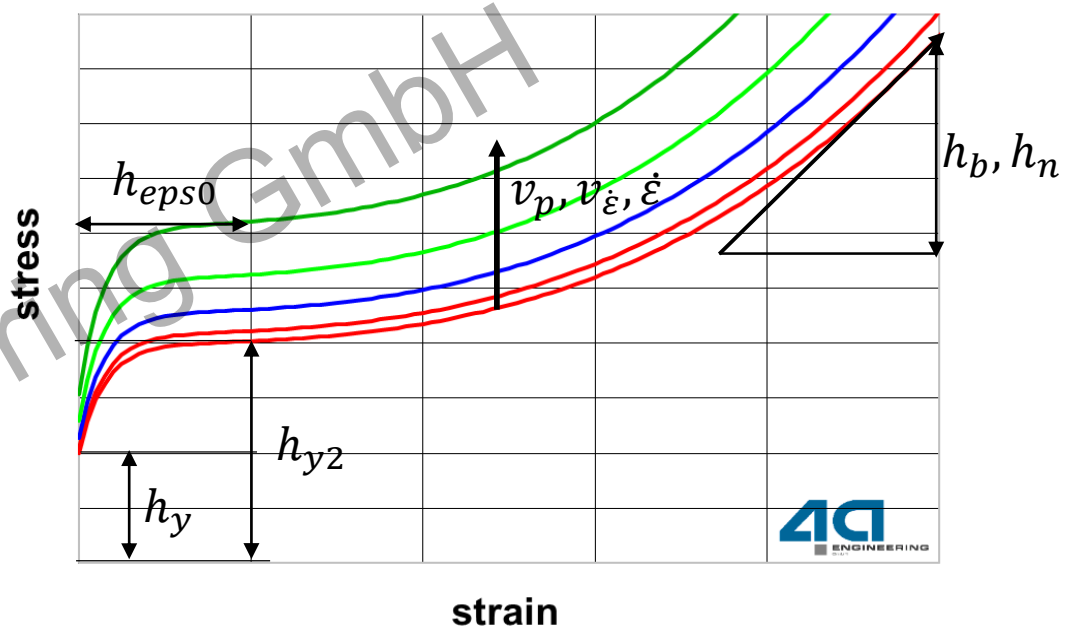


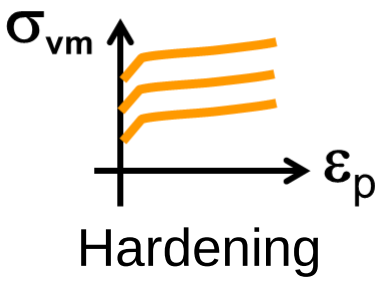


Workflow for Material Card Generation - AUTOFIT

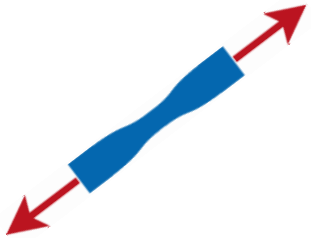


parametrized material card

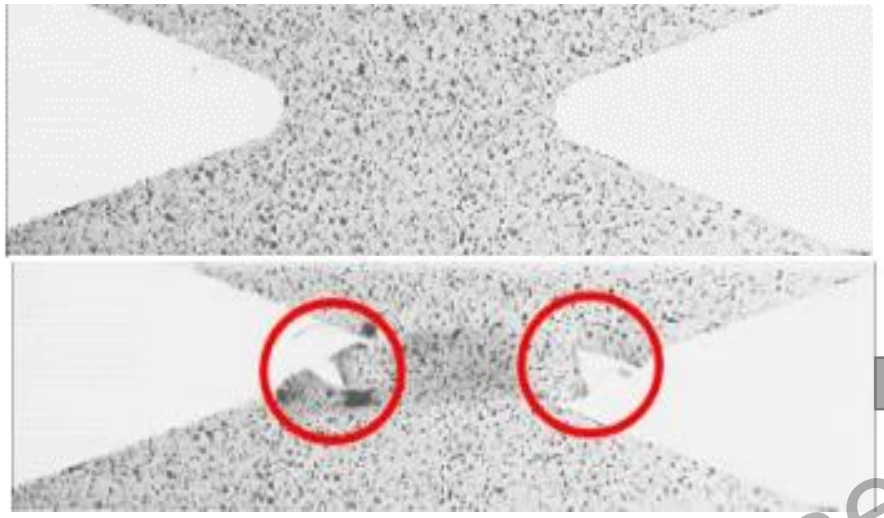




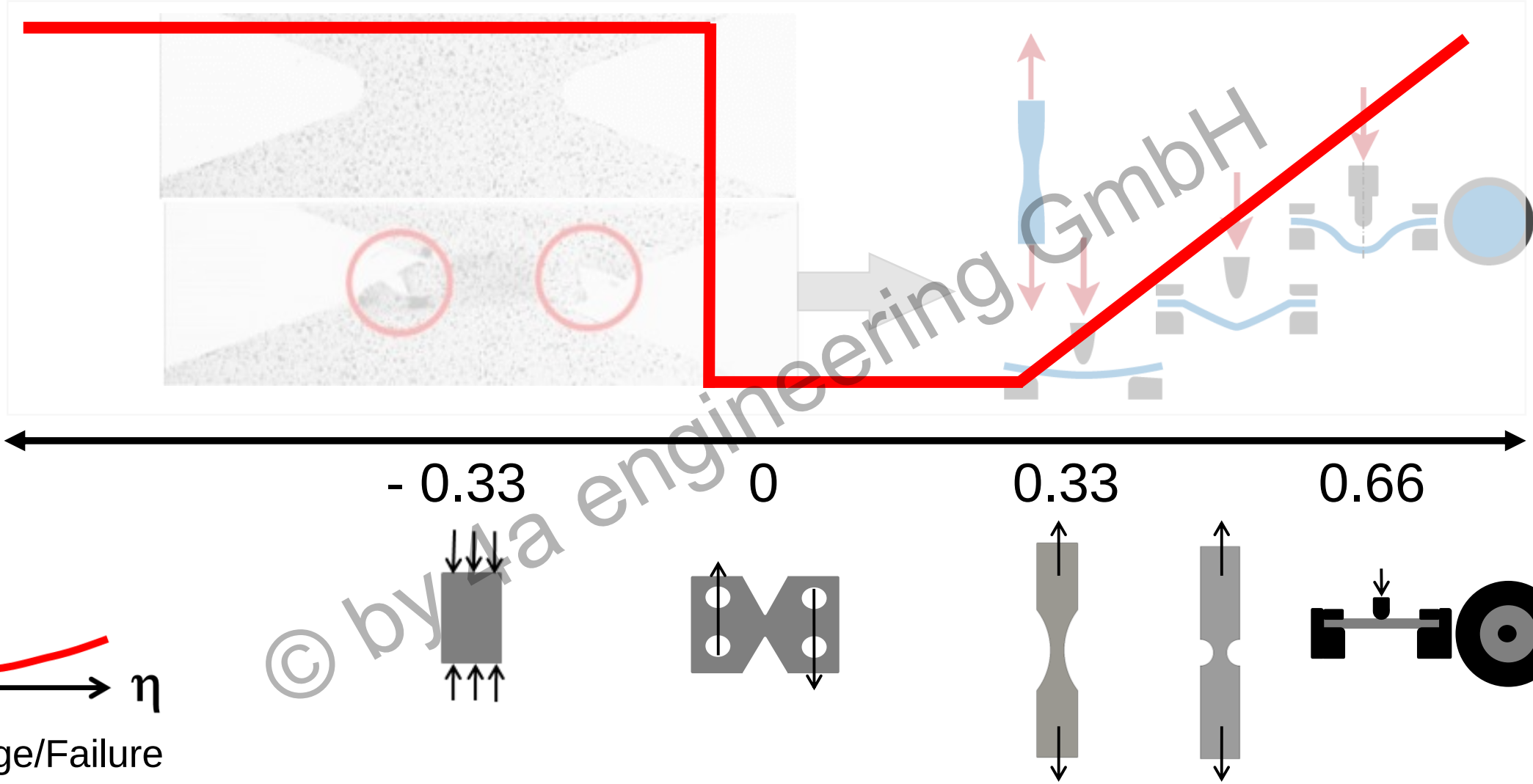
Hardening



From test to material card

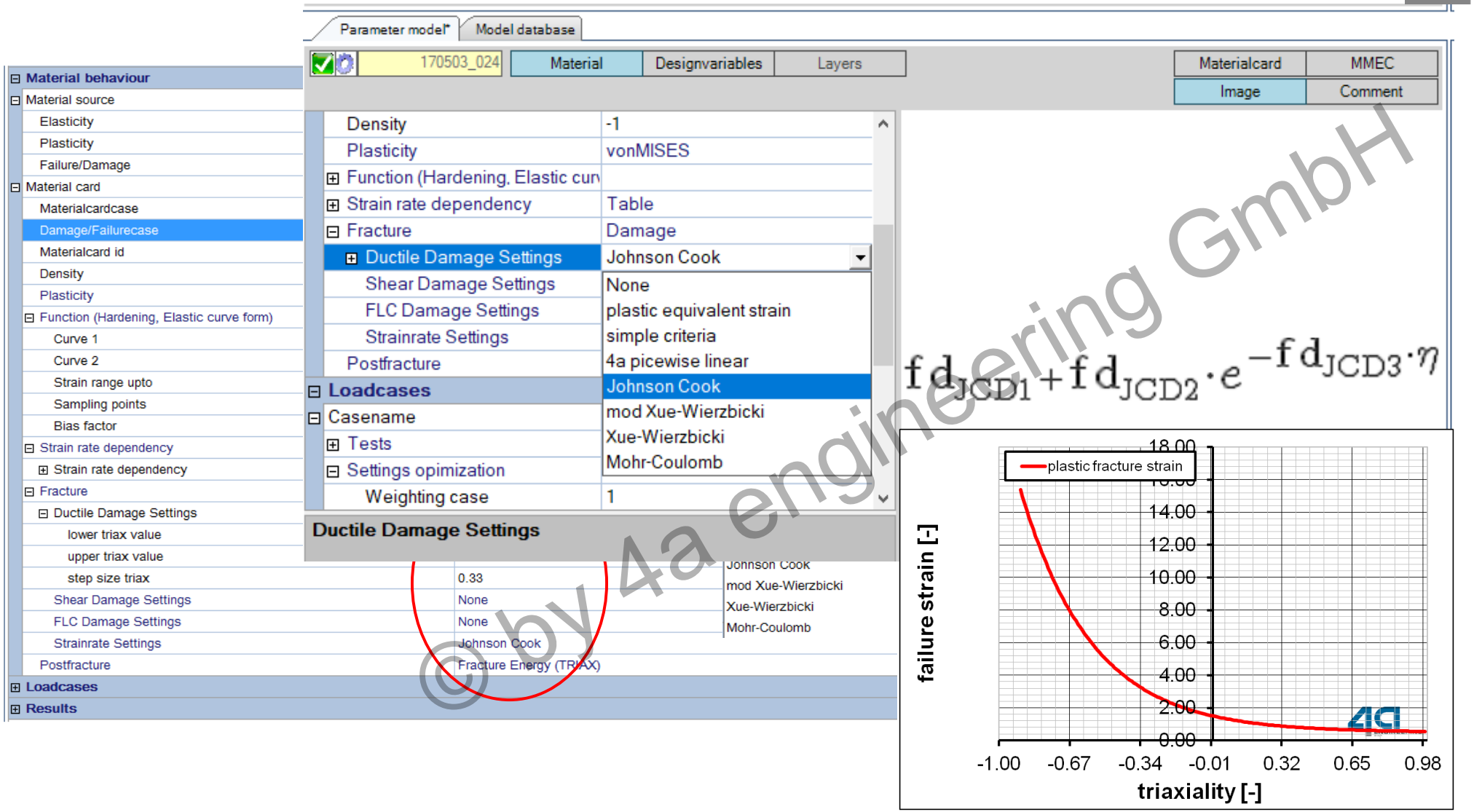


From test to material card

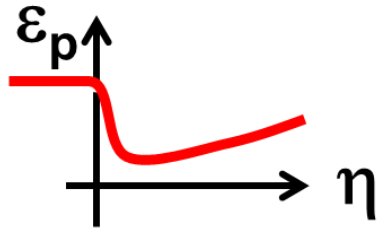


Fracture models → *MAT_ADD_EROSION

VALIMAT



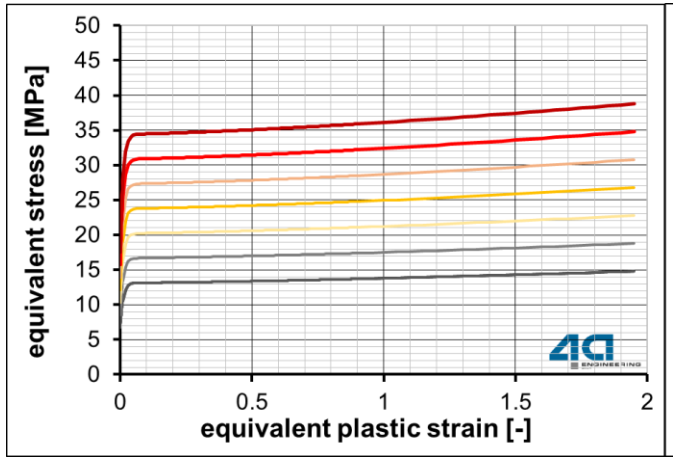
$$fd_{JCD1} + fd_{JCD2} \cdot e^{-fd_{JCD3} \cdot \eta}$$

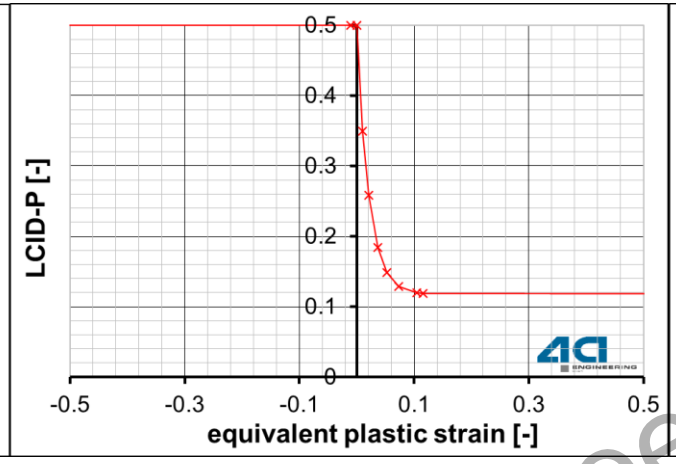


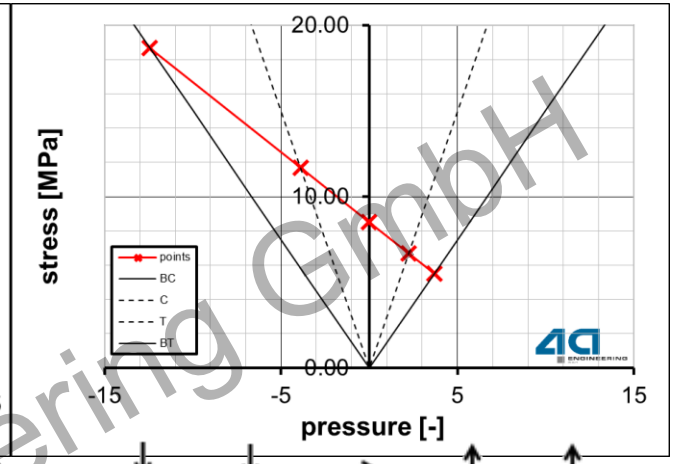
Damage/Failure

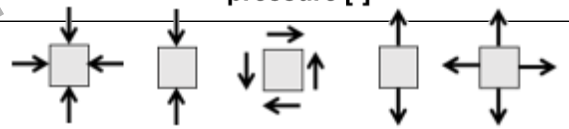
Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT

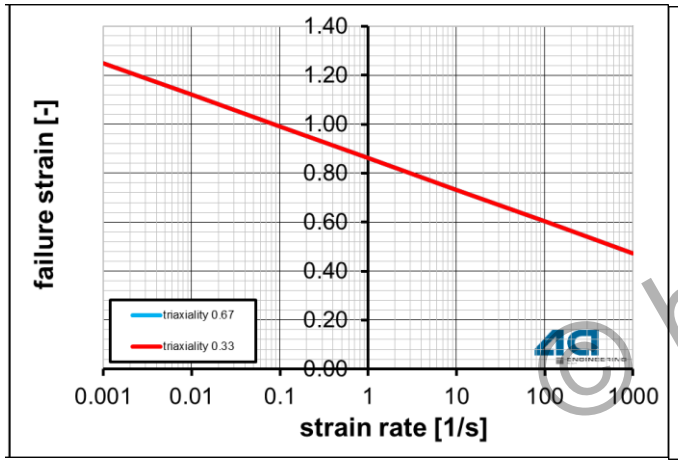
VALIMAT

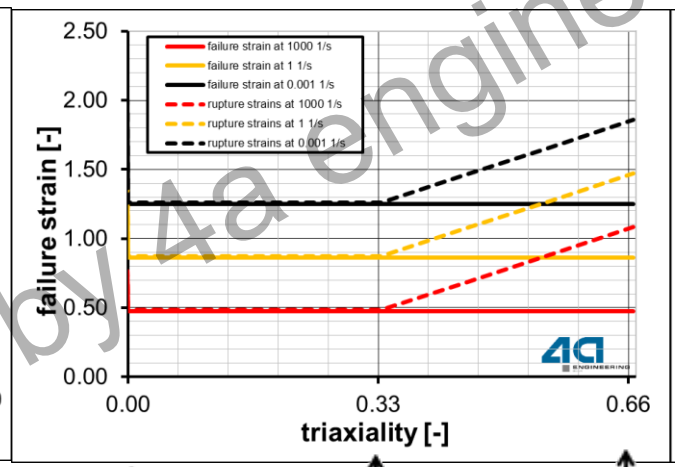


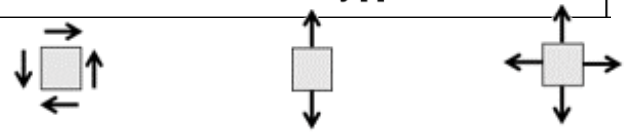


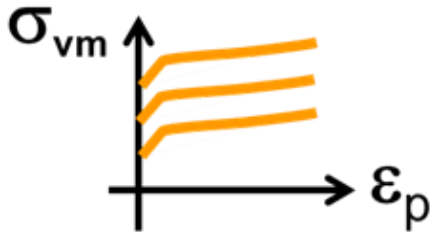




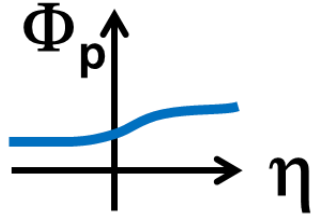




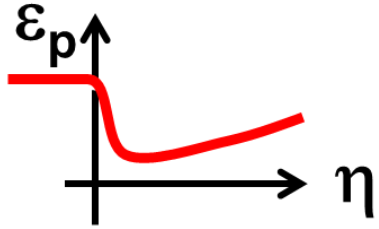




Hardening



Triaxiality

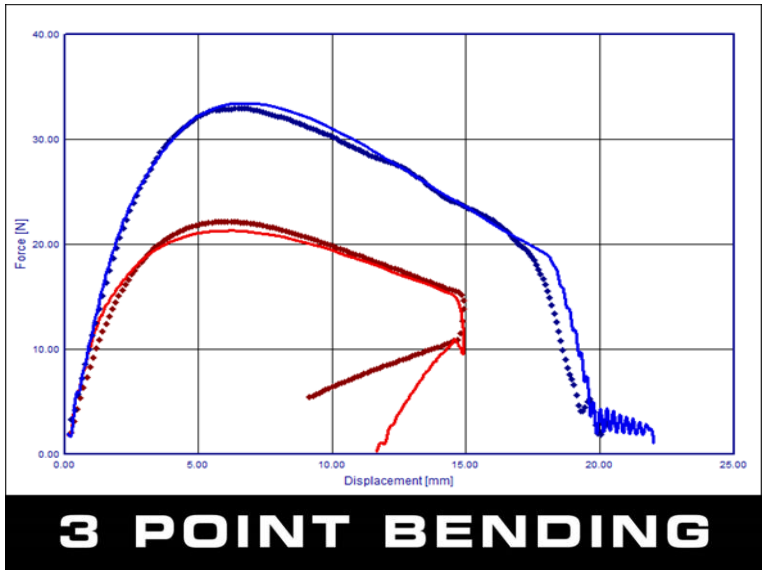


Damage/Failure

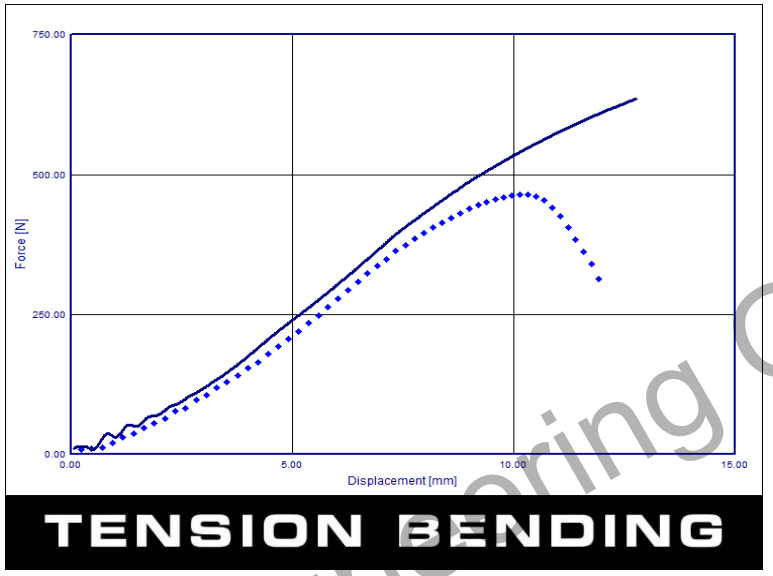
source: Benjamin Hirschmann, master thesis

Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT

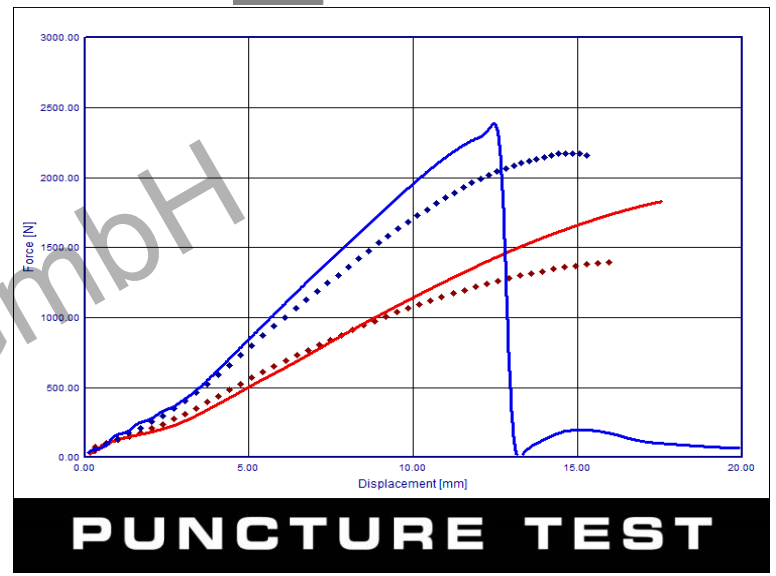
VALIMAT



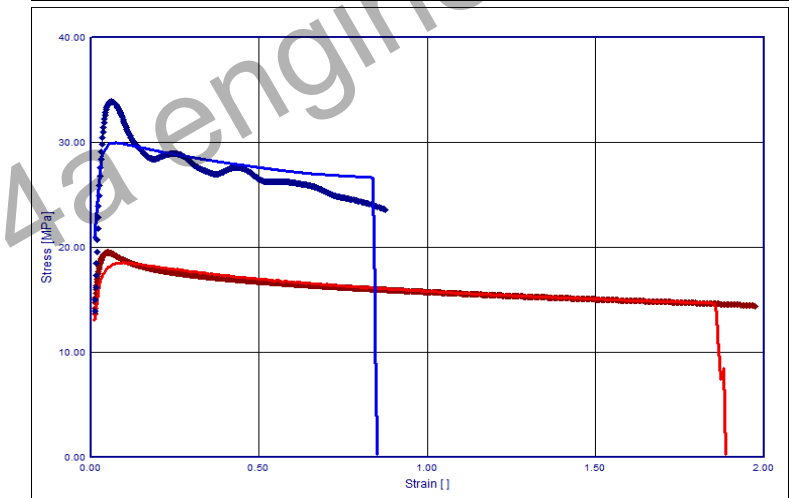
3 POINT BENDING



TENSION BENDING



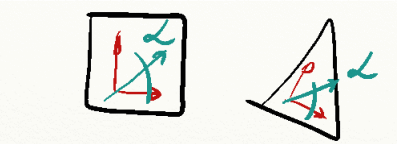
PUNCTURE TEST



TENSION TEST

IMPETUS® ~ 3 m/s

static ~ 1mm/s



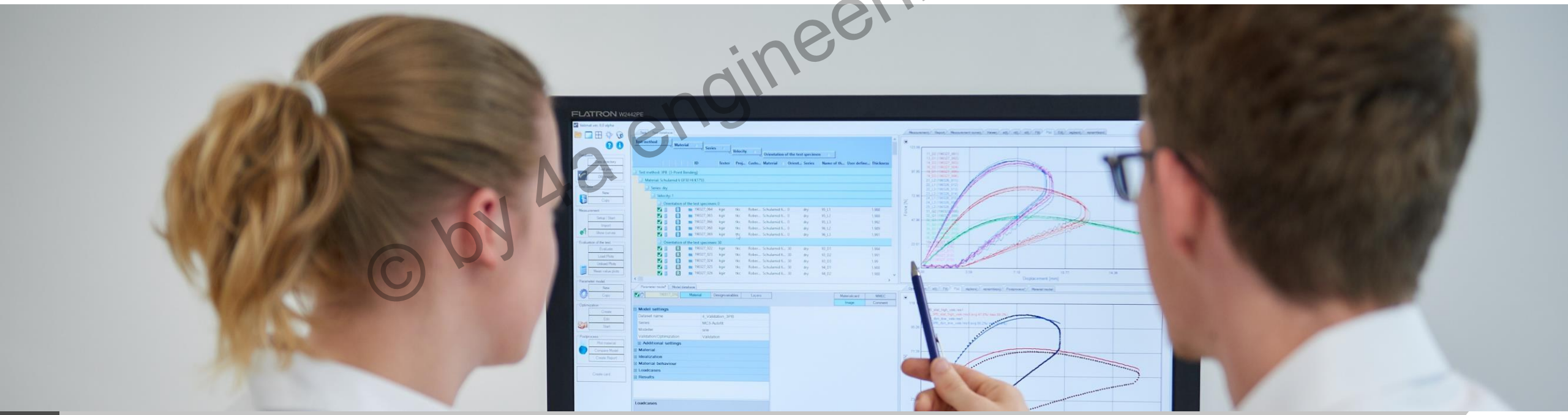
···· averaged test curves

— result of simulation

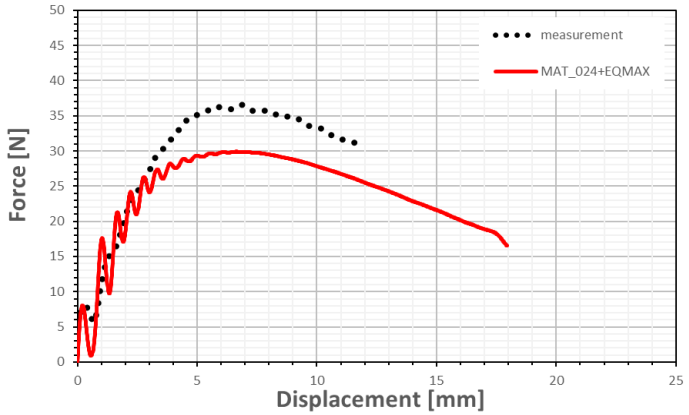
source: Benjamin Hirschmann, master thesis

Comparison different material models

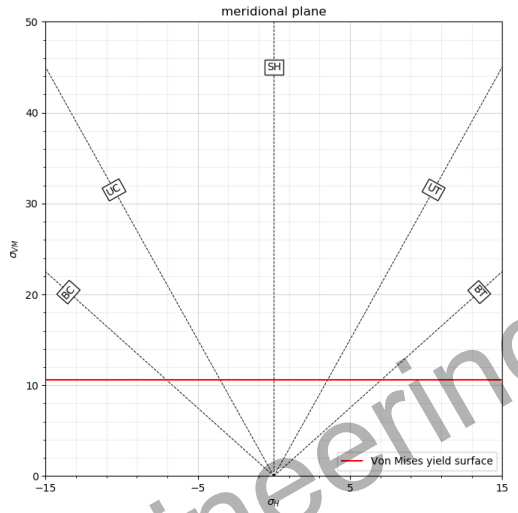
- stability
- numerical cost
  - number of operations in material model ➔ Translation into simulation model (localization, load path,…)
  - relative numerical cost of the material model (measurement model comparison)
- accuracy

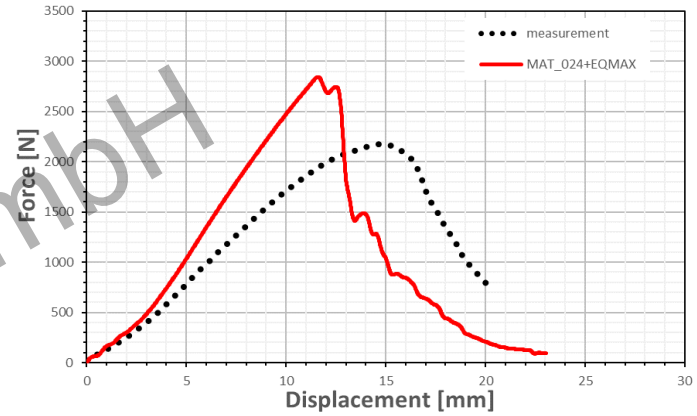


Relative Numerical Cost of the Material Model – MAT_024

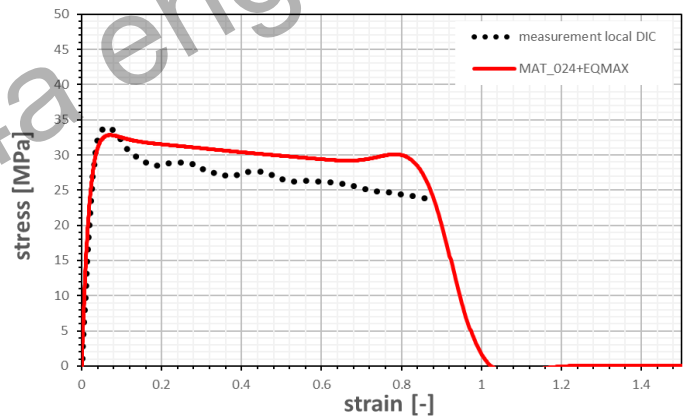


3 POINT BENDING





PUNCTURE TEST



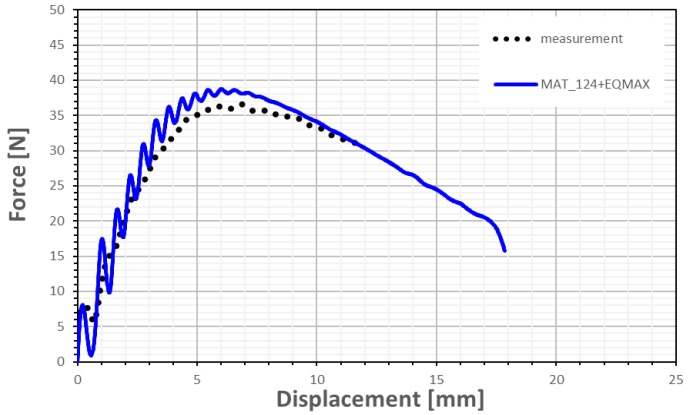
TENSION TEST

IMPETUS™ ~ 3 m/s

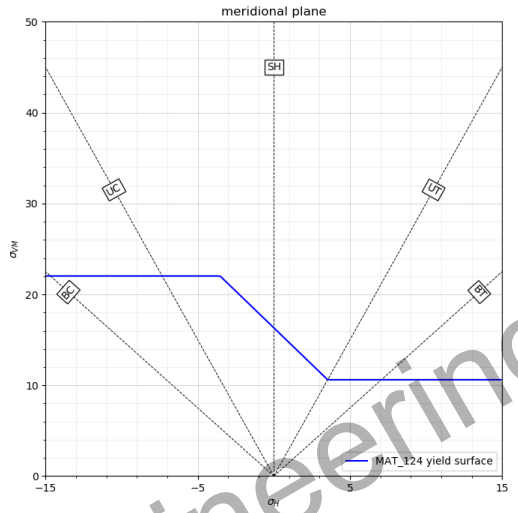
···· averaged test curves
— result of simulation

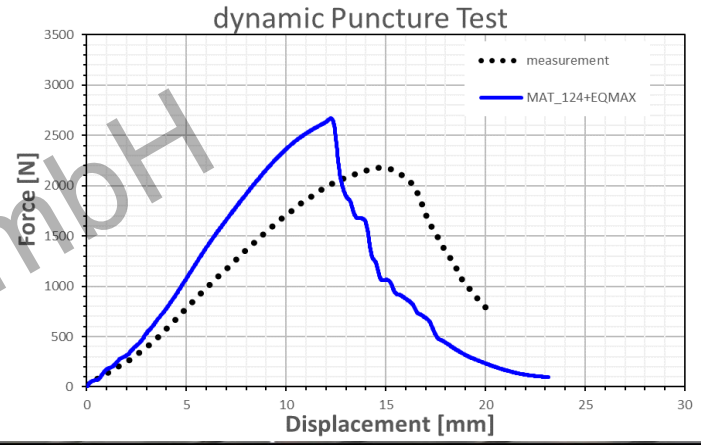
source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_124



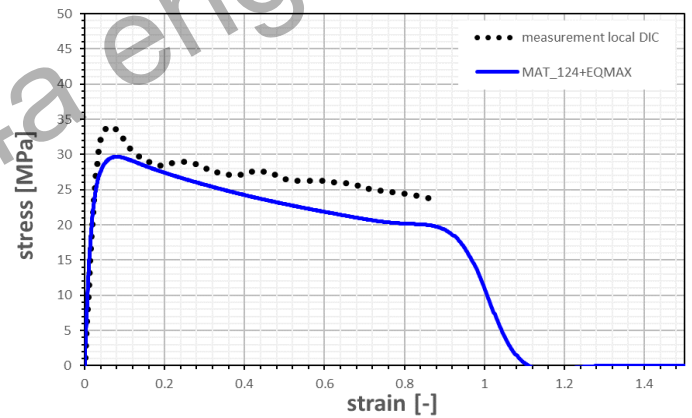
3 POINT BENDING





PUNCTURE TEST

IMPETUS™ ~ 3 m/s

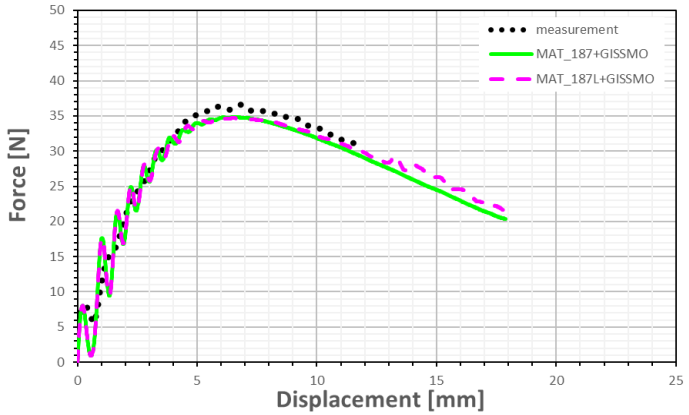


TENSION TEST

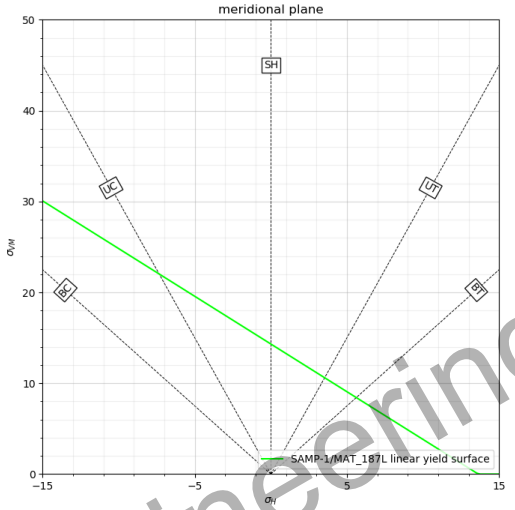
···· averaged test curves
— result of simulation

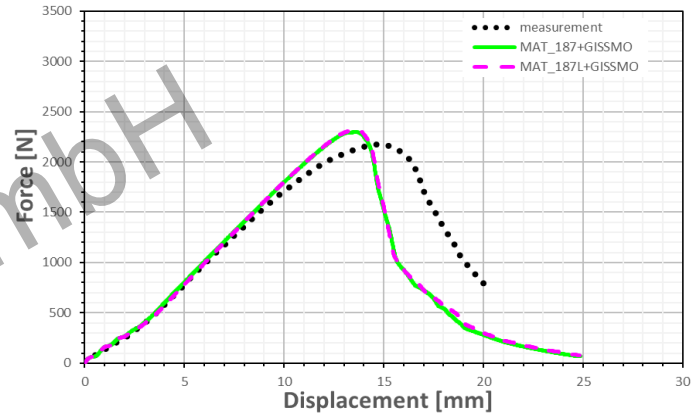
source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_187



3 POINT BENDING





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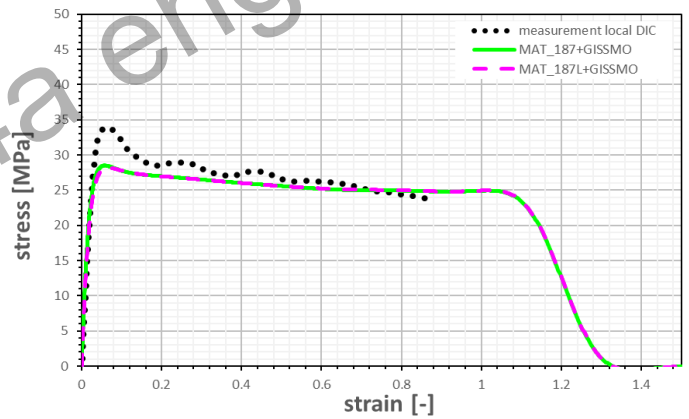


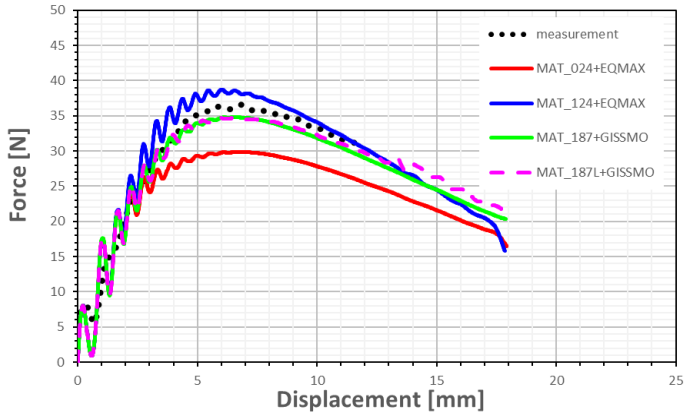
TENSION TEST

IMPETUS™ ~ 3 m/s

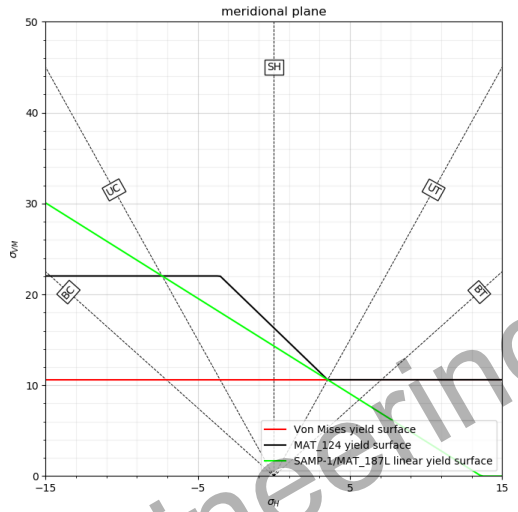
···· averaged test curves
— result of simulation

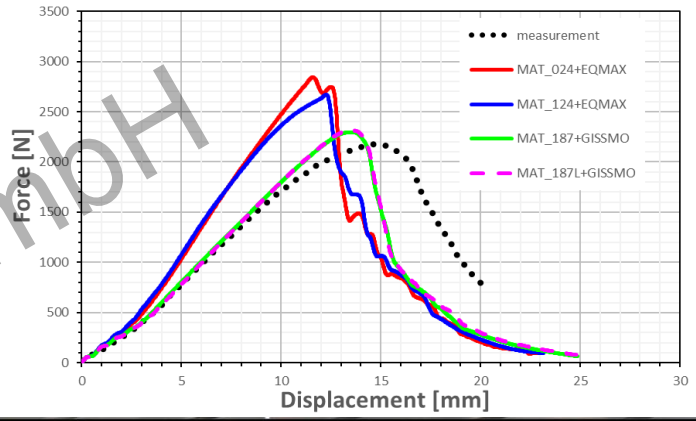
source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model



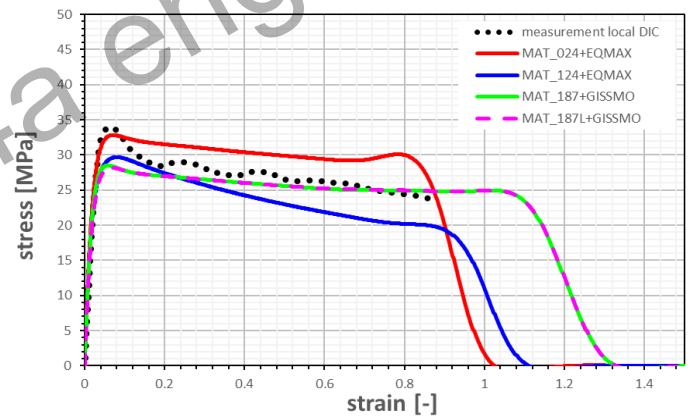
3 POINT BENDING





PUNCTURE TEST

IMPETUS™ ~ 3 m/s

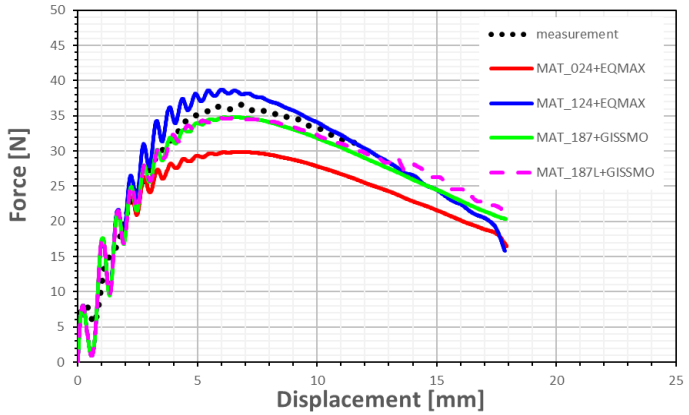


TENSION TEST

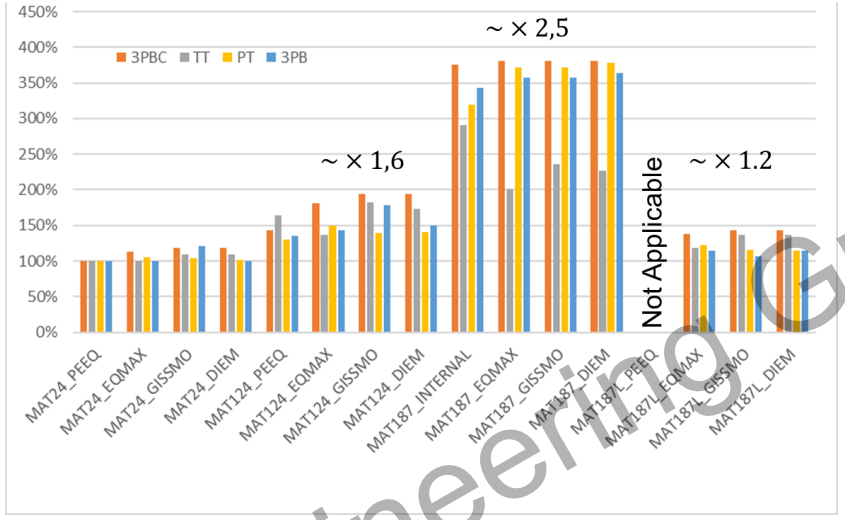
···· averaged test curves
— result of simulation

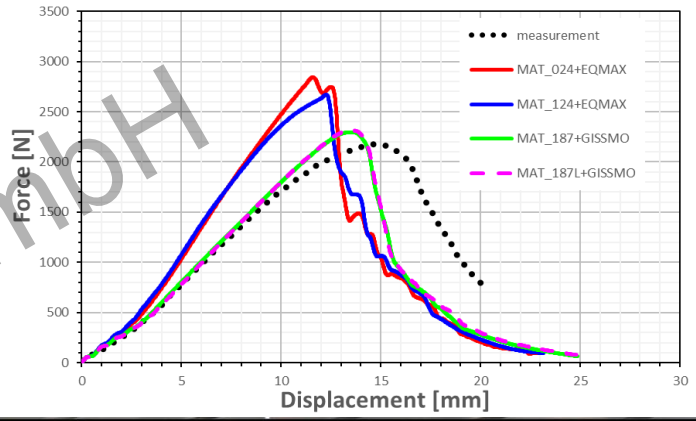
source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model



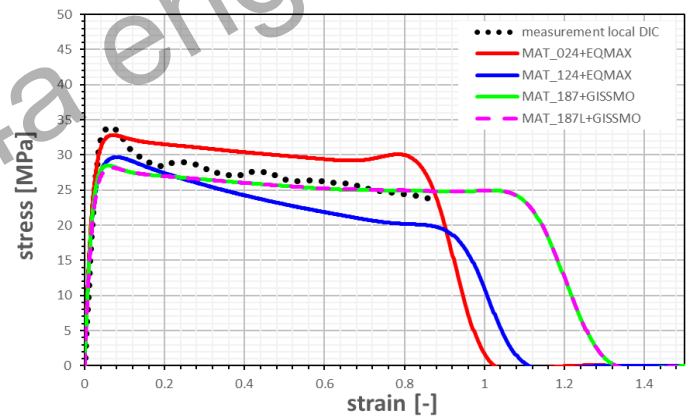
3 POINT BENDING





PUNCTURE TEST

IMPETUS™ ~ 3 m/s

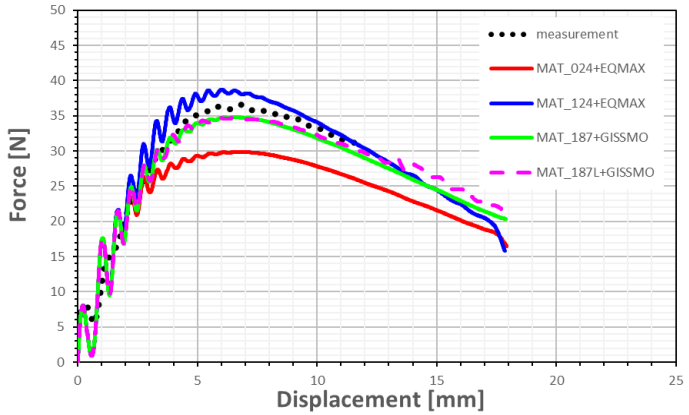


TENSION TEST

···· averaged test curves
— result of simulation

source: Benjamin Hirschmann, master thesis

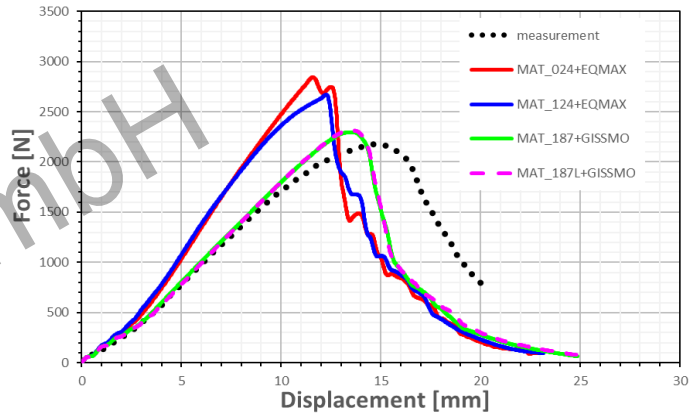
Relative Numerical Cost of the Material Model



3 POINT BENDING

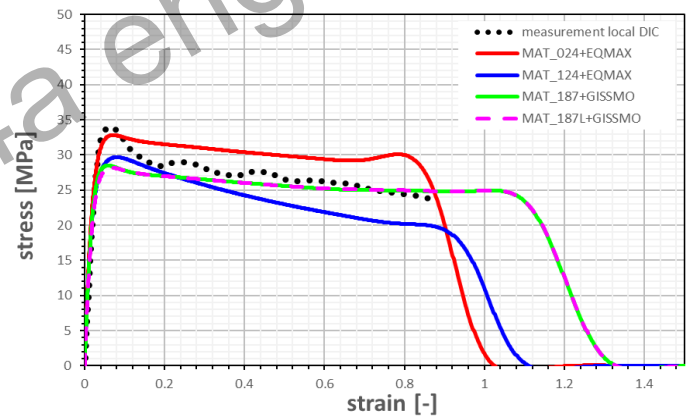
Material model	CPU Time
*MAT_024	1
*MAT_124	1.6
*MAT_187	2.5
*MAT_187L	1.2

CPU Time comparisons



PUNCTURE TEST

IMPETUS™ ~ 3 m/s



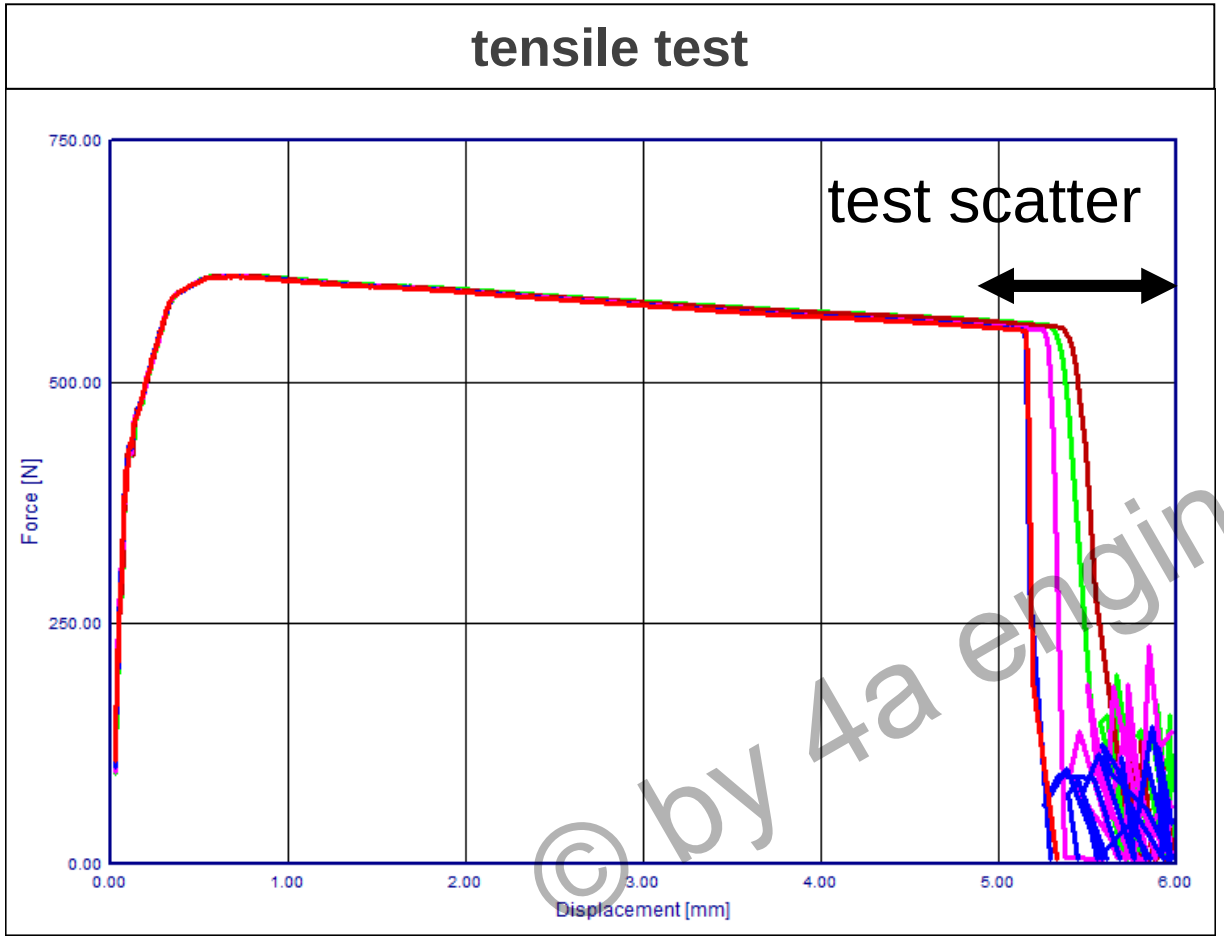
TENSION TEST

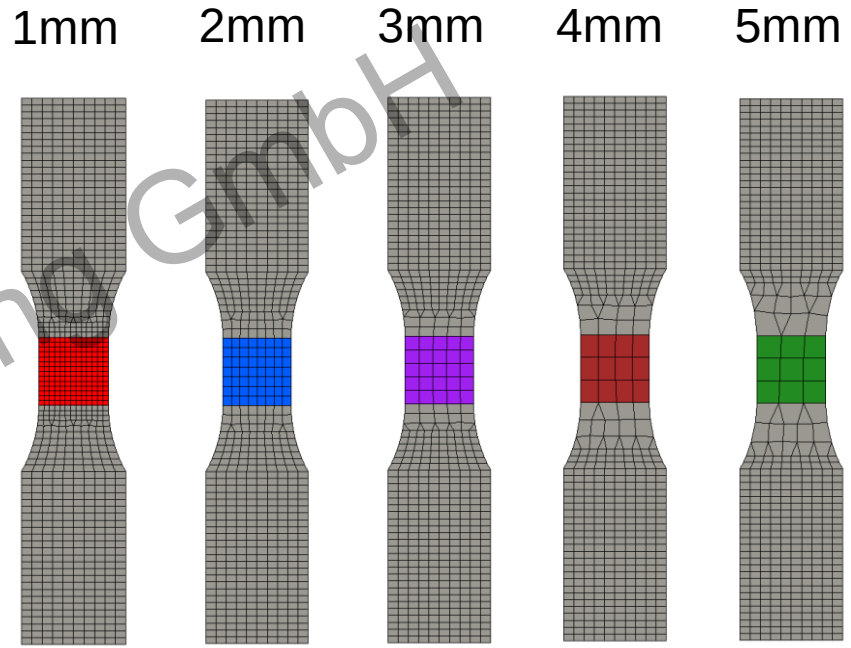
···· averaged test curves
— result of simulation

source: Benjamin Hirschmann, master thesis

Element Regularisation

*MAT-SAMP 1 with internal failure model – influence element size



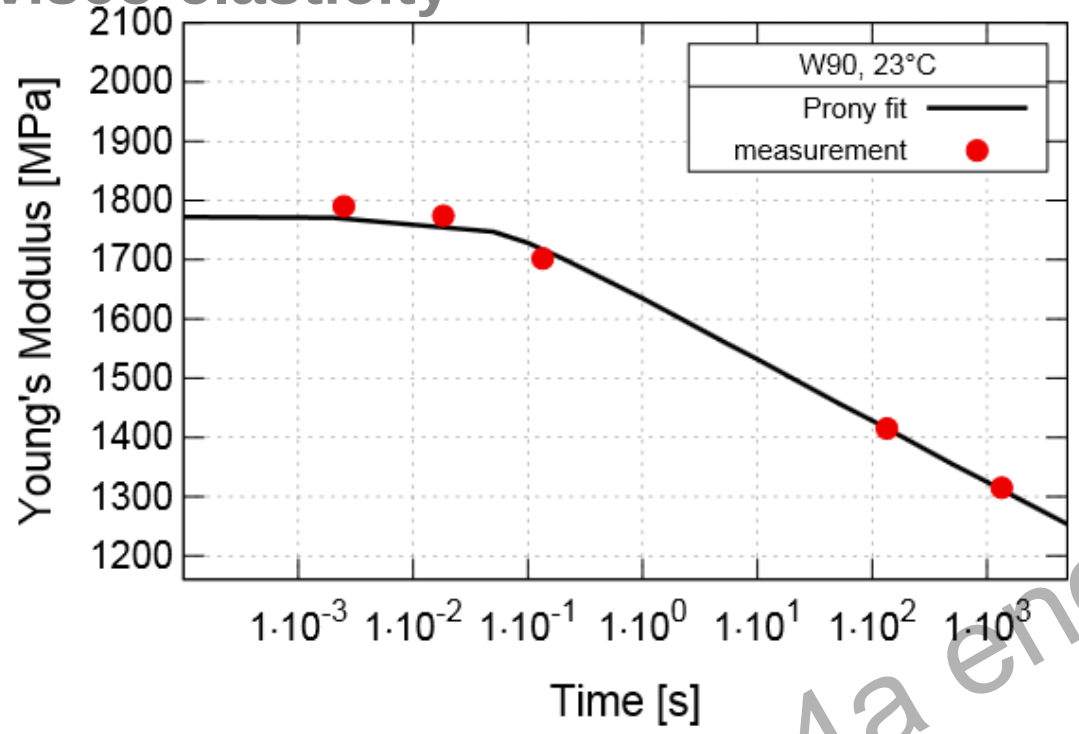


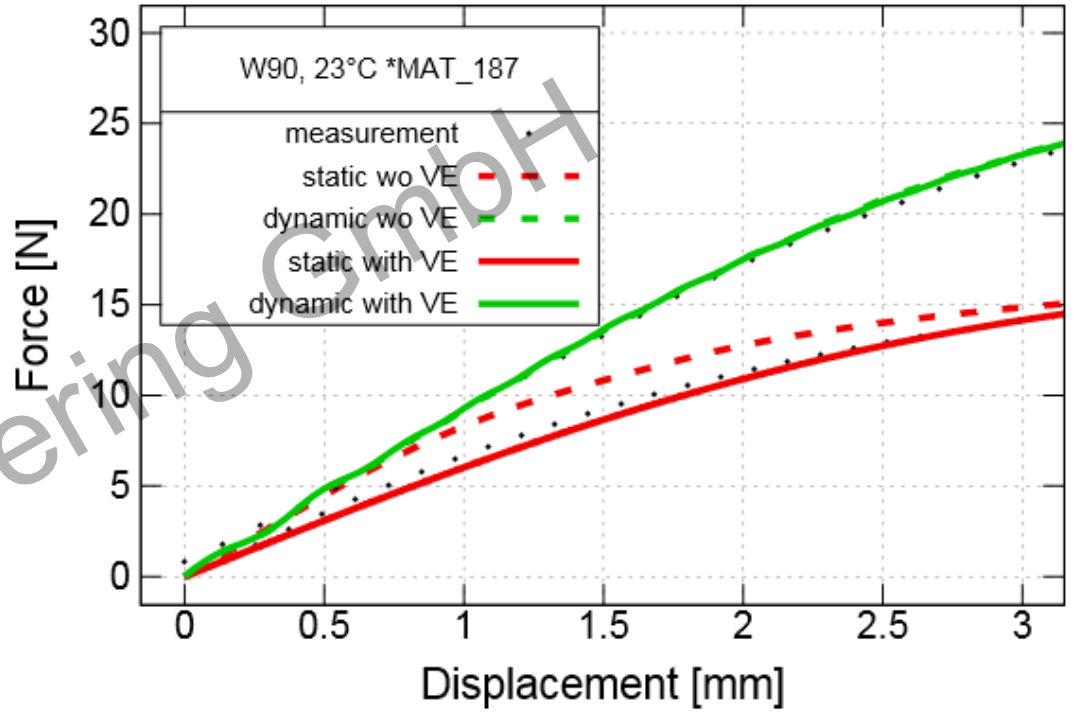
VALIMAT

source: Benjamin Hirschmann, master thesis

UPCOMING MODELS
**MAT_ADD_INELASTICITY*

Upcoming material models visco-elasticity



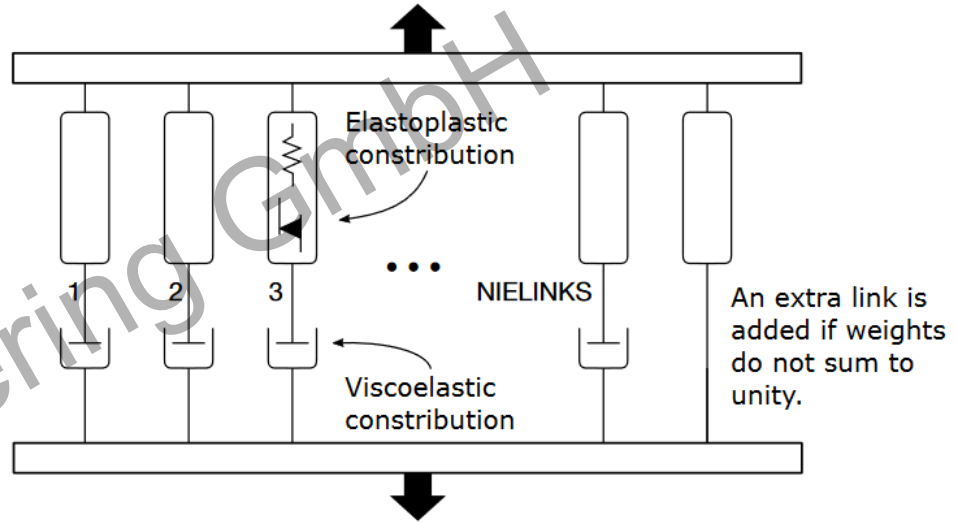


→ implementing visco-elasticity:
6-term Prony fit to use in ***MAT_124**

→implementing visco-elasticity:
strain-rate dependent Young's Moduli
to use in ***MAT_187**

Upcoming material models
*MAT_ADD_INELASTICITY

- the purpose of this card is to add inelastic features to a standard arbitrary material card → modular concept
- supported in implicit and explicit for a few element types→ under development
- inelastic features
  - isotropic hardening plasticity
  - creep
  - Visco-elasticity



LS-DYNA_Manual_Volume_II_Dev (r:11680)

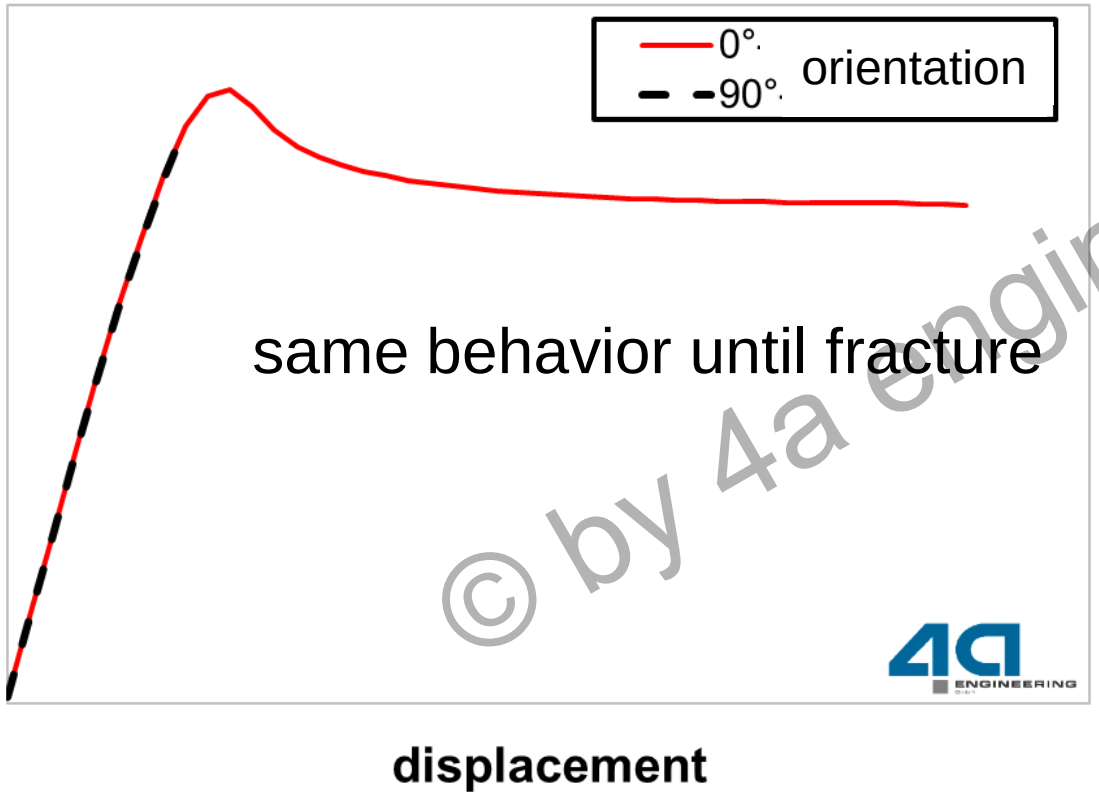
Anisotropic Failure

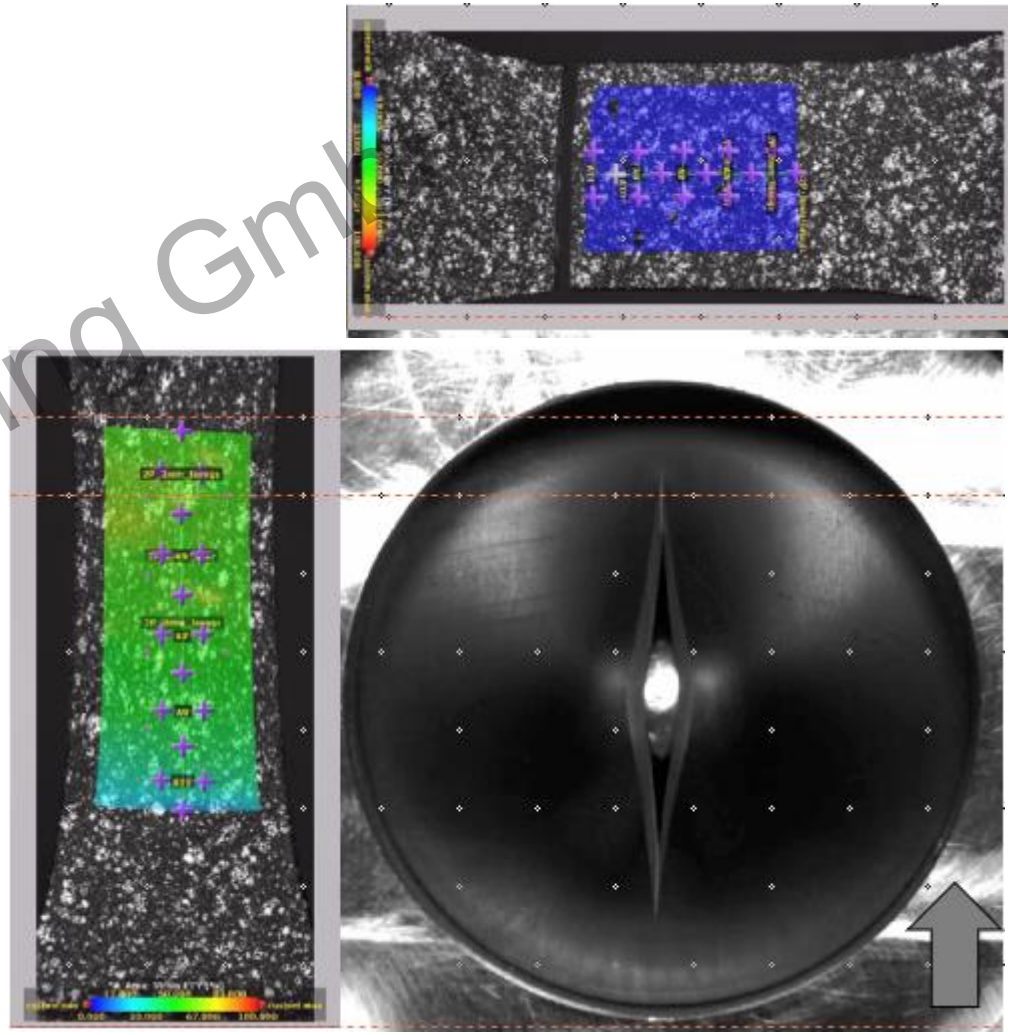
*(*MAT_ADD_GENERALIZED_DAMAGE)*

Plastics ?

Influence of manufacturing process on failure

- example: ABS
  - The induced orientation by the injection molding process leads to an anisotropic failure behavior.





Summary
Part 1: Modeling of isotropic thermoplastics

Summary Deformation

- Motivation and general material behavior of thermoplastics
- dynamic and static measurements for a talc filled PP
- discussed material models
  - **`*MAT_024`** → **`*MAT_SAMP-1`**
  - describe observed deformation behavior
  - numerical costs

- **`*MAT_187L`** – new material model
  - small increase in numerical costs **1.2**
  - **qualitative accuracy** of the simulation results could be **improved**.

Summary Failure

- material characterization in the triaxiality range of 0.33 to 0.66
- GISSMO ≠ DIEM (each model has some specialties)
  - GISSMO can be used for plastics
    → benefits of model often not used for plastic materials
  - DIEM → table input for initial failure enables more flexibility over triaxiality / over strain rate → BIAX
- **Simple as Possible, as Complex as Necessary**
- tools needed to handle data and to fit complex failure models

IMPETUS VALIMAT

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

IMPETUS

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MICROMEC

FIBERMAP

Foams

Thermoplastics

Fiber reinforced Plastics (SFRT & LFRT)

Composites (Carbon)

Metals

efficient
dynamic testing

from test to validated
material cards

3D anisotropic
material cards

individual mapping
process information

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

IMPETUS

efficient
dynamic testing

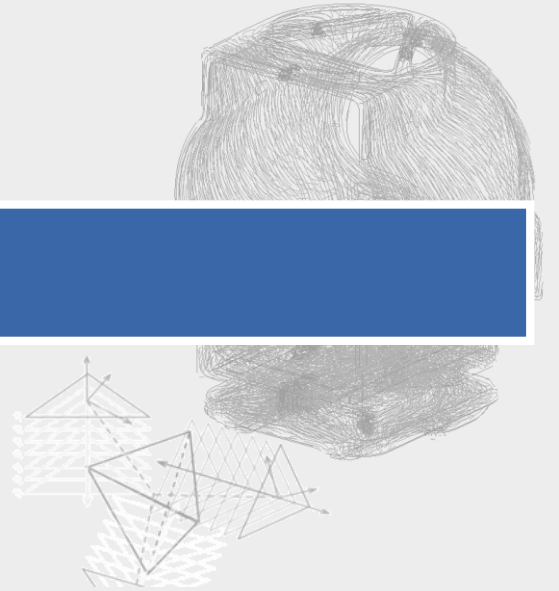
VALIMAT

from test to validated
material cards

MICROMEC

3D anisotropic
material cards

FIBERMAP

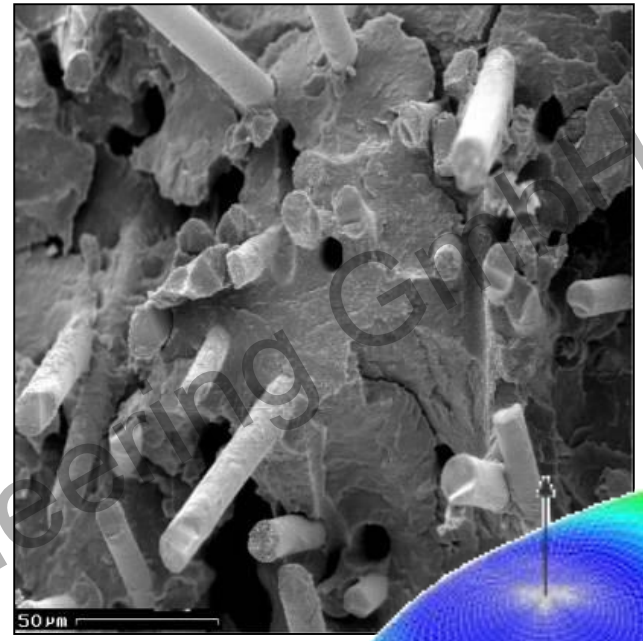


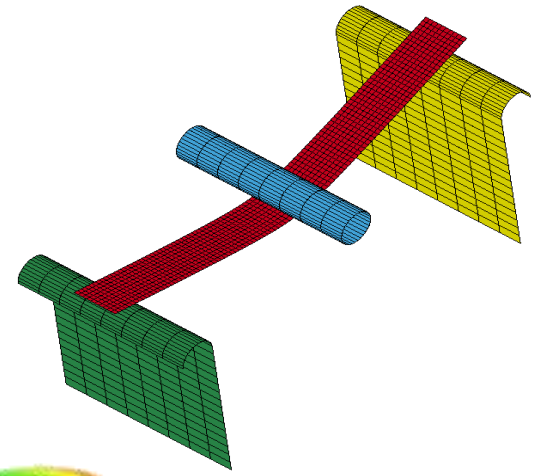
individual mapping
process information

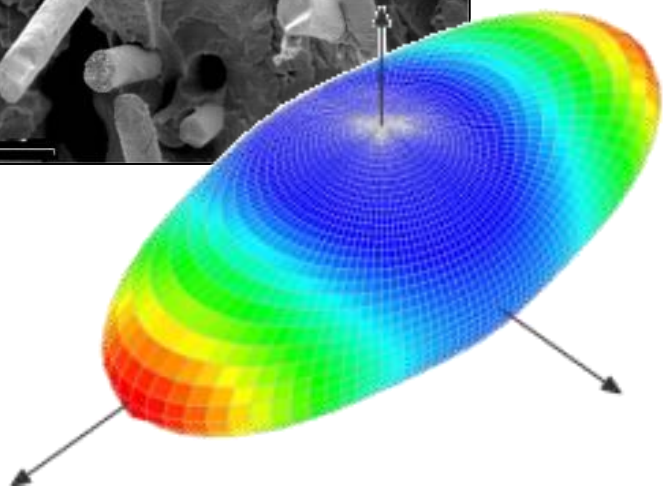
Fiber reinforced Plastics (SFRT & LFRT)

Short and long fiber reinforced thermoplastics

- Material model in LS DYNA
- Motivation
- Manufacturing influence
- Material model approaches
- Material characterization
- Casestudy - sleeve

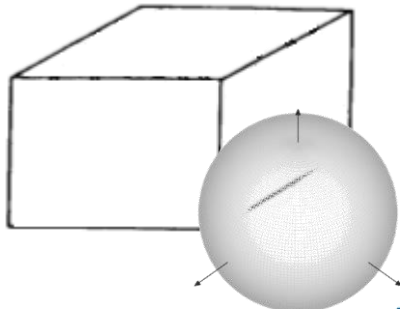






Motivation – current simulation standard

*MAT_024

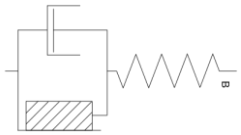


macro scale

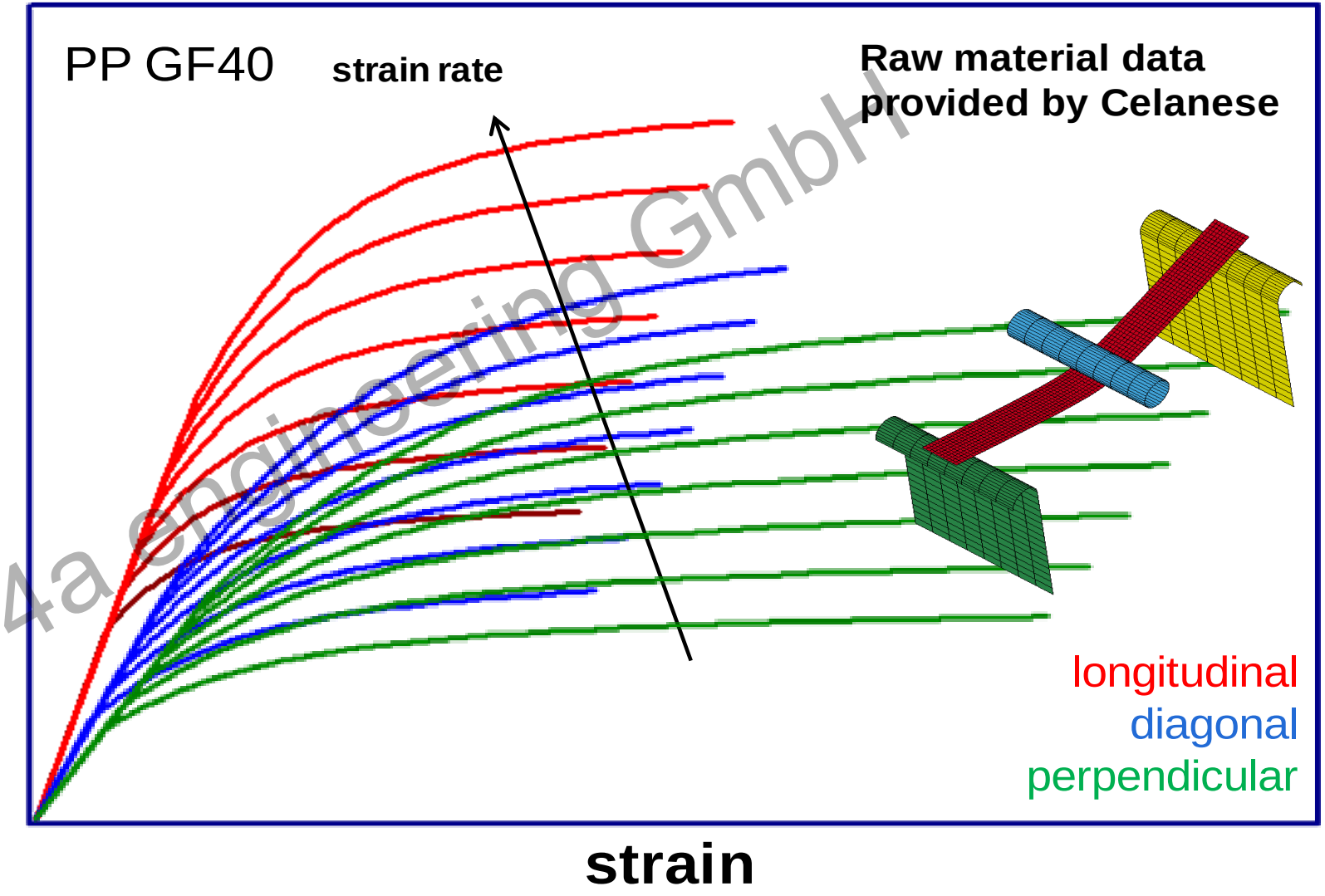
constitutive law

Mises plasticity

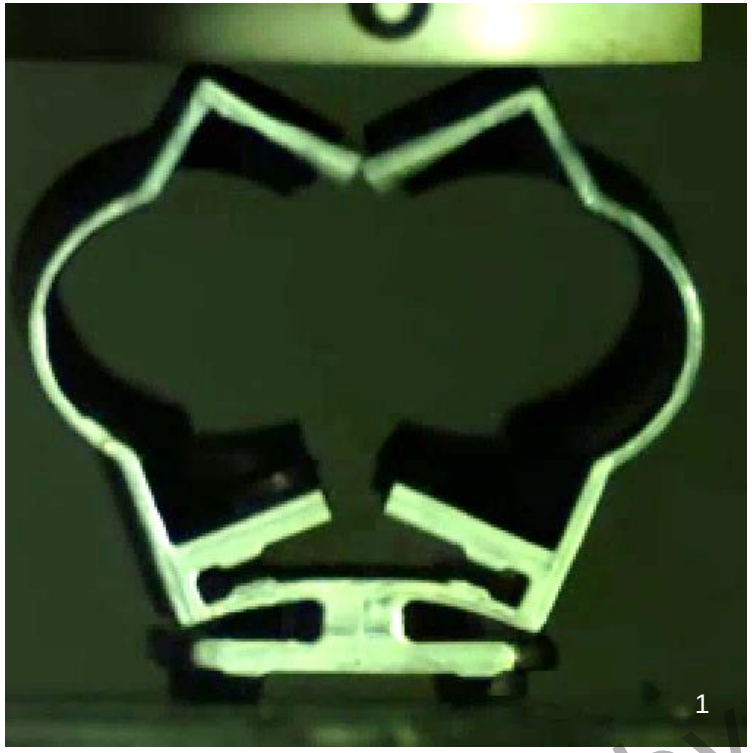
- quick & dirty



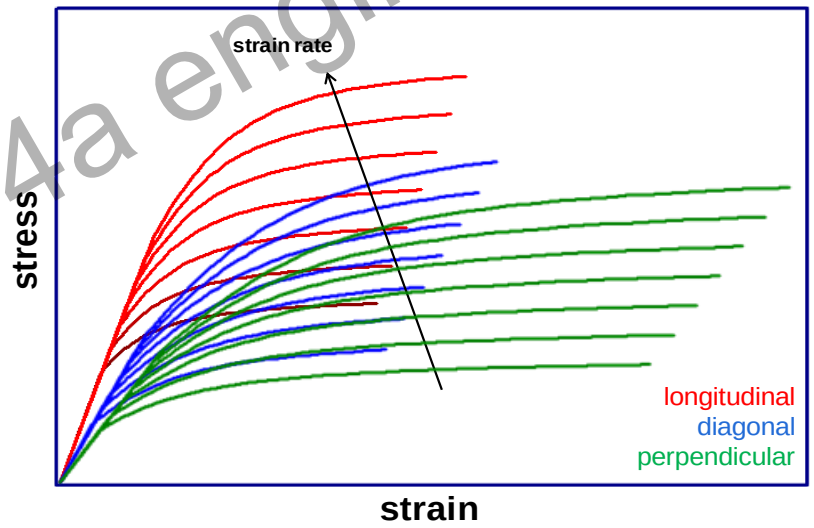
- critical loading
  transversal
  to fiber orientation

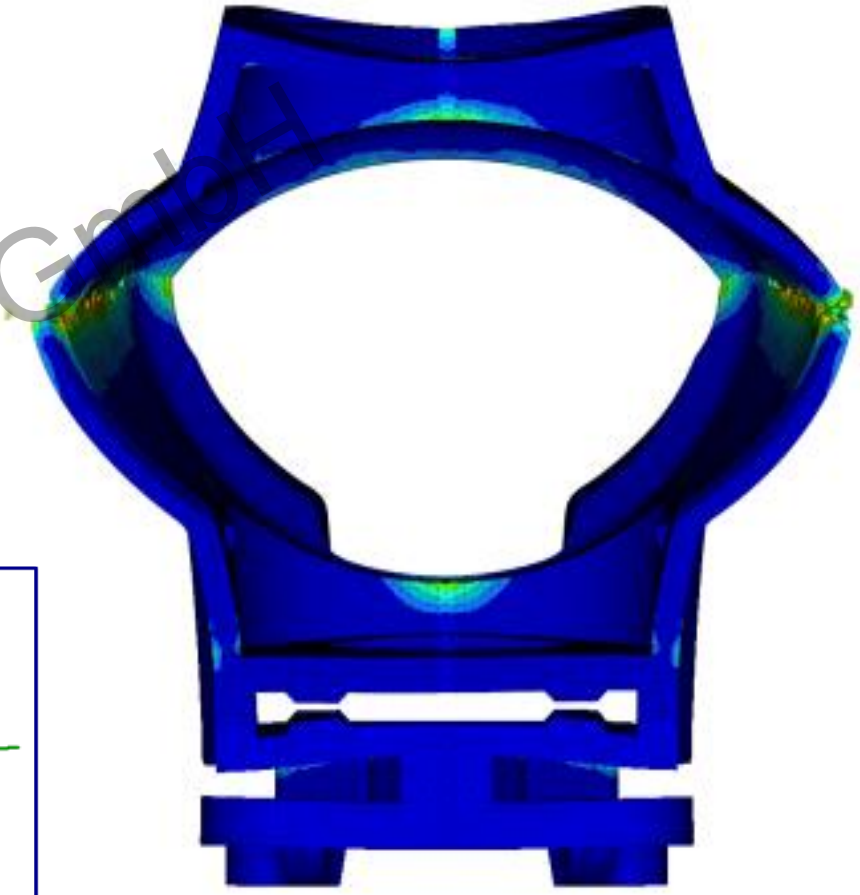


Motivation – current simulation standard

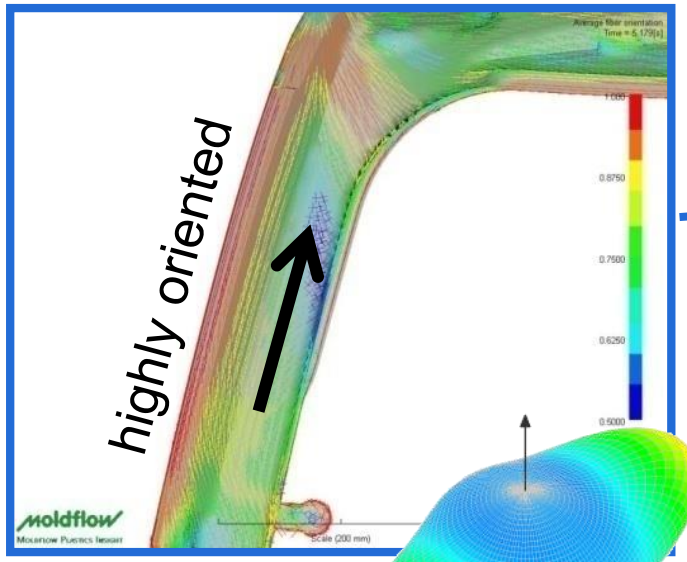


isotropic

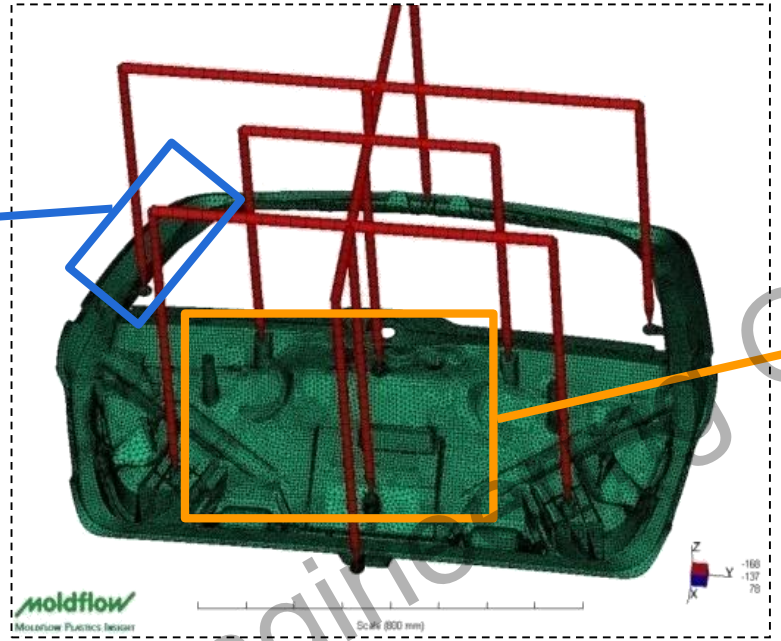


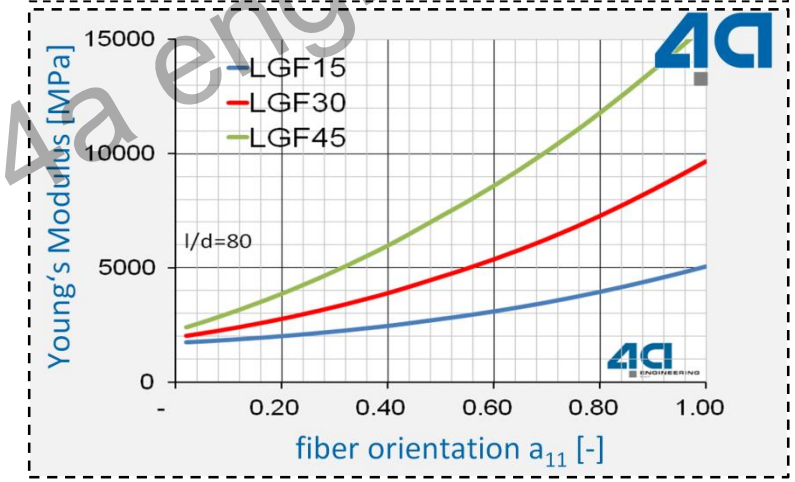


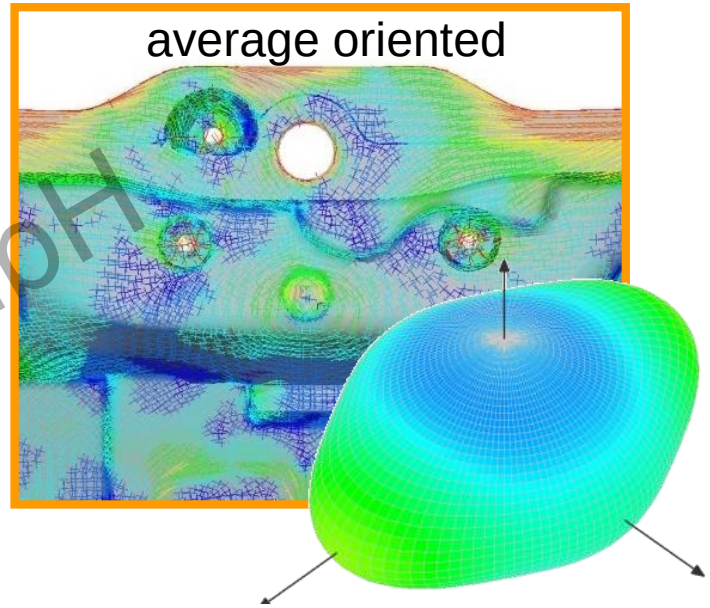
Fiber orientation – development in typical part



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





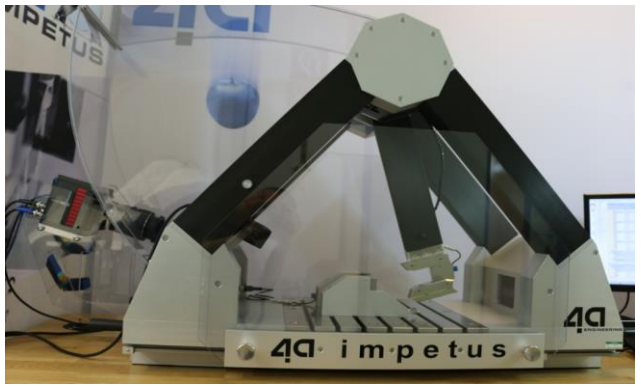


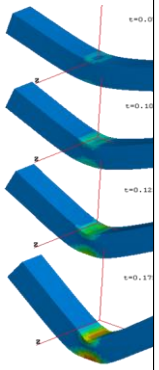
$$a_{ij} = \begin{bmatrix} 0{,}66 & 0 & 0 \\ 0 & 0{,}32 & 0 \\ 0 & 0 & 0{,}02 \end{bmatrix}$$

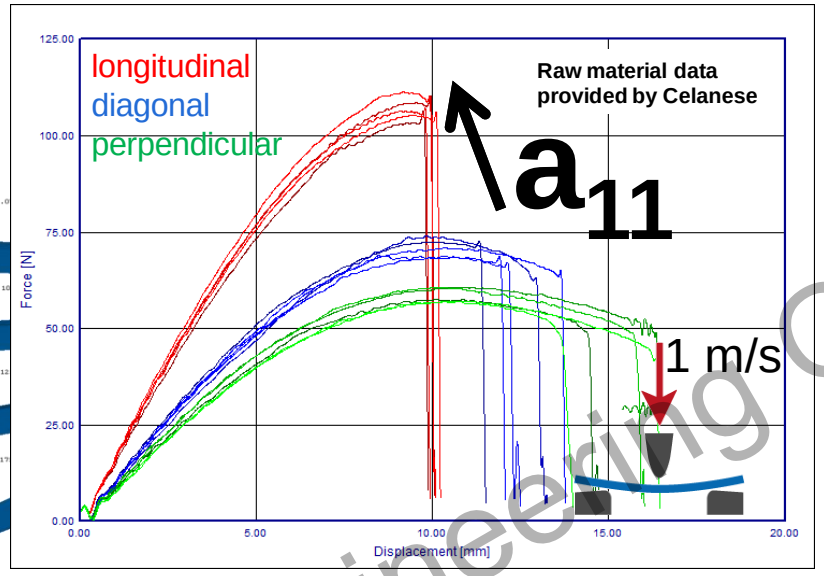
Source: P. Reithofer - *Integrative Simulation – Berücksichtigung der prozessbedingten Anisotropie,* 4a Technologietag 2011

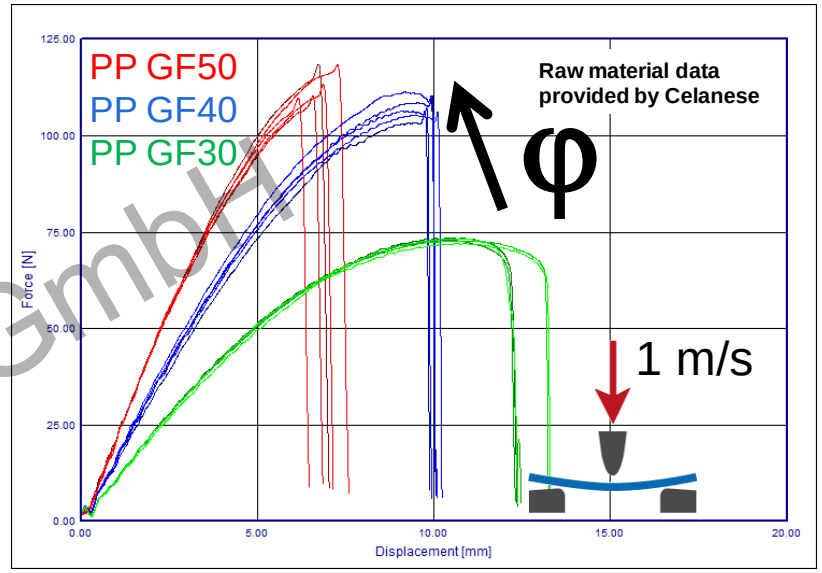
Typical material behavior – SFRT / LFRT

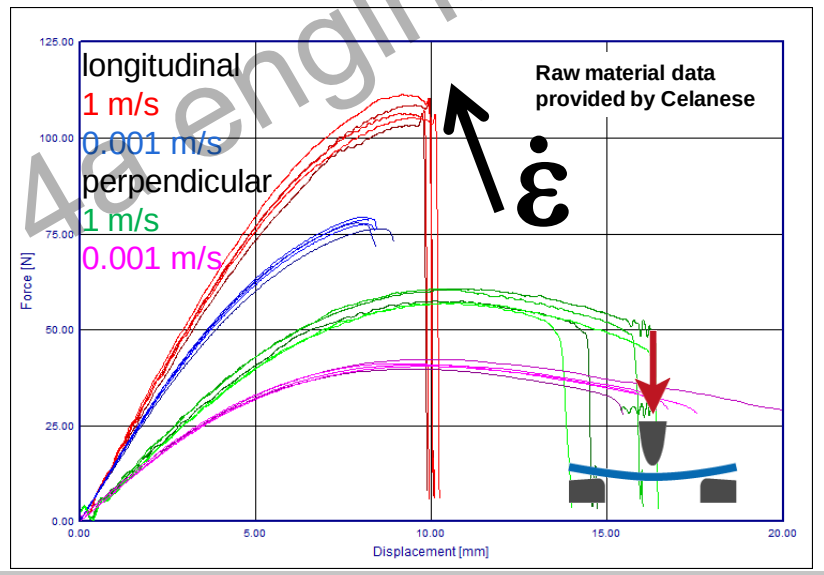
IMPETUS

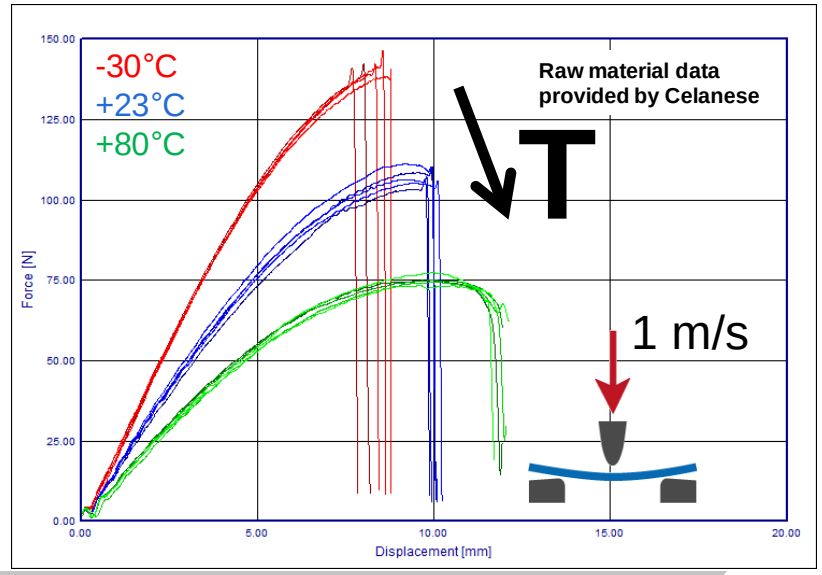




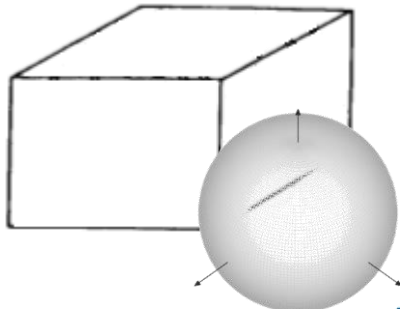


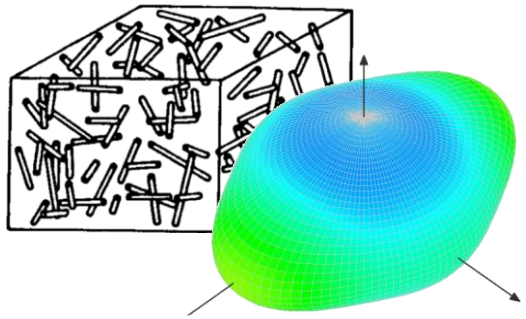






Typical material models in LS-DYNA





Hill plasticity → „extended“ von Mises

$$\sigma_{eq} = \sqrt{F(\sigma_{22}-\sigma_{33})^2 + G(\sigma_{33}-\sigma_{11})^2 + H(\sigma_{11}-\sigma_{22})^2 + \cdots}$$

macro scale

constitutiv law → composi

Mises plasticity

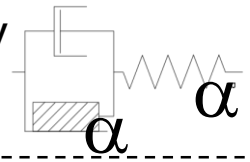
- quick & d
- criti g
  t
  orientation

elastic

- orthotro
- aniso
- elasti stic
- city

*MAT_024

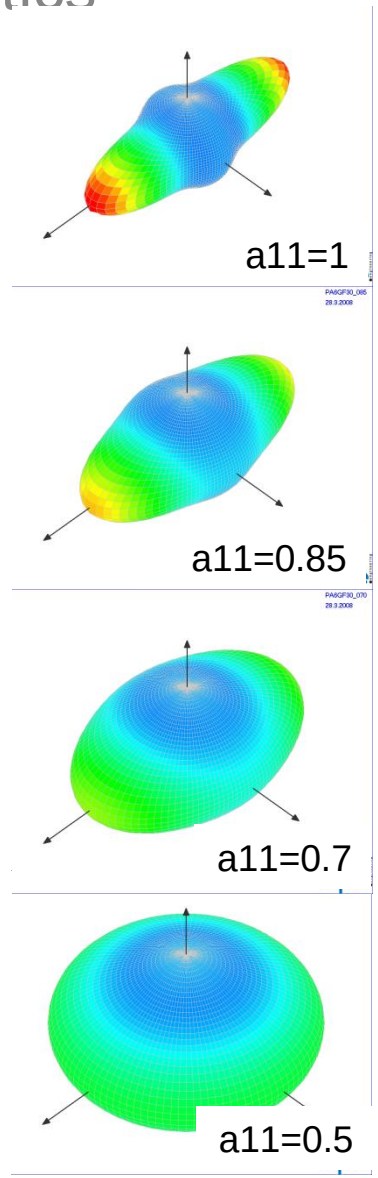
*MAT_157



α – orientation dependent

material models in LS DYNA – short and long fiber reinforced thermoplastics

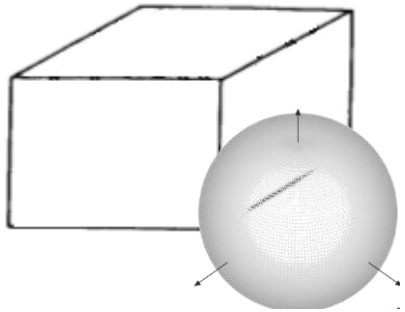
description	variables	Number of variables	dependencies
anisotropic stiffness	Cij	21	$C_{ij}\left(a_{ij},\varphi,C^{M},C^{F}\right)$
Hill plasticity	3D: F, G, H, L, M, N 2D: r00, r45, r90	6	$f\left(a_{ij},\varphi,\sigma^{M},\sigma^{F}\right)$
stress-strain curve	Loadcurve	3	$f\left(a_{ij},\varphi\right)$
failure	Loadcurve	6	$f\left(a_{ij},\varphi\right)$

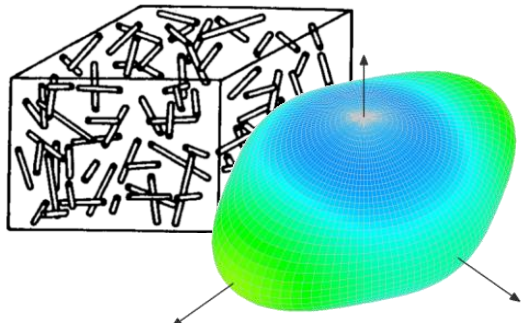


- Not possible to generate samples with **explicit defined and varying a_{ij}**
- **Hard to characterize, too many possibilities in a_{ij}**

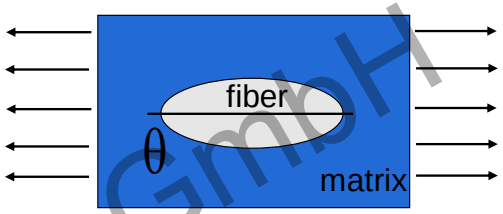
→ Micro mechanical model is needed

Typical material models in LS-DYNA





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



Eshelby Tensor

macro scale

constitutiv law → composi

micro scale

homogenizat

Mises plasticity

- quick & d
- criti g
  t
  orientation

elastic

- orthotro
- aniso

elasti tic

- city

M… matrix

- isotropic elas
  viscoplast

F… fiber

- iso tic

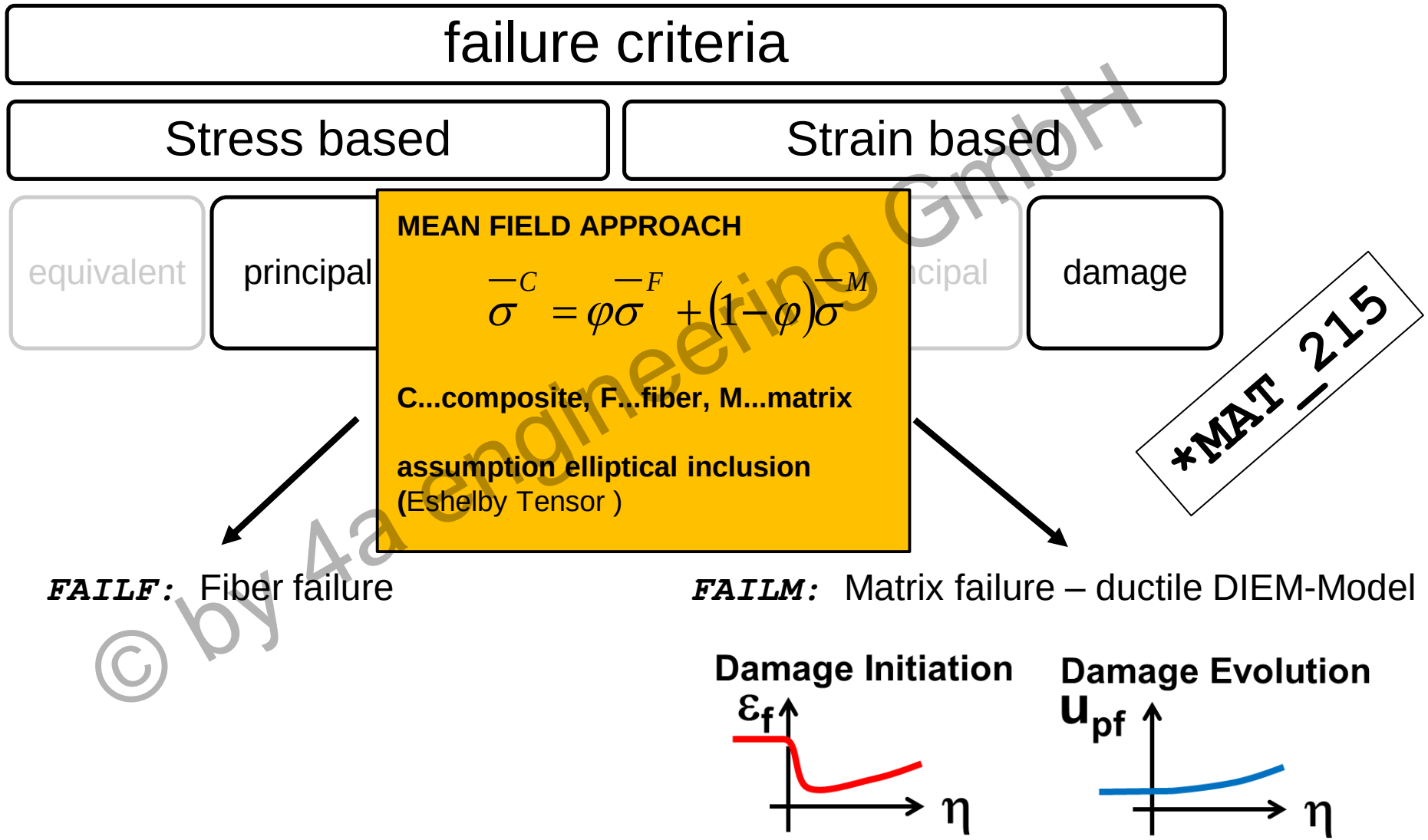
*MAT_024

*MAT_157

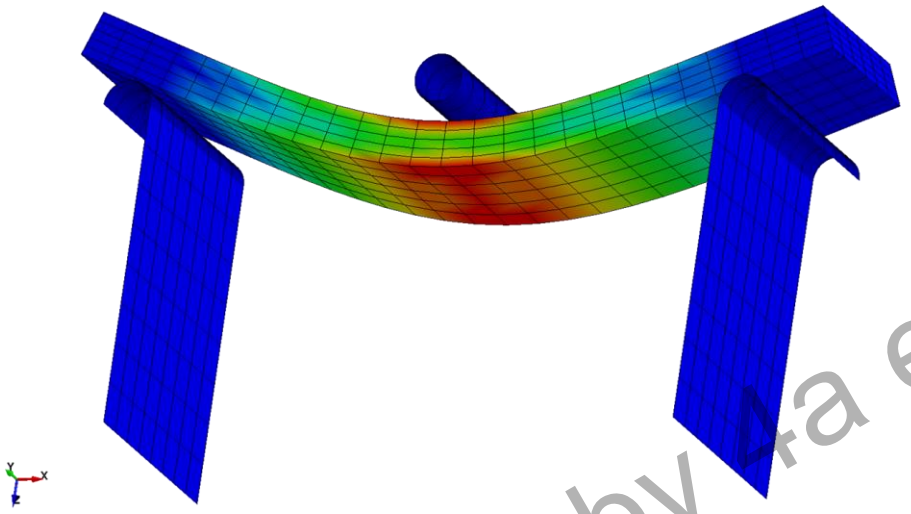
*MAT_215

α – orientation dependent

Micro mechanical motivated failure

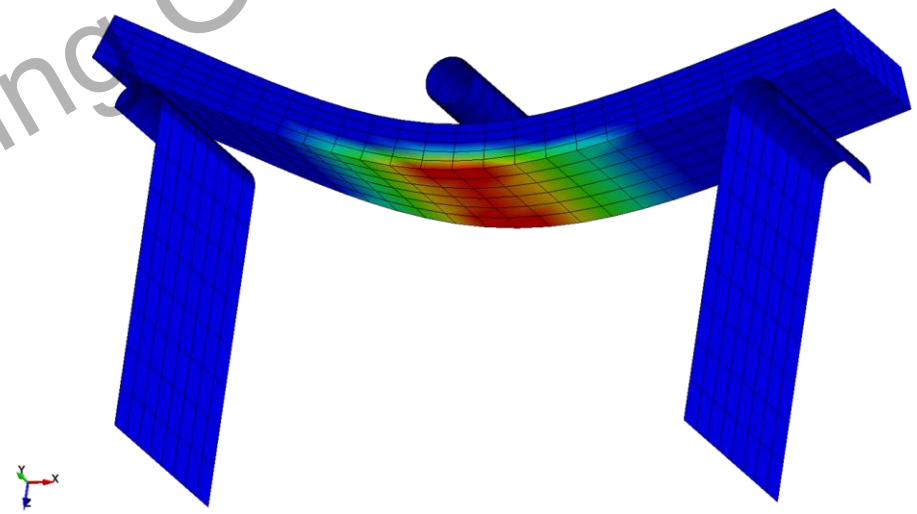


Micro mechanical motivated failure



History#6 (step8: 0-0.13):

Fiber damage init.

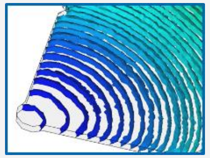


History#4 (step8: 0-0.81):

dm - matrix damage init.

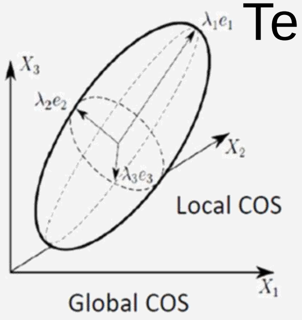
Material models – present approaches

Process simulation



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

Tensor 2nd order



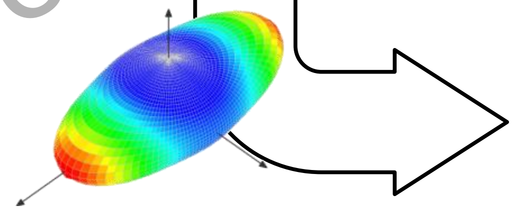
CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

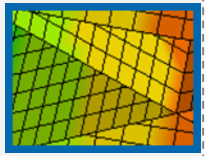
FIBERMAP

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



MICROMEC

Structural simulation



Homogenization (Micro Scale)

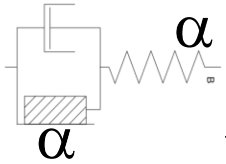
Mean Field Theory

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

*MAT_215

Composite (Macro Scale)

Hill Plasticity



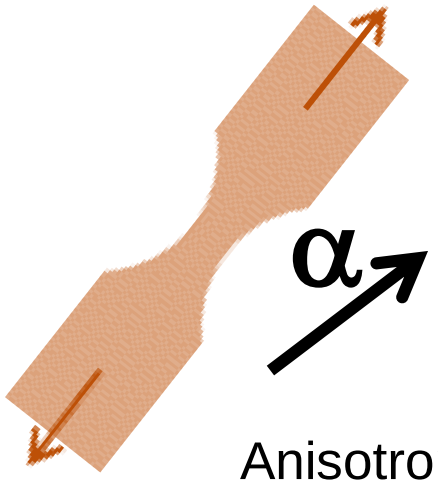
*MAT_157

LSTC Livermore Software Technology Corp. LS-DYNA®

P. Reithofer, A. Fertschej pres_18020901_pr_afer_eng_4aimpetus

P. Reithofer, B. Hirschmann, H. Pothukuchi, St. Kleinermose pres_20062901_pr_bhir_hpot_srie_eng_DYNAMOREexpress-modeling-plastics.pptx

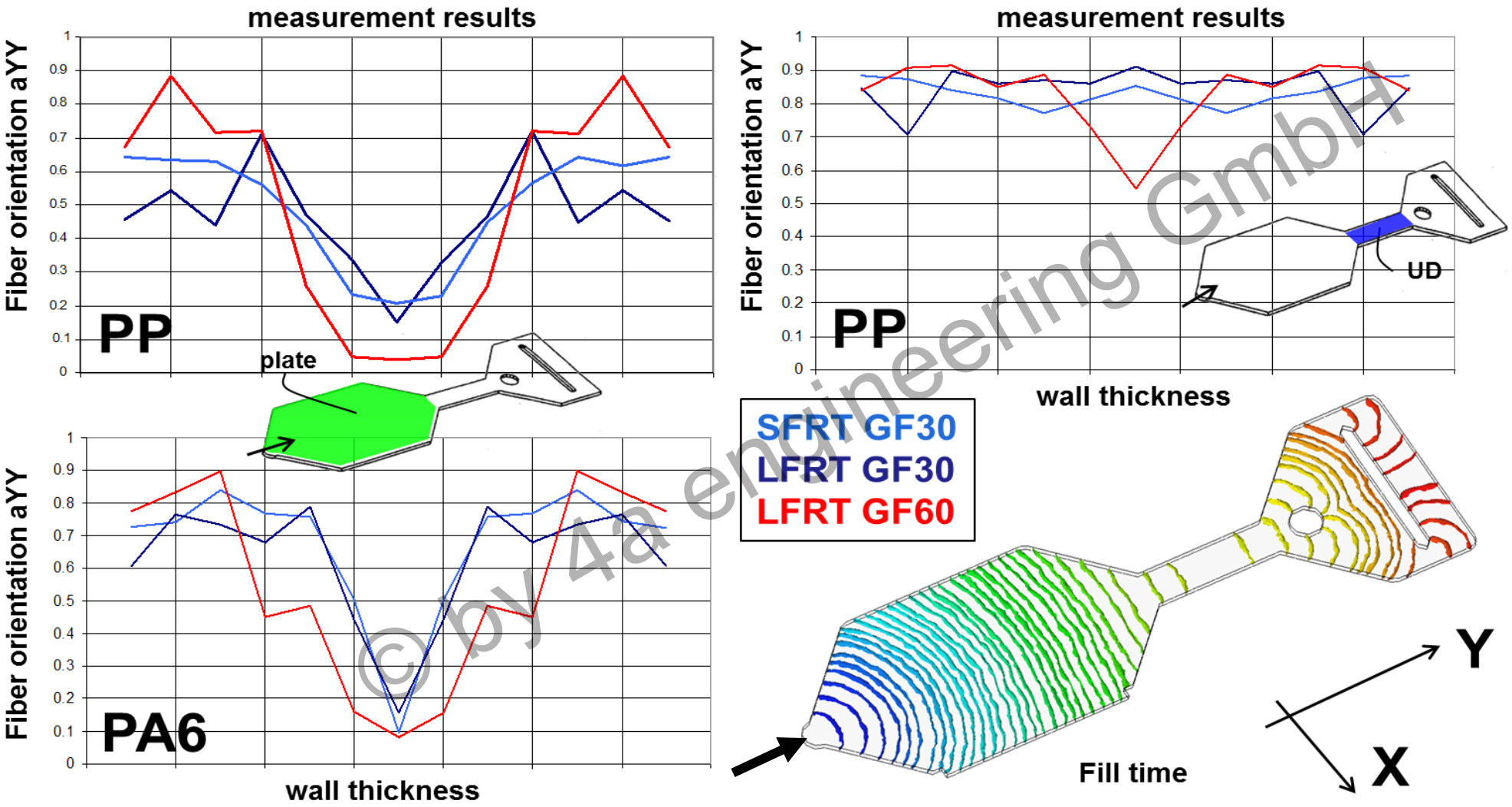
From test to material card



Anisotropic

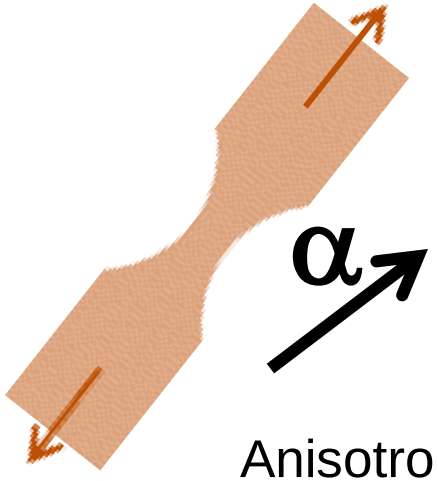
Why not tension (only)?

Fiber orientation – development based on flow / viscosity



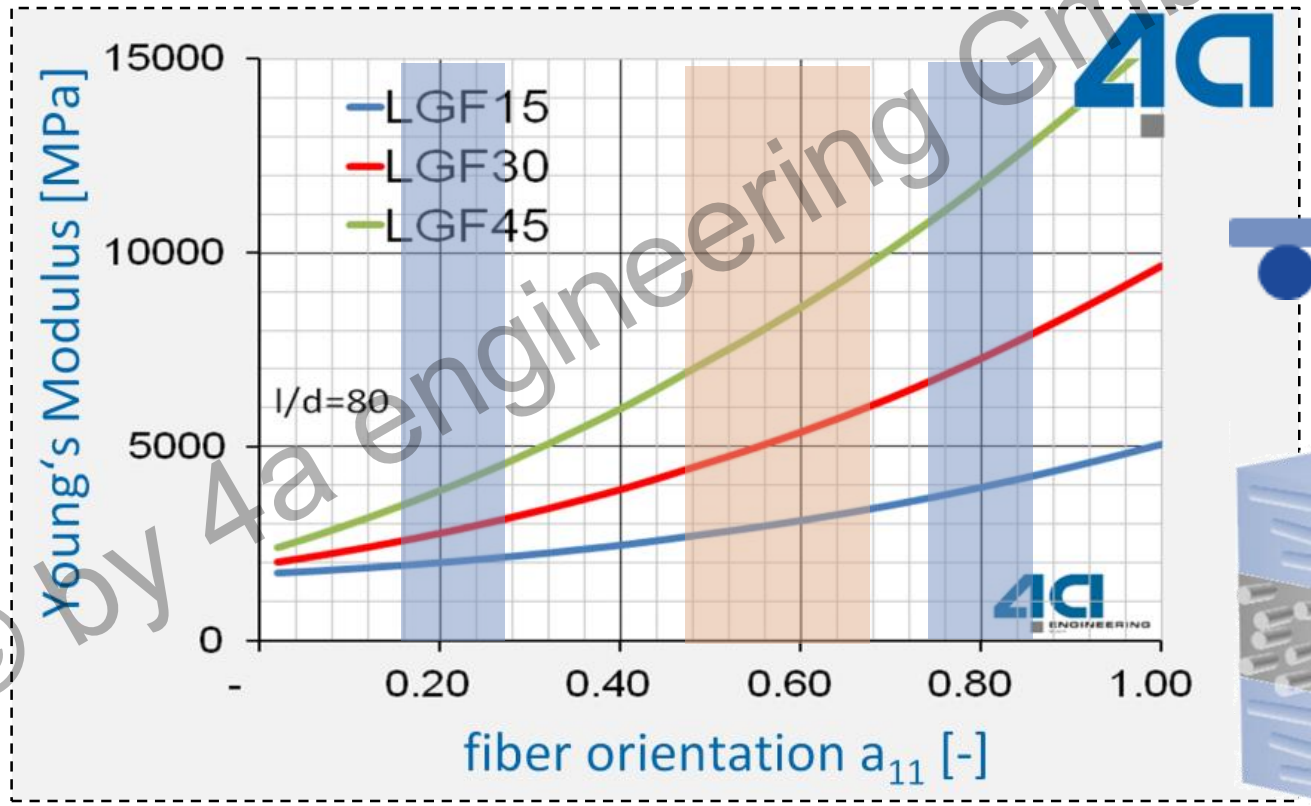
Source: 4a – EU Nelofite project , 2005

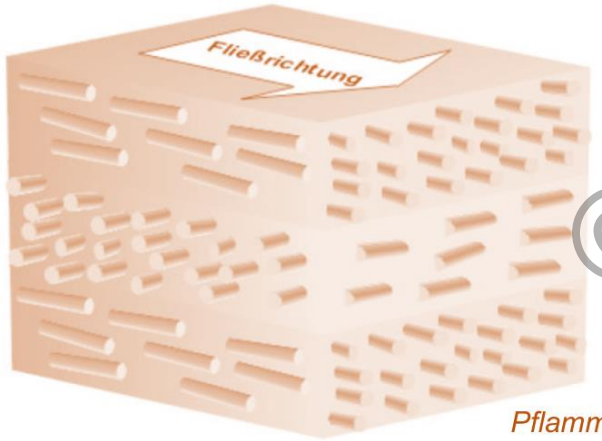
From test to material card



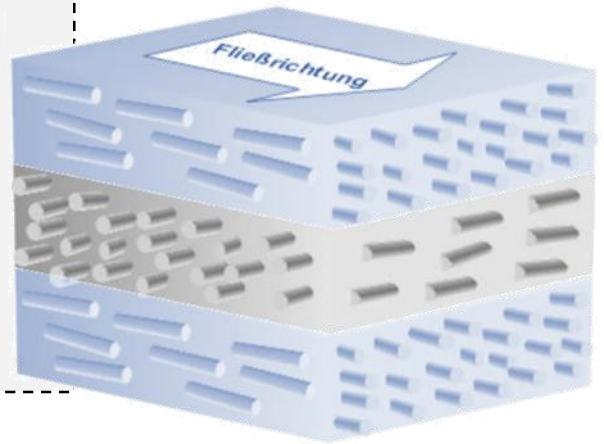
Anisotropic

Why not tension (only)?

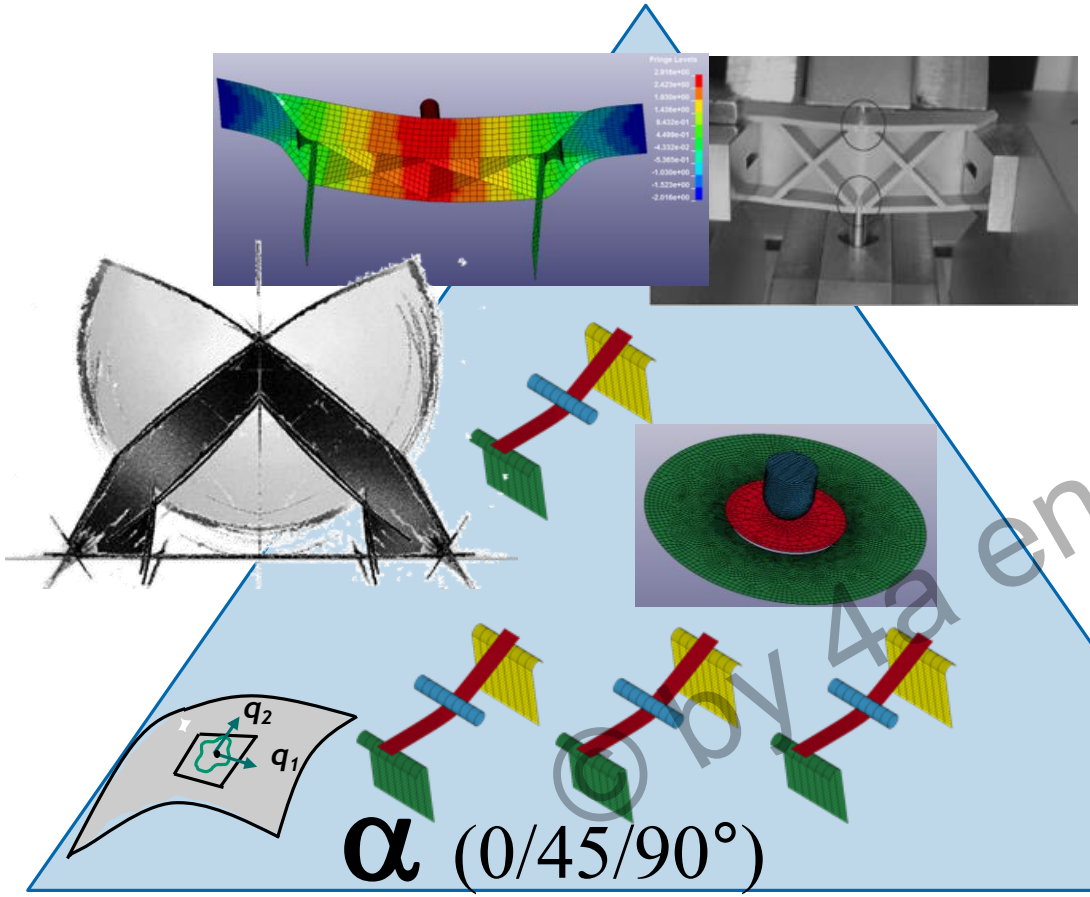




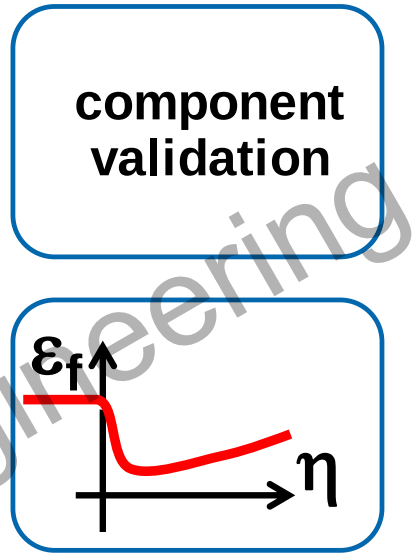
Pflamm-Jonas 2001

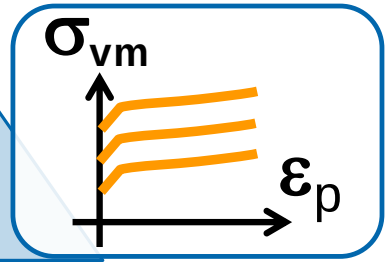


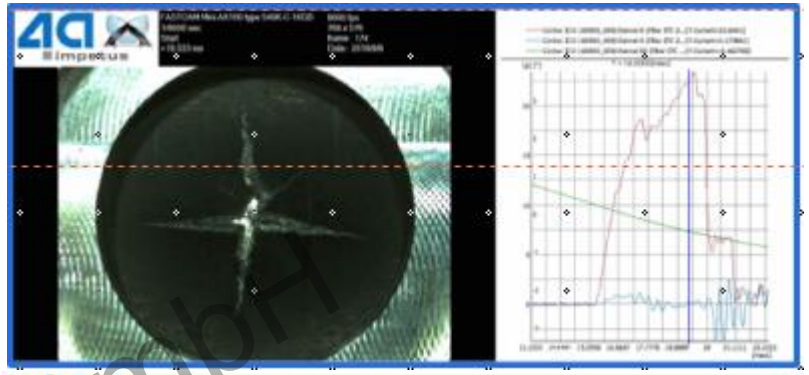
From test to material card

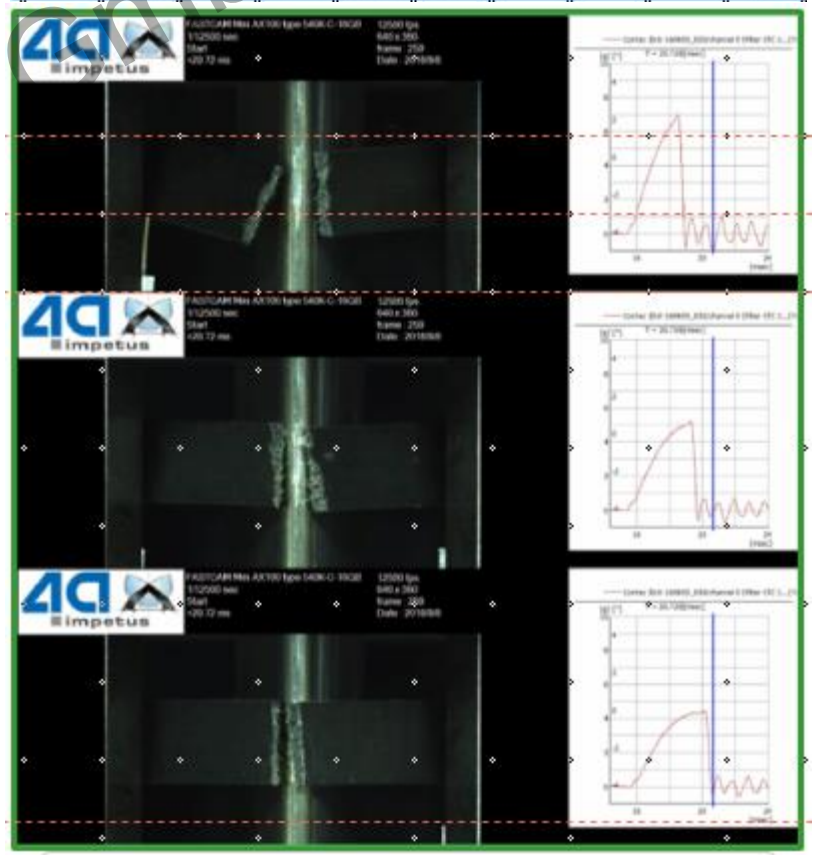


component validation









Source: P Reithofer, et.al., failure criteria SFRT and LFRT,

How to get *MAT_215 ?

VALIMAT

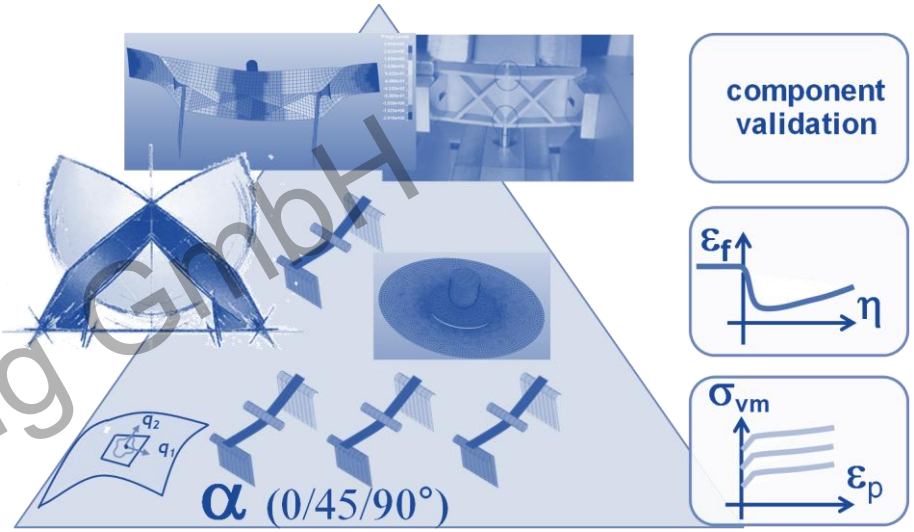
fiber

- mechanical properties
- fiber content
- aspect ratio
- fiber orientation

literature

engineering judgement

tests (µCT, ..)



matrix

- pseudo mechanical properties
  - yield
  - hardening
  - failure

REVERSE ENG.

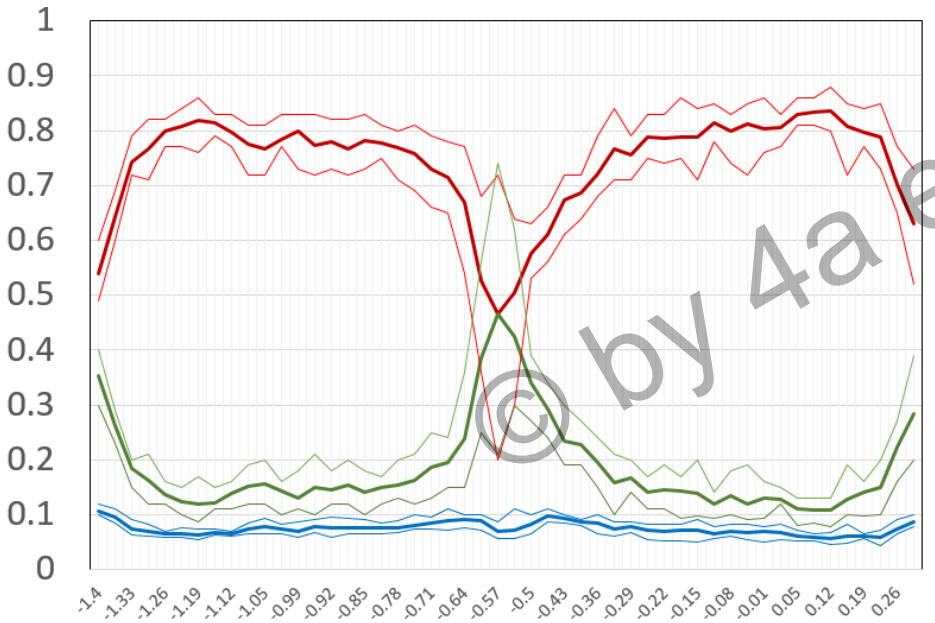
tests

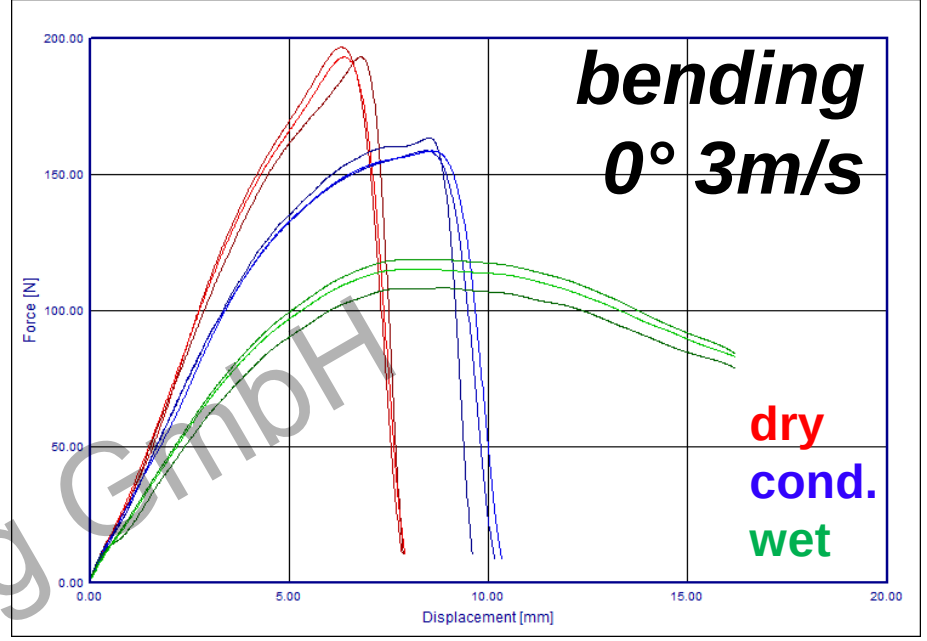
- bending and/or tensile
  - testing in different directions 0°, 30° (45°), 90° sample orientation
- uniaxial and biaxial
- static and dynamic

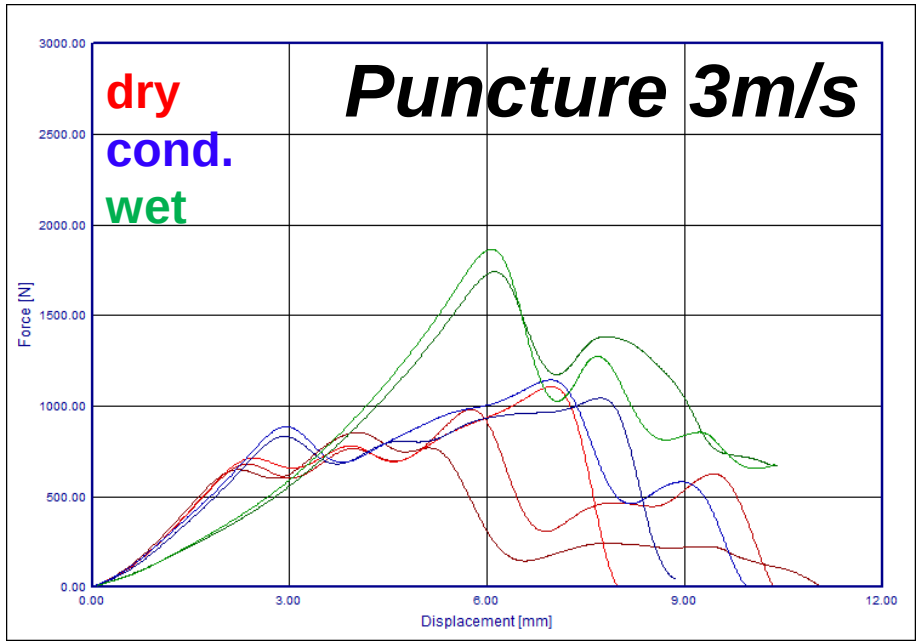
How to get **MAT_215 – case study PA6 GF30 I*

Provided by consortium (PCCL, HILTI, Hirtenberger)

- plaques for puncture tests
- bending samples (0°, ~30°, 90°)
- different moisture contents (dry, cond., wet)
- µCT measurements





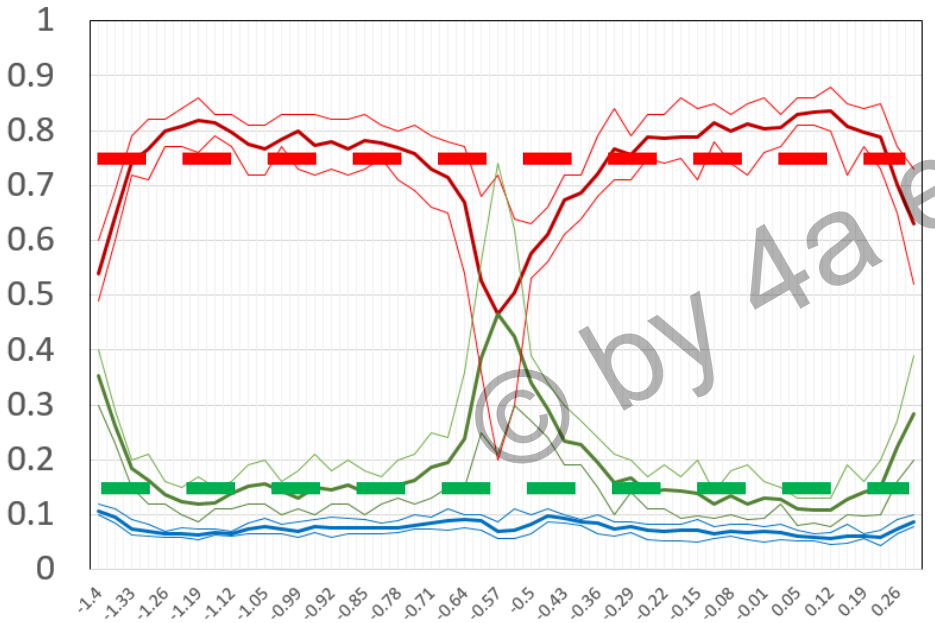


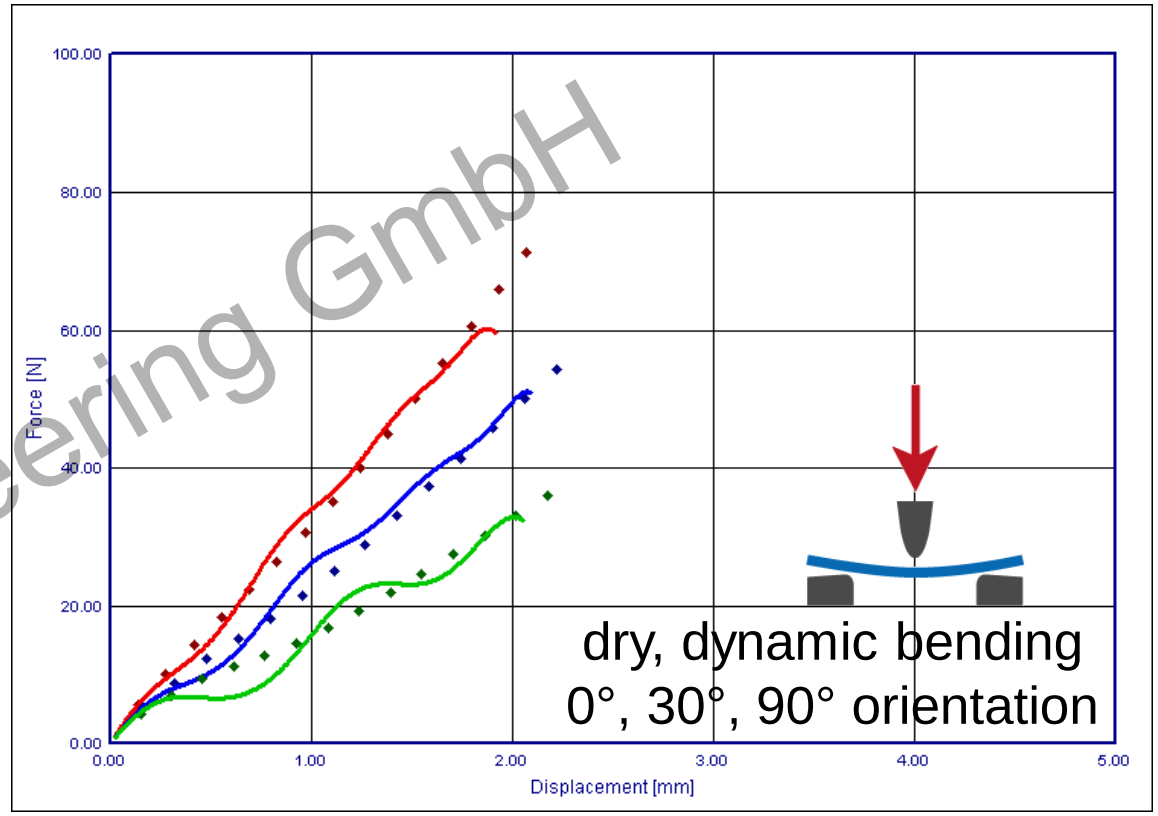
How to get **MAT_215 – case study PA6 GF30 I*

VALIMAT

1st step: set up the composite

- Fiber properties from literature
- Fiber content 30%wt → **-0,3**
- Aspect ratio typical for short fibers l/d=20
- µCT measurements → average



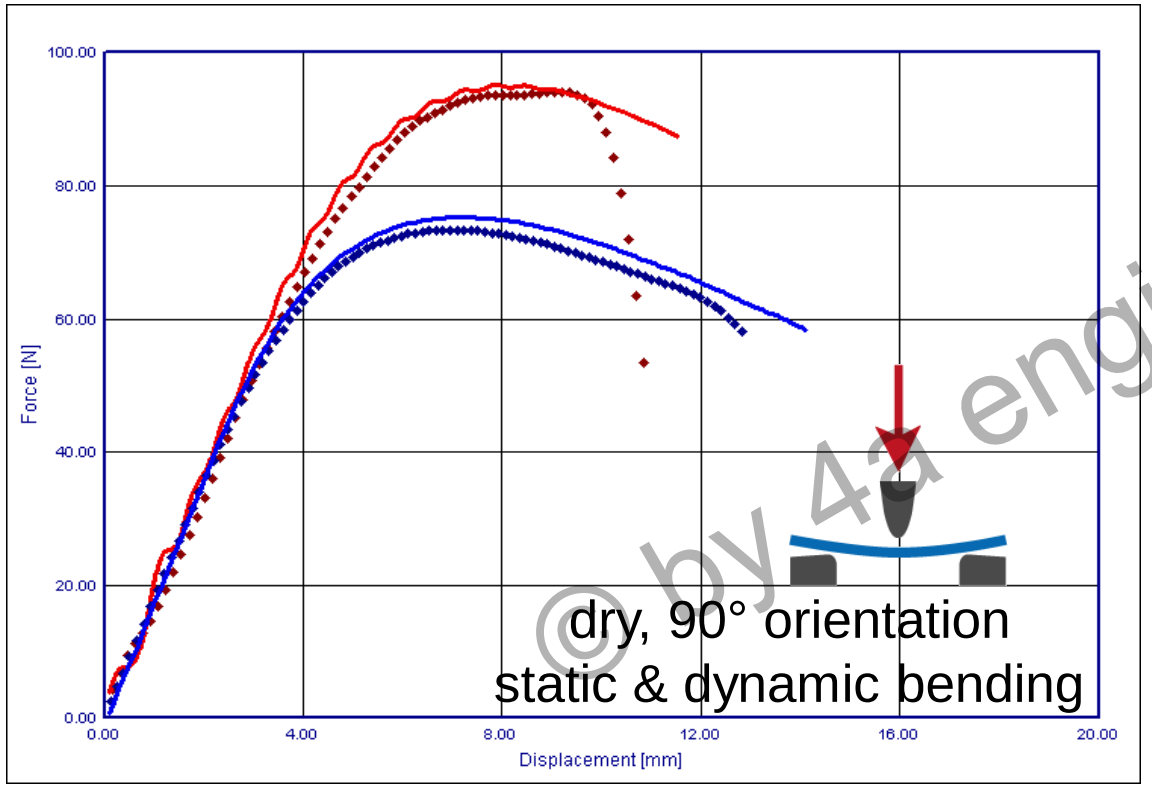


How to get **MAT_215 – case study PA6 GF30 I*

VALIMAT

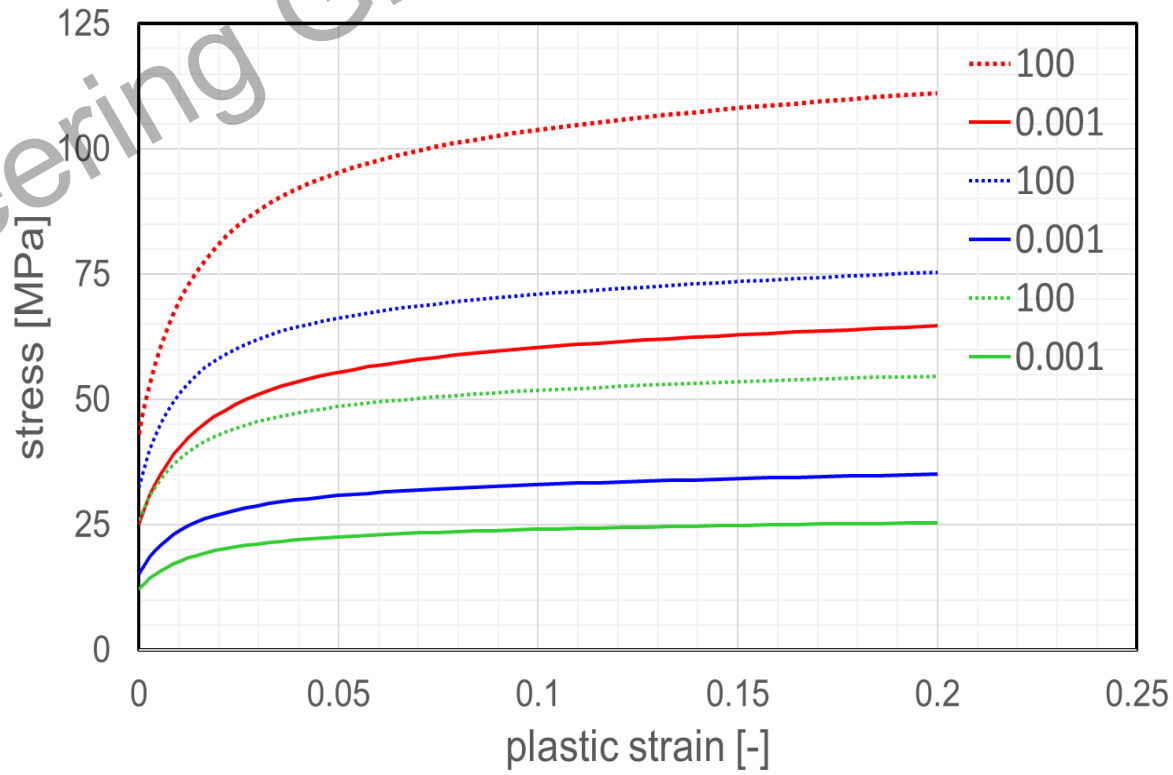
2nd step: matrix hardening

- parameter identification of hardening law



Matrix in dependence of moisture

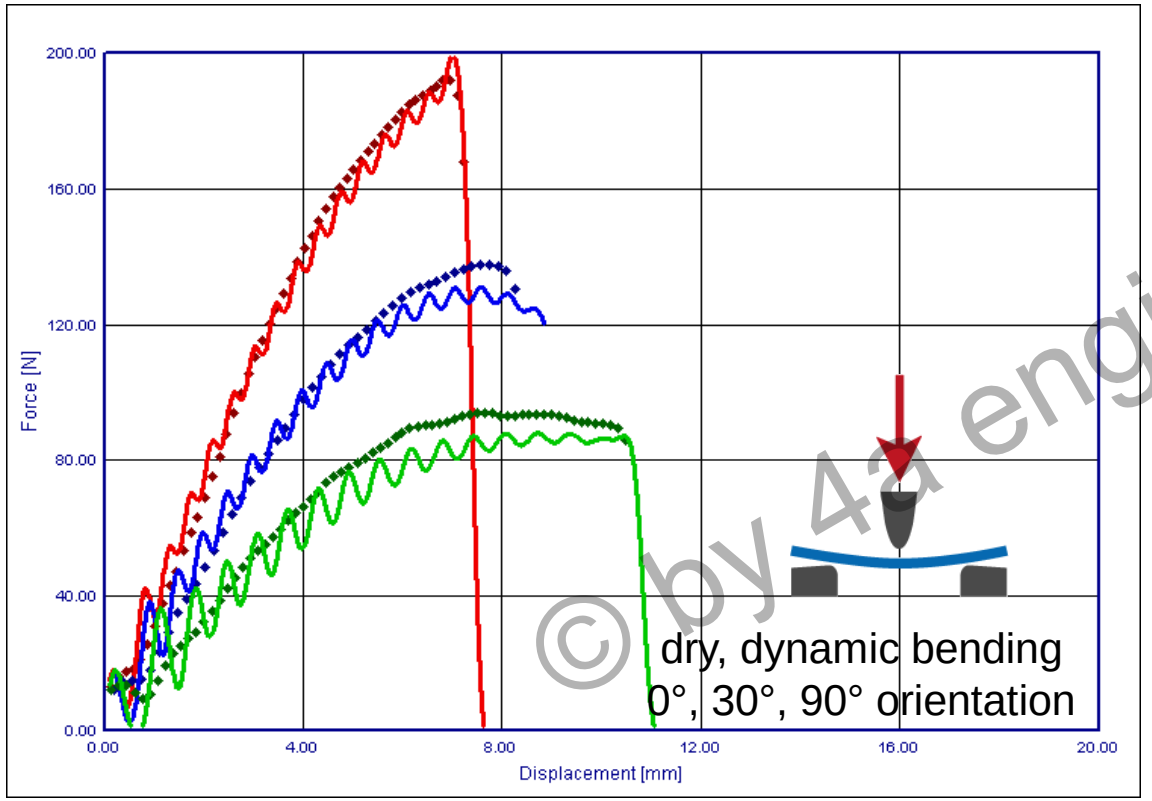
Young's Mod.	dry	cond.	wet
[MPa]	2500	1600	1450



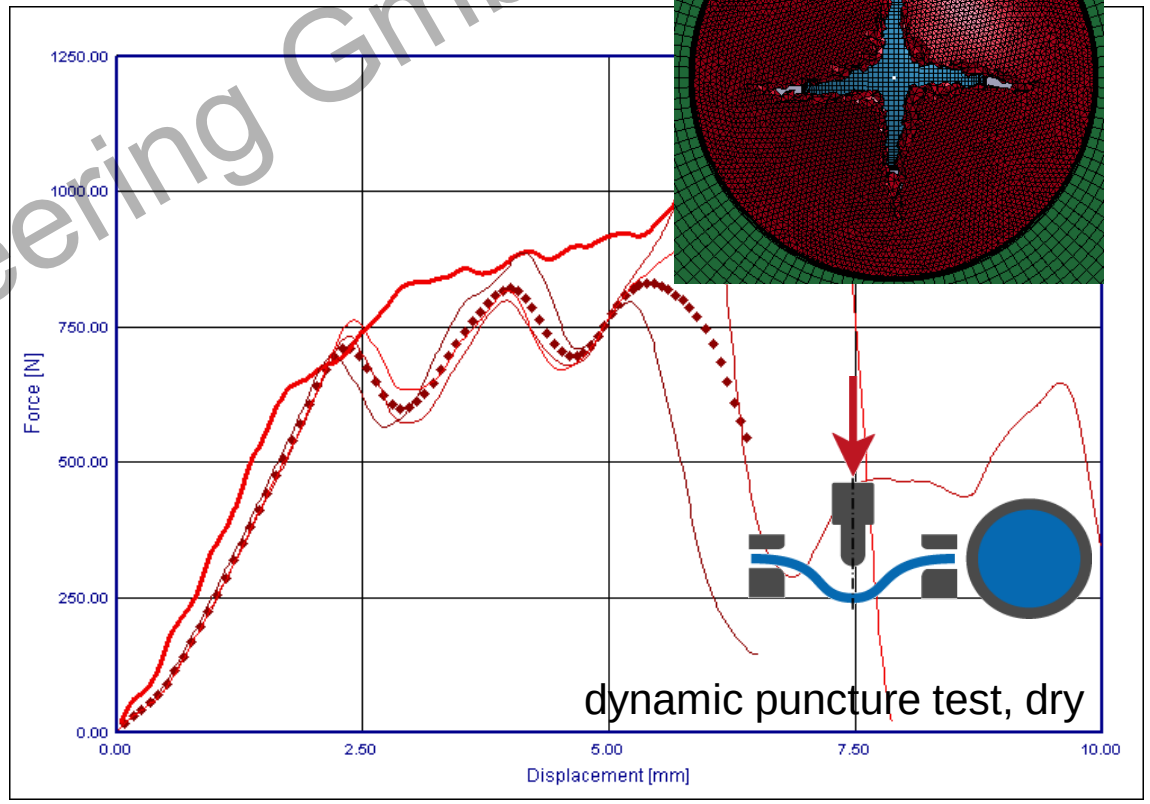
How to get **MAT_215 – case study PA6 GF30 I*

3rd step: validation on dynamic bending

4th step: failure strains

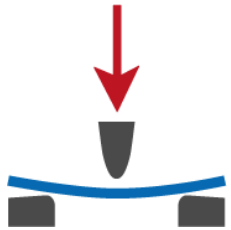


5th step: validation on dynamic puncture

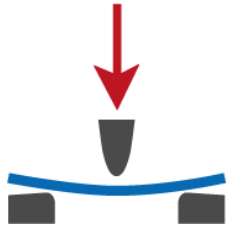


Second material - PA6 GF30 different moisture contents

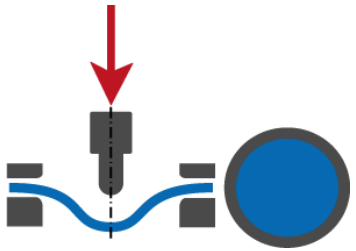
VALIMAT



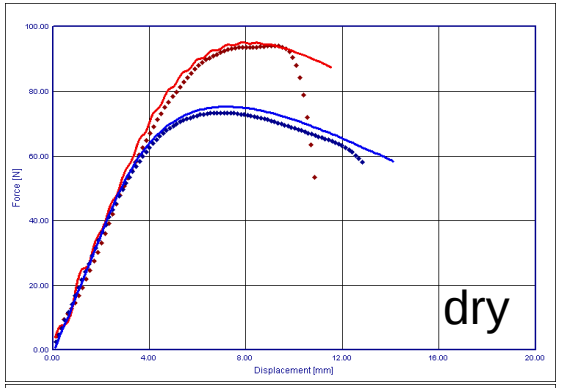
90° orientation
static & dynamic bending

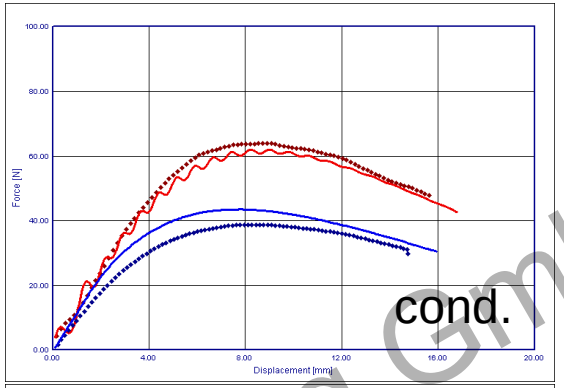


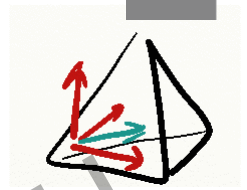
dynamic bending
0°, 30°, 90° orientation



dynamic puncture test

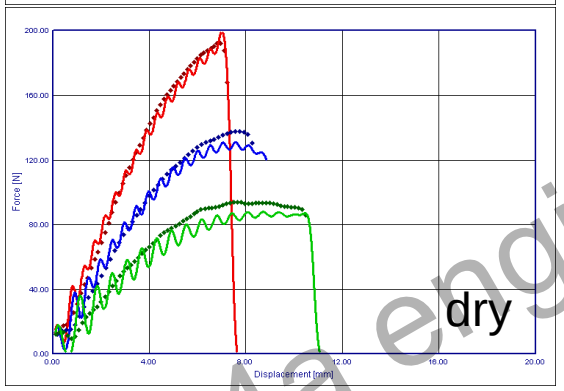


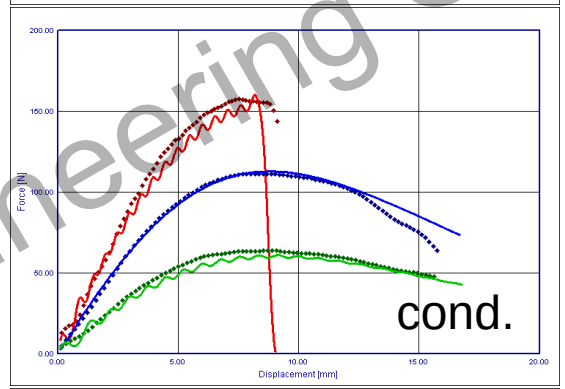


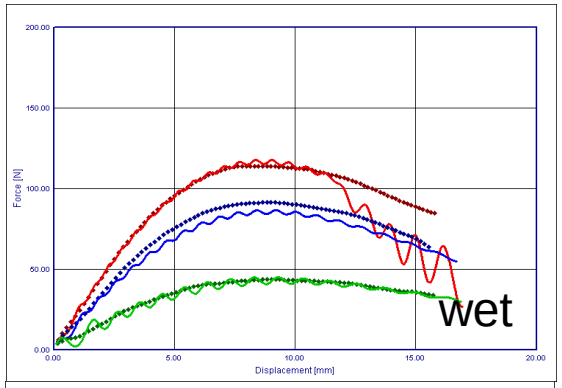


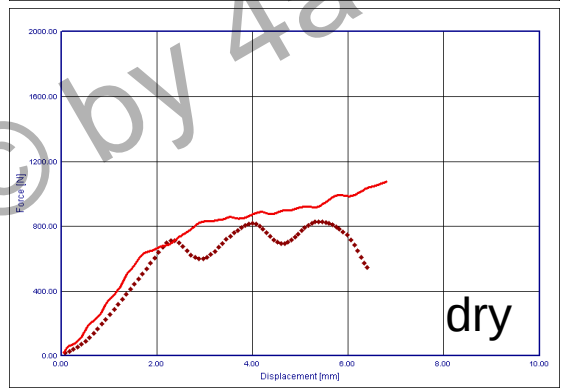
ELTYP4
0.5 mm

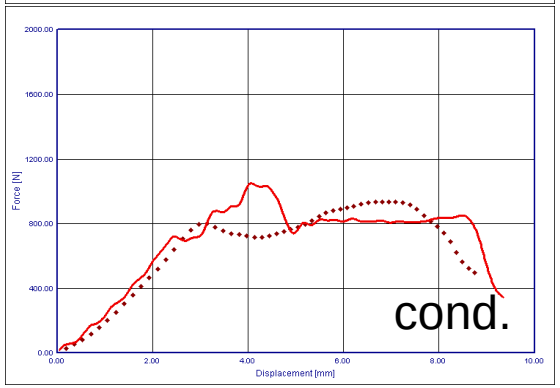
… averaged test curves
— result of simulation

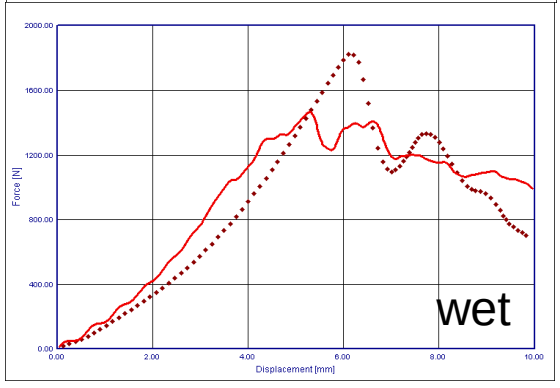










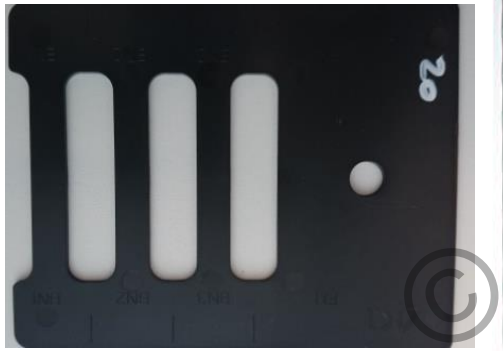


Source: P Reithofer, et.al., failure criteria SFRT and LFRT

injection mold for material characterization

DOM & Wall thickness

Melt- & Weldlines



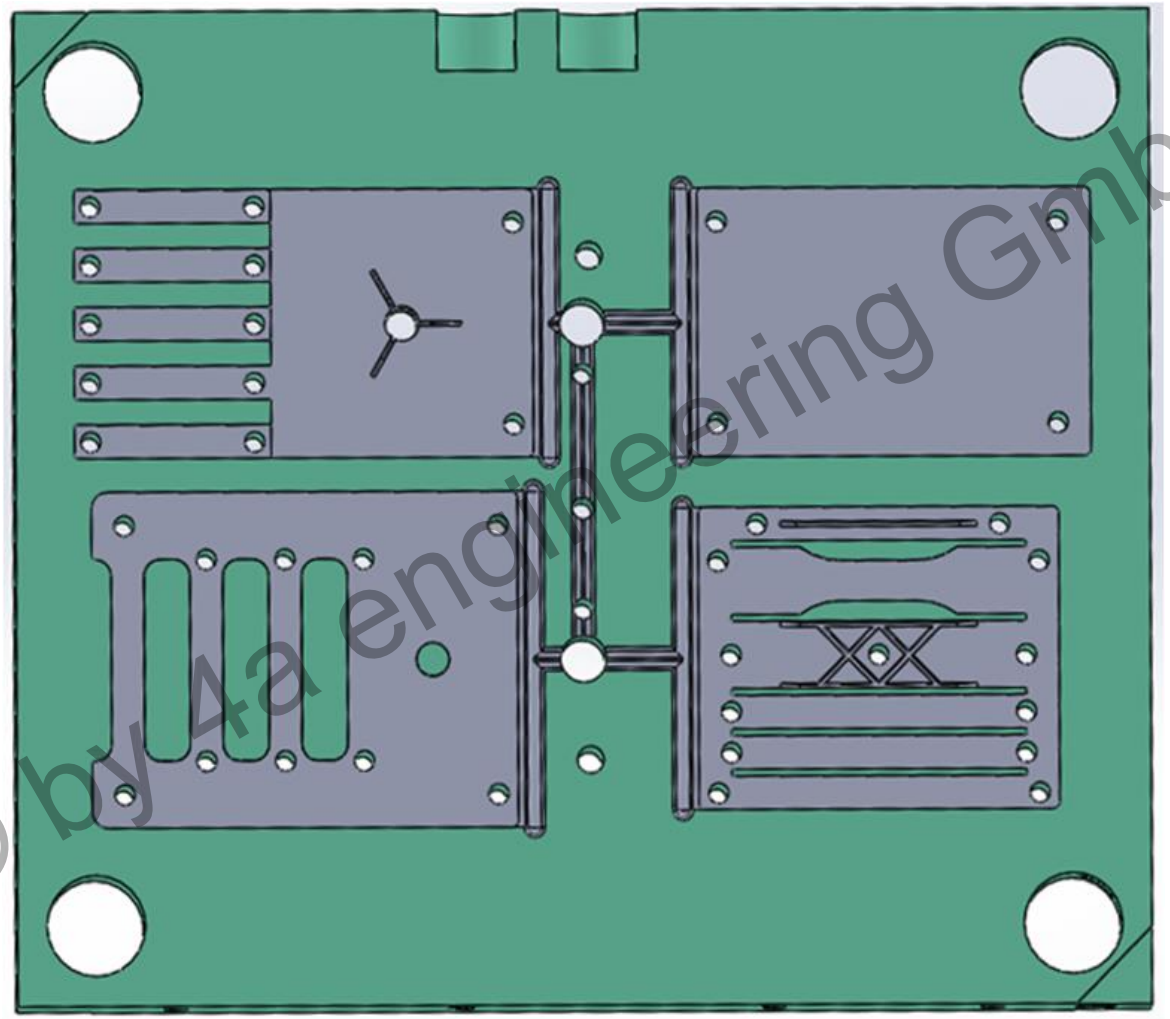
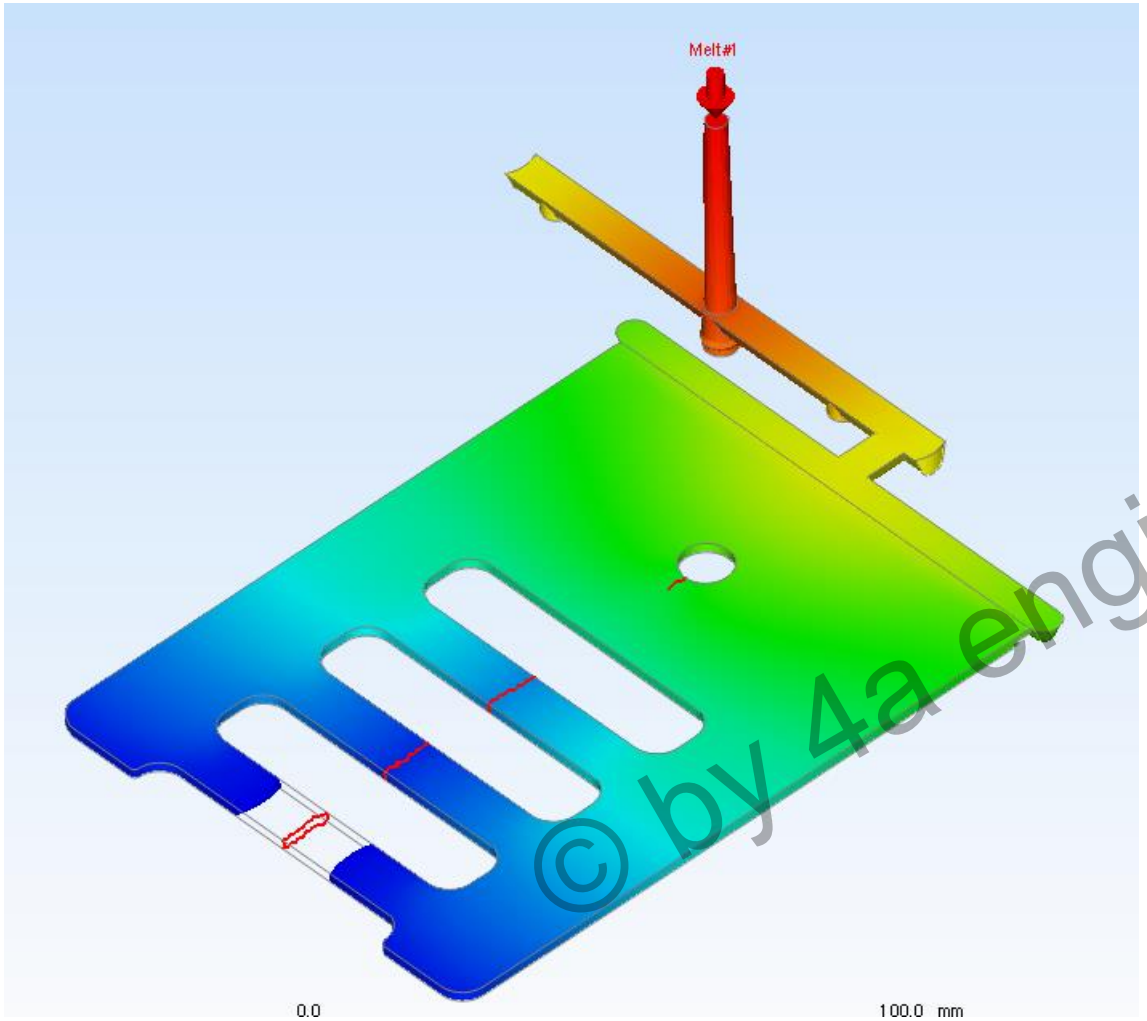
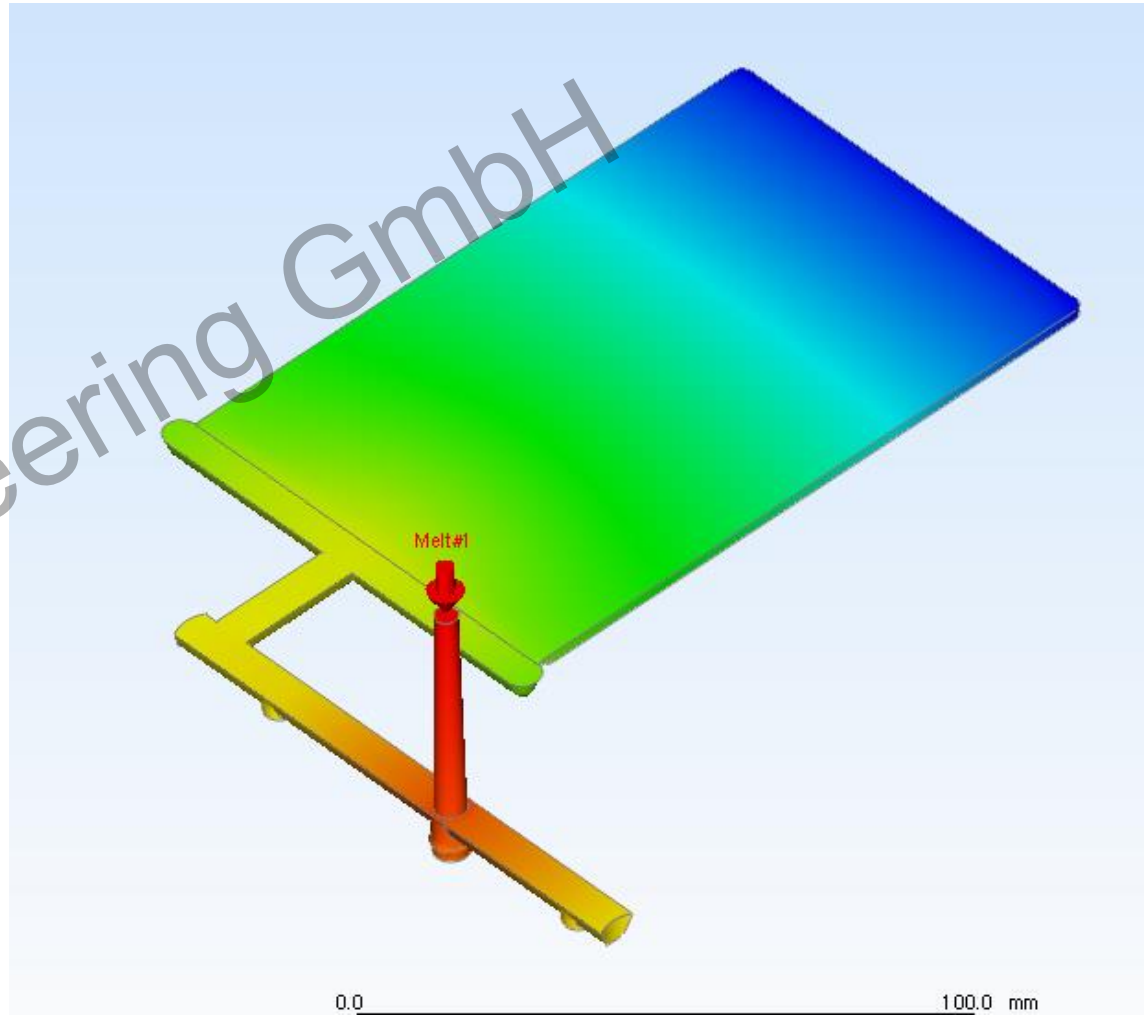


Plate 120 x 80 x 2 mm

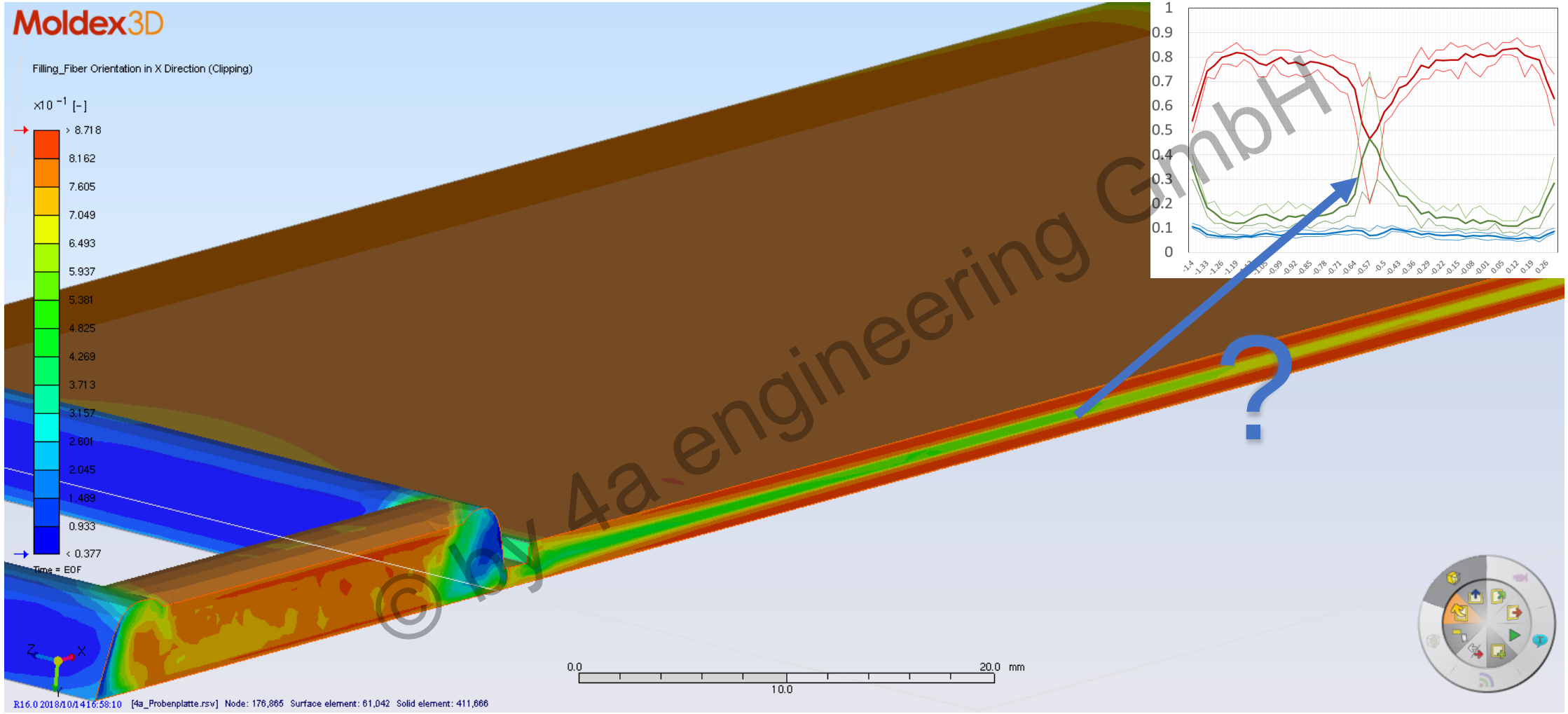
Multi-Specimen &
Rib & Component

injection mold – process simulation



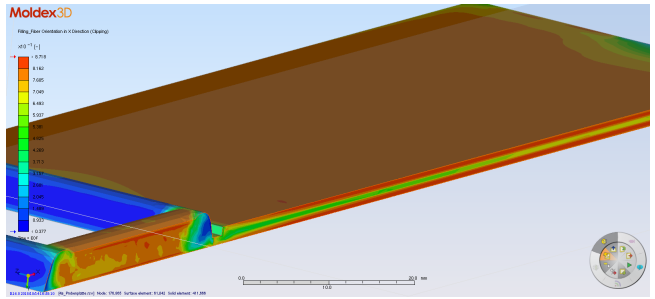


injection mold – process simulation fiber orientation

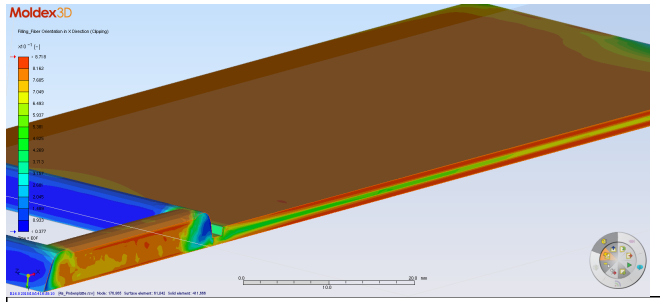


injection mold – process simulation & mapping

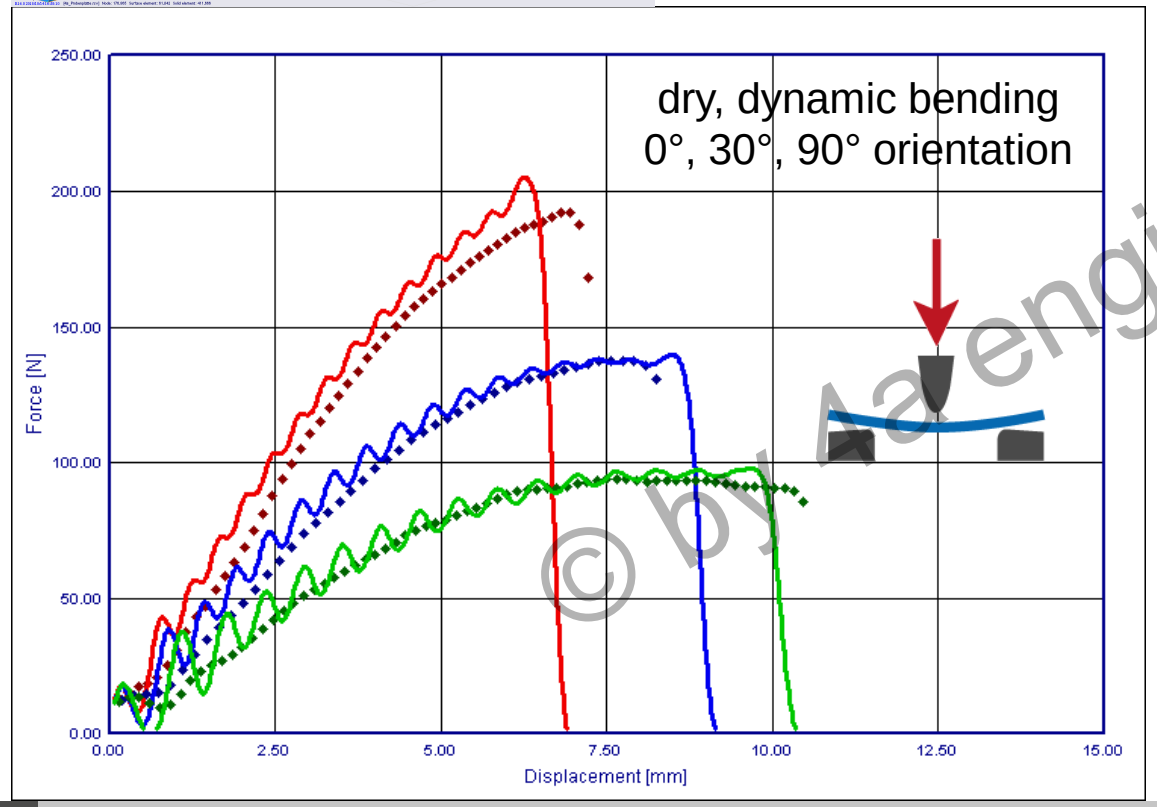
FIBERMAP

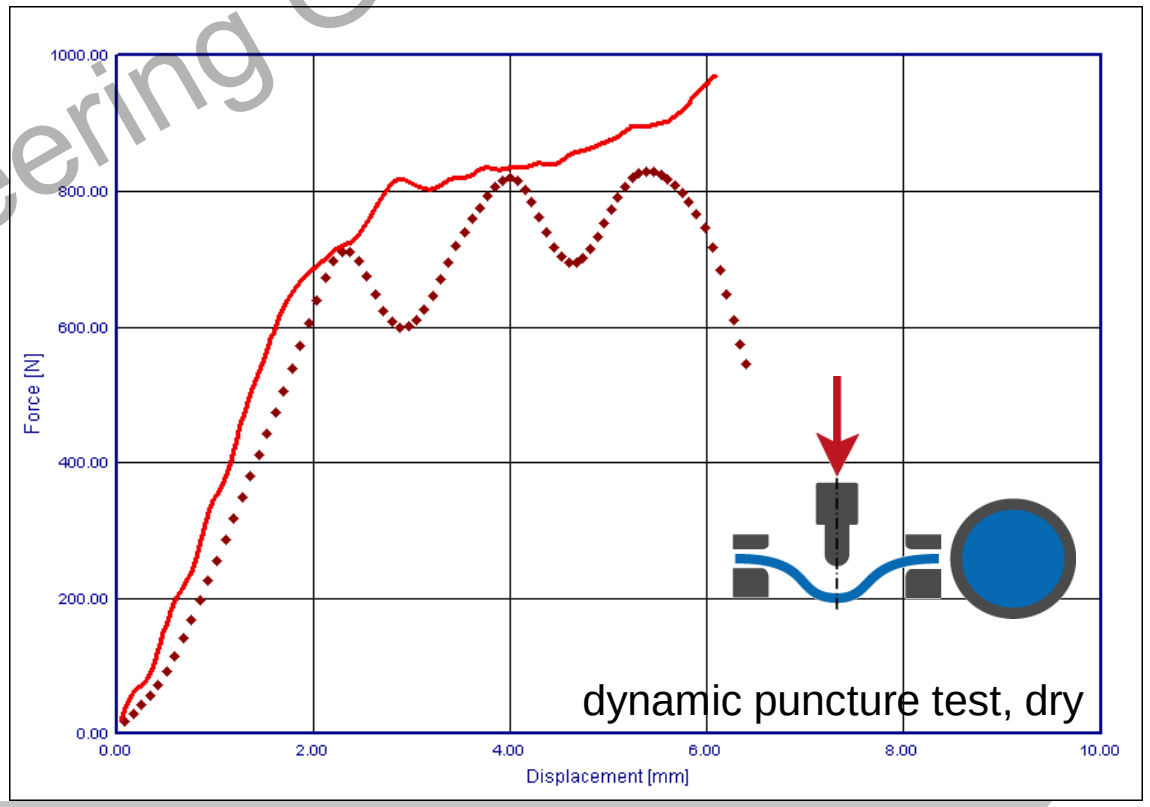


FIBERMAP



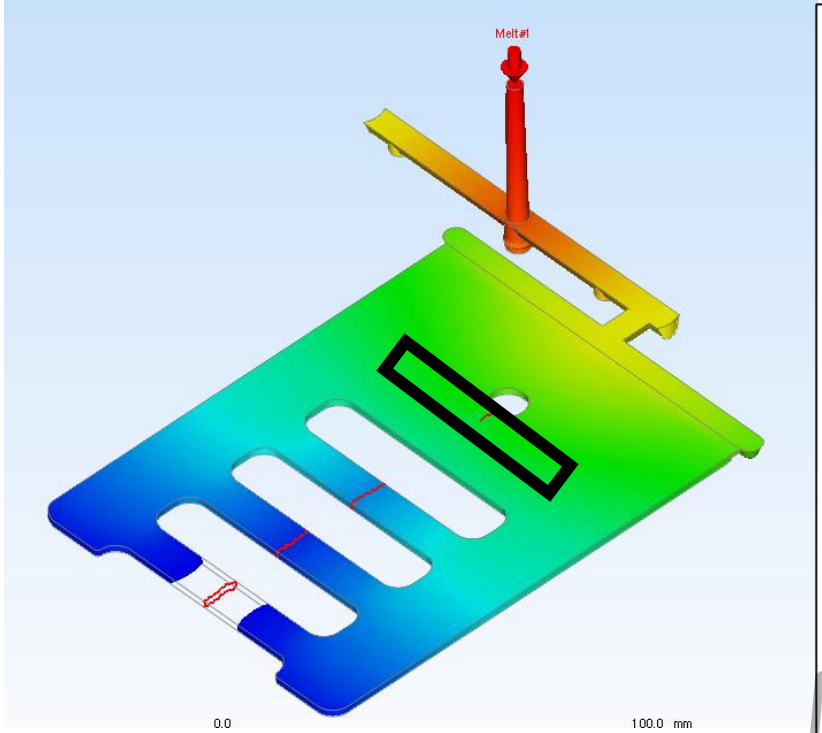
Scale of hardening curve ~20%



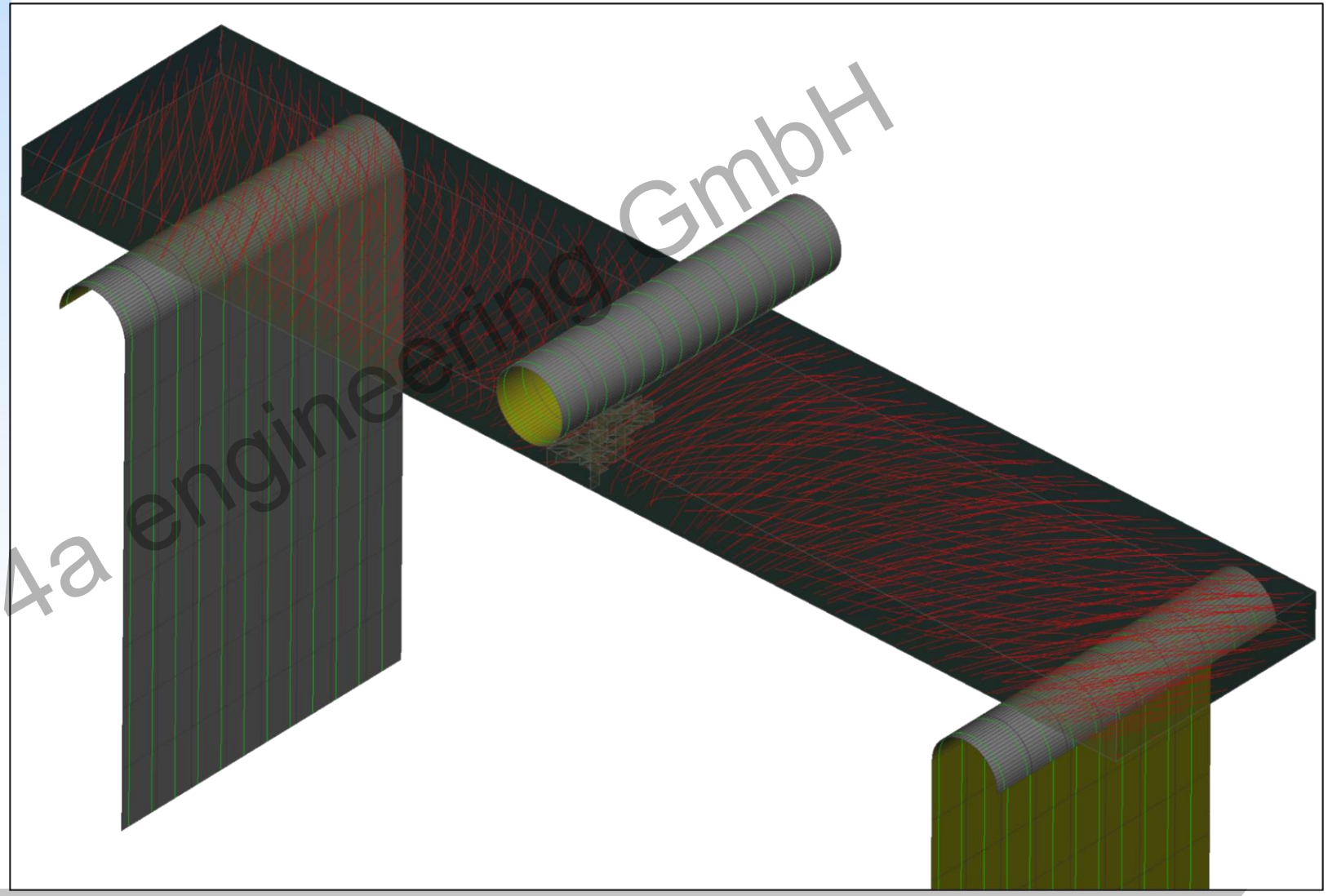


injection mold – process simulation & mapping

FIBERMAP

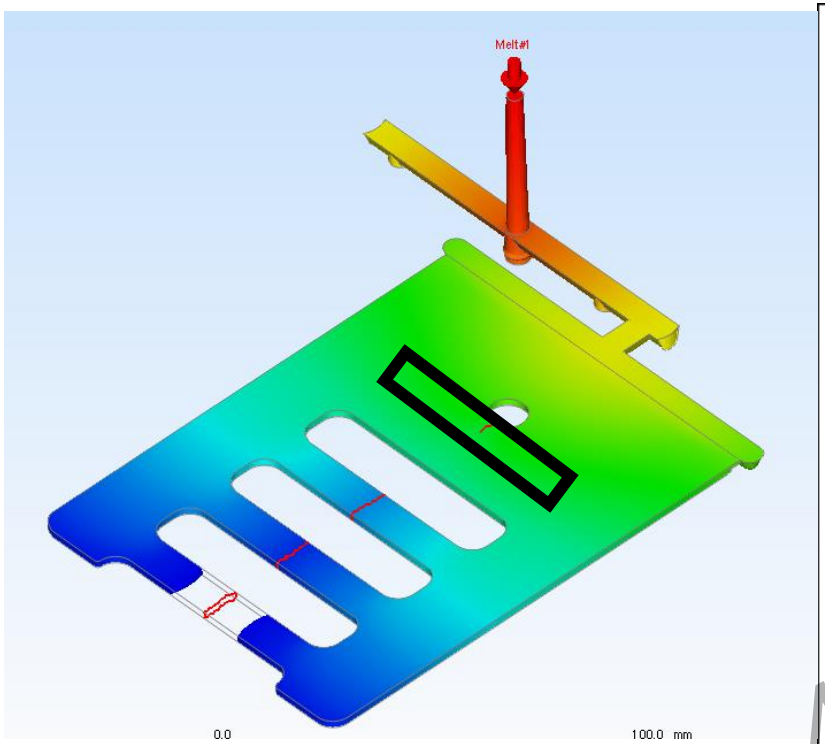


meltline



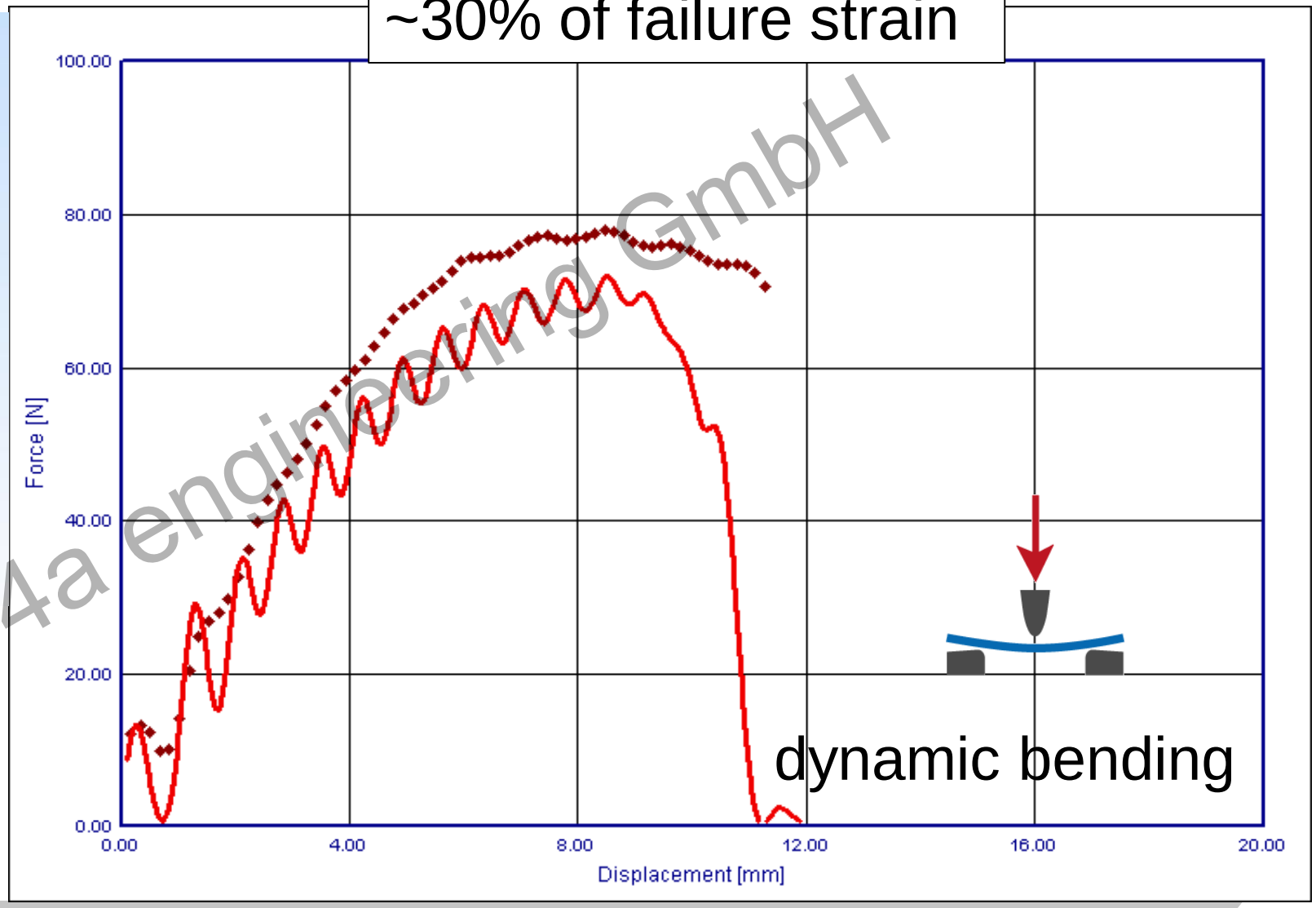
injection mold – process simulation & mapping

FIBERMAP



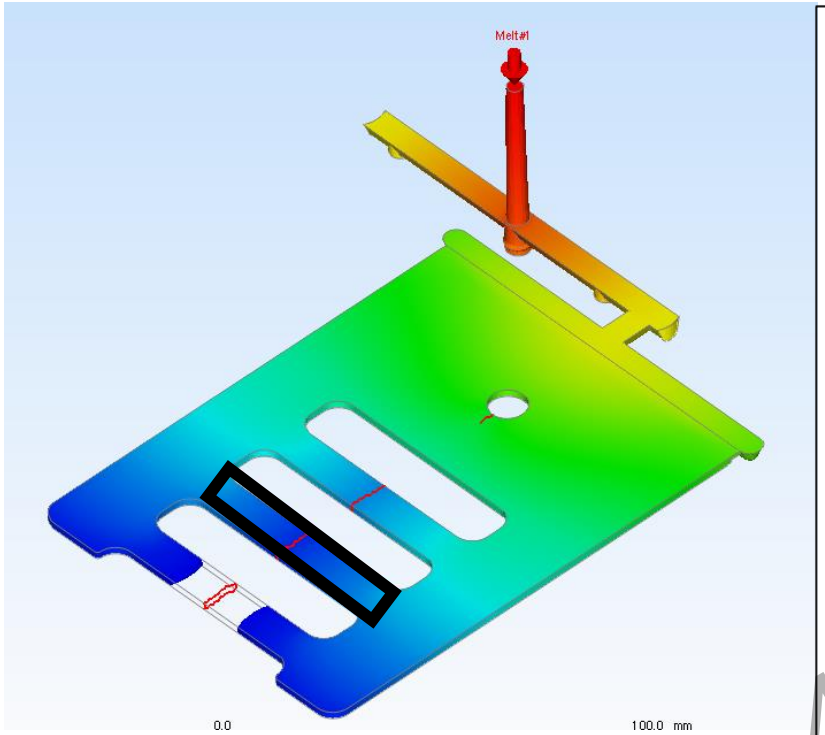
meltline

~30% of failure strain

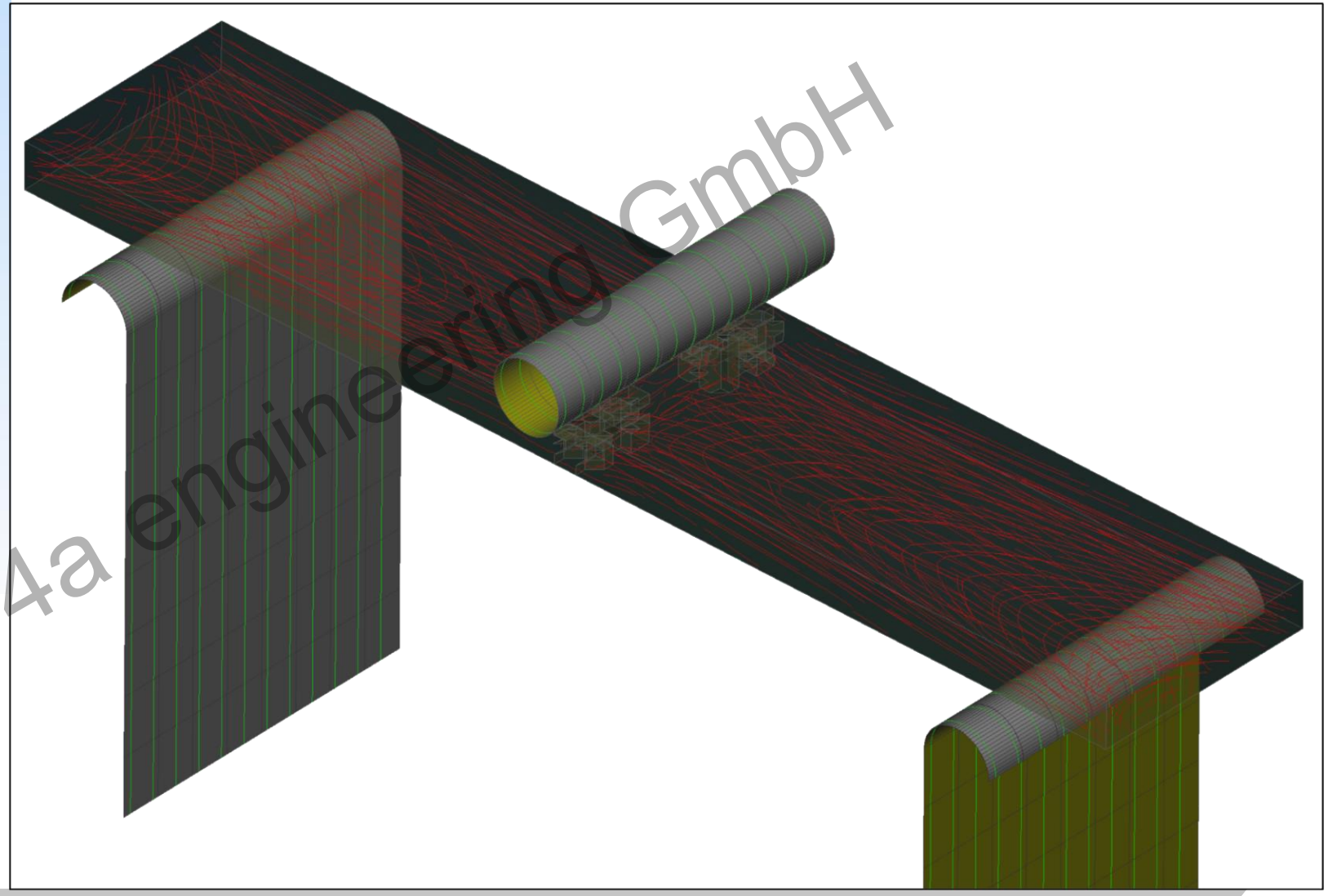


dynamic bending

injection mold – process simulation & mapping

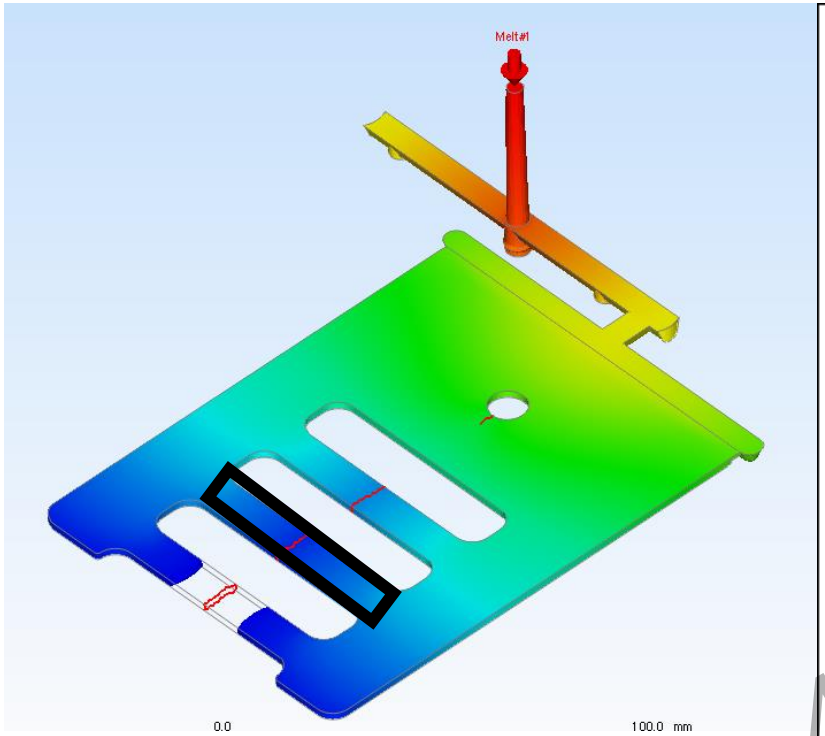


weldline



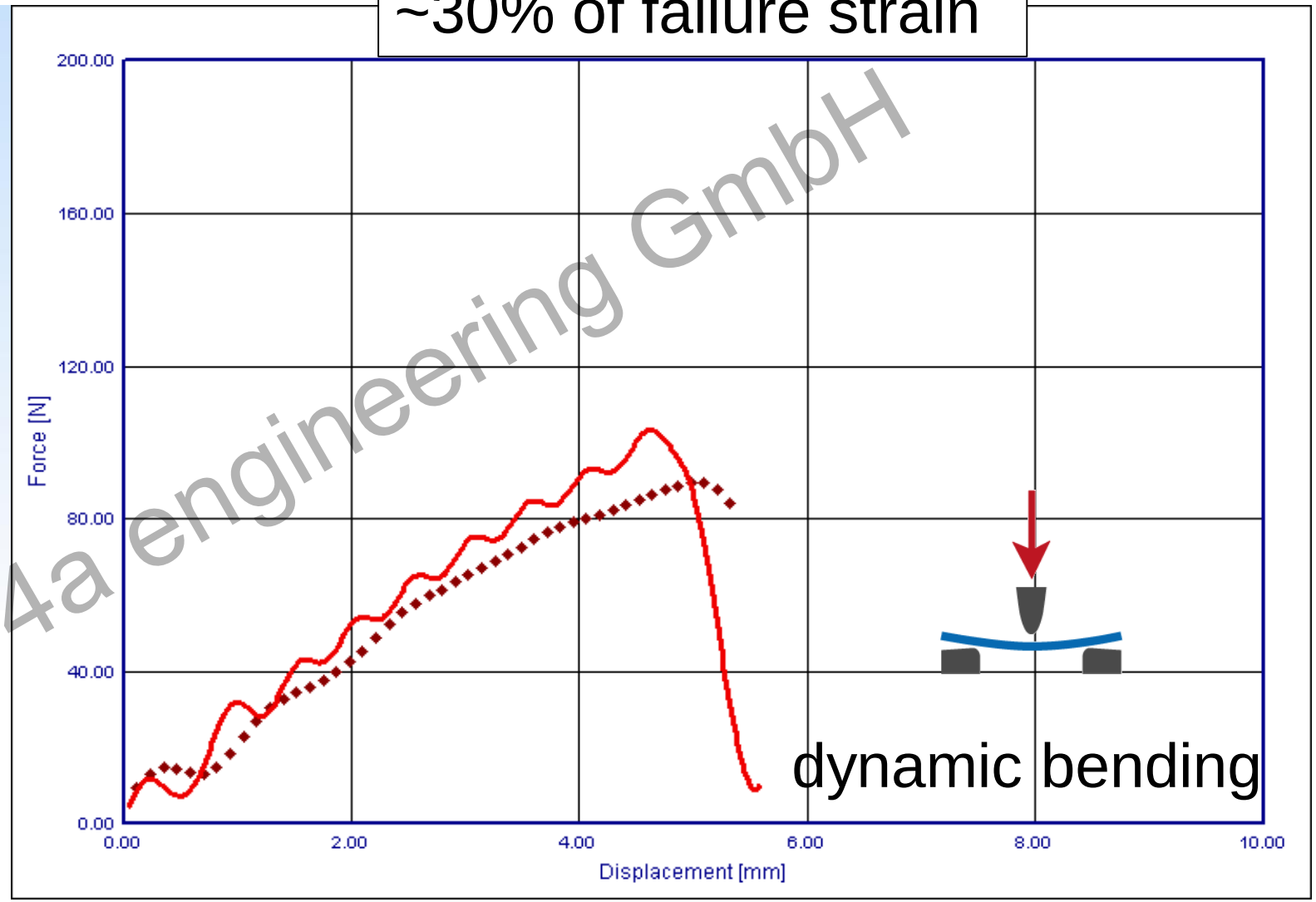
injection mold – process simulation & mapping

FIBERMAP



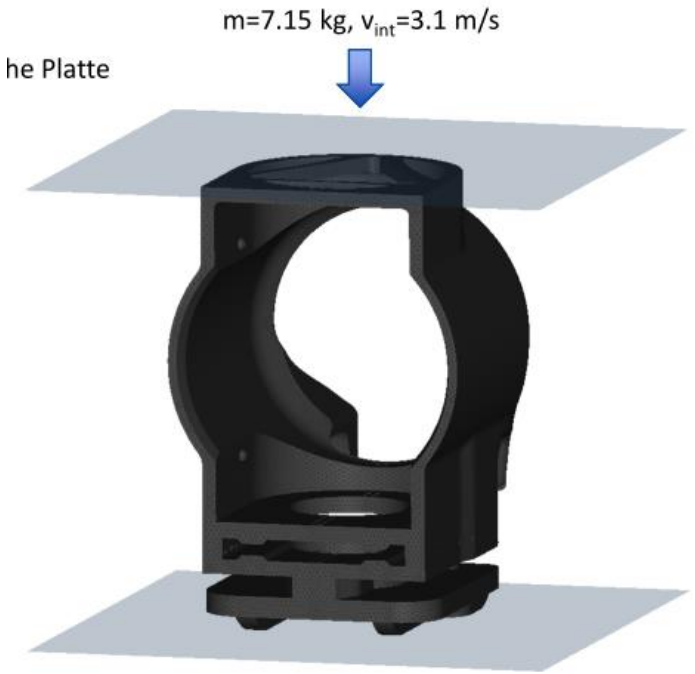
weldline

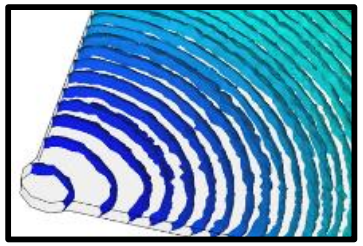
~30% of failure strain



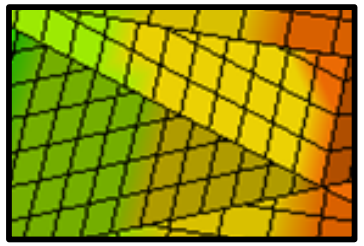
dynamic bending

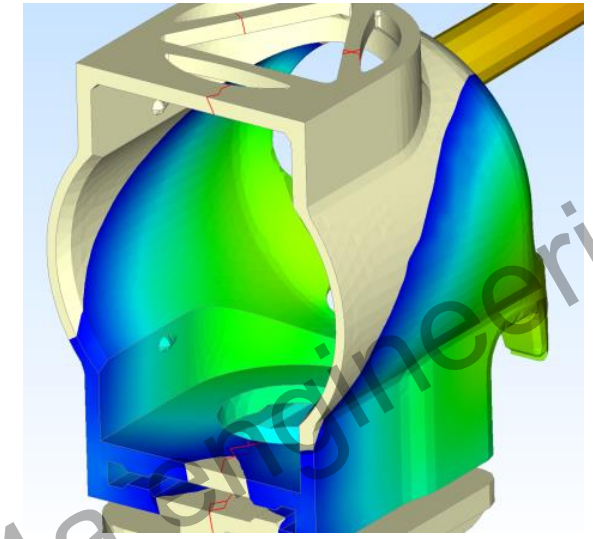
Casestudy - sleeve

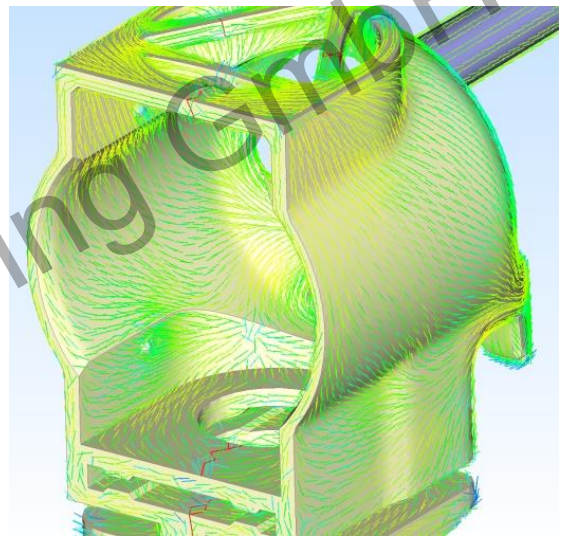


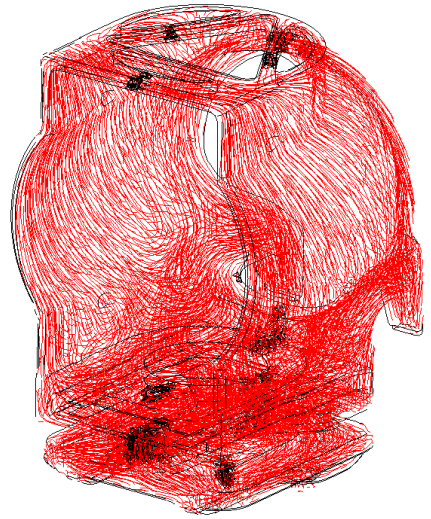


FIBERMAP







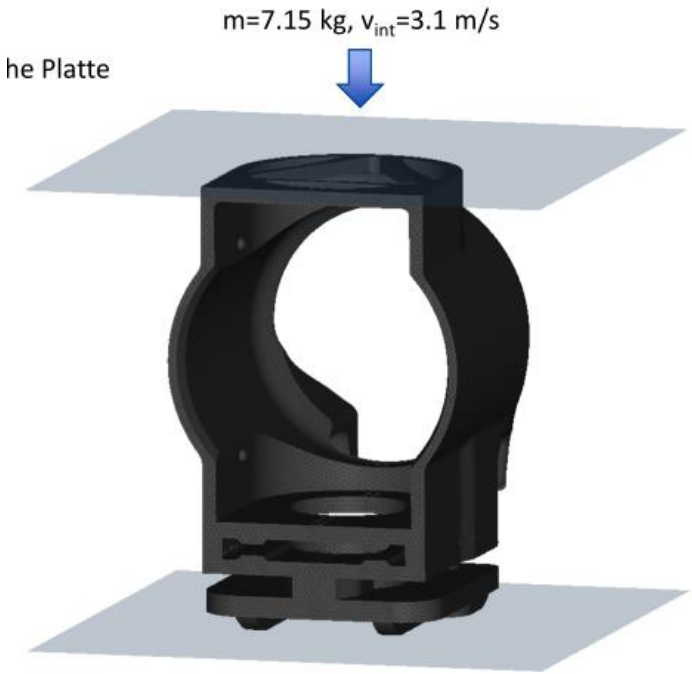


Typische Elementgröße: 0.25mm
Elementtyp: Tetrahedron Type 10
Elementanzahl: 469 470

hirtenberger
Automotive Safety

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

Casestudy - sleeve



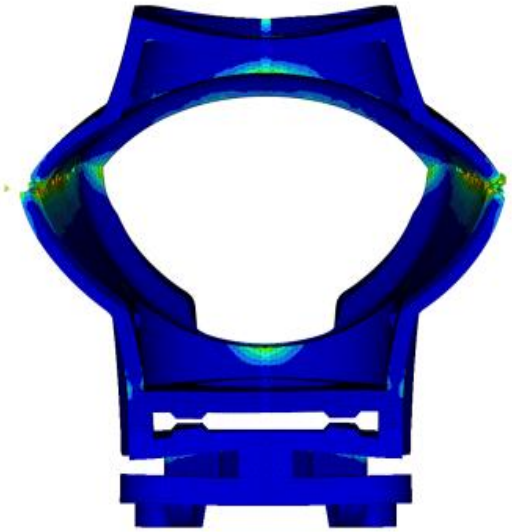
test

****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*

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

IMPETUS

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MICROMEC

FIBERMAP

Foams

Thermoplastics

Fiber reinforced Plastics (SFRT & LFRT)

Composites (Carbon)

Metals

efficient
dynamic testing

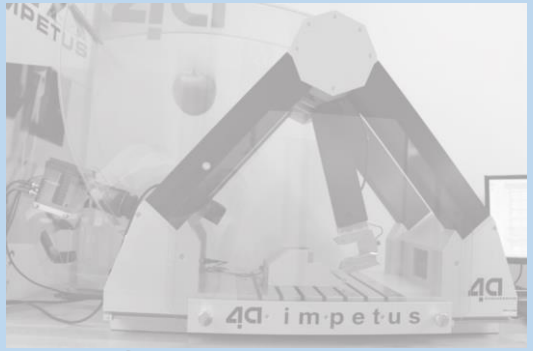
from test to validated
material cards

3D anisotropic
material cards

individual mapping
process information

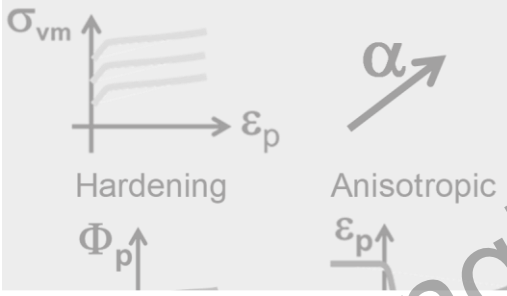
Intelligent reliable solutions for plastics, composites, metals, foams, ...

IMPETUS



efficient
dynamic testing

VALIMAT

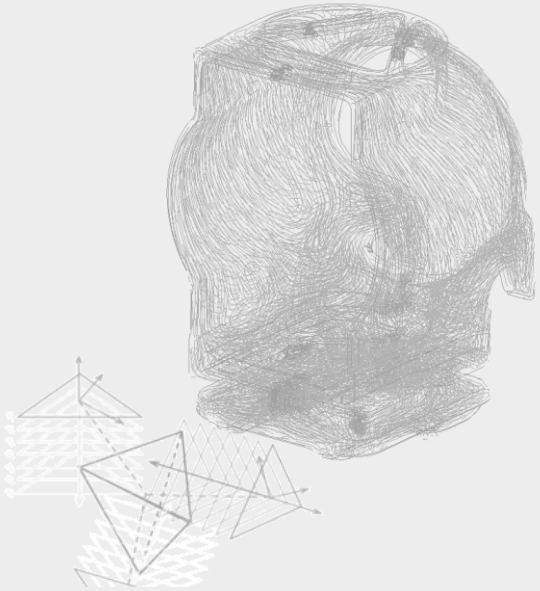


from test to validated
material cards

MICROMEC

3D anisotropic
material cards

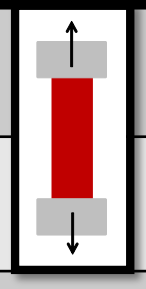
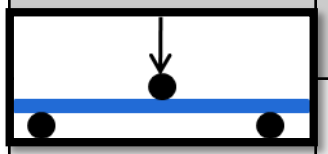
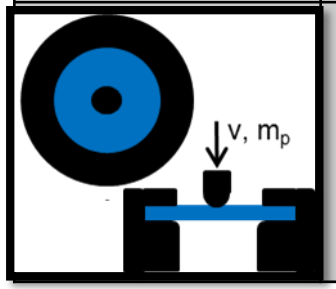
FIBERMAP

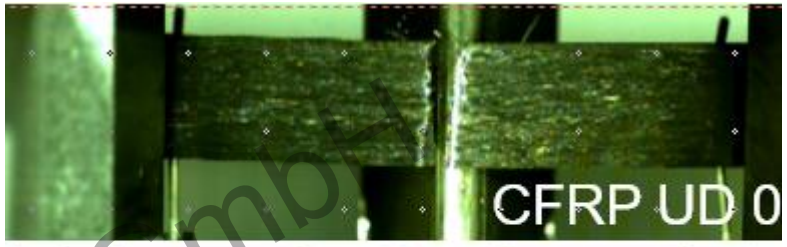


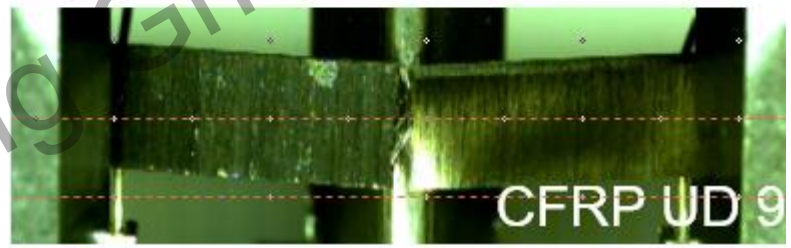
individual mapping
process information

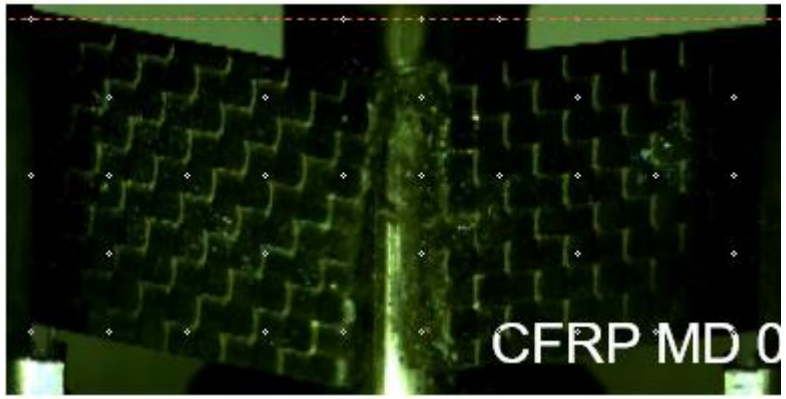
Composites (Carbon)

Composites – typical test setup

specimen		0°	45°	90°	
	UD	static			Material Card
	MD		static, cyclic		
	UD	static, dynamic			
	MD	static, dynamic			
	MD	Puncture			Validation







Composites – available LS-DYNA material models

VALIMAT

No.	Elastic	Plastic	Damage	Strain rate	Failure	
22	Orthotropic	None	None	None	Orientation dependent	Carbon, Glass, Kevlar endless & fabric
54/55	Orthotropic	None	Elastic Orthotropic	Strength	Chang-Chang/ Tsai-Wu Orientation dependent	
58	Orthotropic	None	Elastic Orthotropic	Strength, Stiffness	mod. Hashin Orientation dependent	
158	Orthotropic	None	Elastic Orthotropic	Visco-elasticity	Orientation dependent	
261	Orthotropic	None	Elastic Orthotropic	None	failure Pinho (Puck) Orientation dependent	
262	Orthotropic	None	Elastic Orthotropic	None	failure Camanho (Puck) Orientation dependent	

Composites – micro mechanical approach

in VALIMAT

*Part_Composite

Material behaviour	
Material source	Implemented
Elasticity	Not isotropic elastic
Plasticity	Not selected
Failure/Damage	Not selected
Material card	*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
Deformation	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Damage/Failure	*MAT_ENHANCED_COMPOSITE_DAMAGE (*MAT_054)
Materialcard id	*MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
Density	*MAT_RATE_SENSITIVE_COMPOSITE_FABRIC (*MAT_158)
Plasticity	*MAT_LAMINATED_FRACTURE_DAIMLER_PINHO (*MAT_261)
Function (Hardening, Elastic curve form)	*MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO (*MAT_262)
Strain rate dependency	*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
Micromec	*MAT_MICROMEC (*MAT_215)
Fracture	*MAT_MICROMEC (*MAT_215)+Carbon
Postfracture	None

Available LS-DYNA materialcards in VALIMAT™

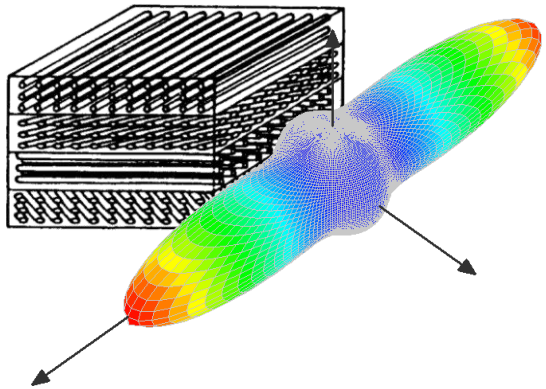
Test | Test database | Measurement | Report | Measurement curves | Viewer | a(t) | v(t) | s(t) | F(t) | F(s) | E(t) | sig(eps) | e

160826_004 | Material | Designvariablen | Layers

Model settings	
Material	
Idealization	
Material behaviour	
Material source	Implemented
	*MAT_COMPOSITE_DAMAGE (*MAT_022)
Materialcardcase	7306_MAT22
Damage/Failurecase	Chang Chang
Materialcard id	1000000
Density	1480
Plasticity	None
Function (Hardening, Elastic curve form)	
Strain rate dependency	None
Micromec	Endless fiber reinforced plastics
Matrix	
Density of the matrix	1093
E-Modulus	3000
Poisson's ratio	0.3
Yield strength	50
Strength at Break	70
Failure strain	0.05
Fiber	
Fillerlength	20000
Fillerdiameter	20
Phi or Psi	φ
Phi	58
Psi	71.7
Fillermaterial	T300
Orientation	
Fillerorientationtype	UD
Strength	
Strength evaluation	Fiber strength
XT	2300
XC	2000
Fracture	Composite
Postfracture	None

Composites – micro mechanical approach

in VALIMAT



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

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

Test | Test database | Measurement | Report | Measurement curves | Viewer | a(t) | v(t) | s(t) | F(t) | F(s) | E(t) | sig(eps) | e

160826_004 | Material | Designvariablen | Layers

⊞	**Model settings**	
⊞	**Material**	
⊞	**Idealization**	
⊟	**Material behaviour**	
⊞	Material source	Implemented
⊟	Material card	*MAT_COMPOSITE_DAMAGE (*MAT_022)
	Materialcardcase	7500_MAT22
	Damage/Failurecase	Chang Chang
	Materialcard id	1000000
	Density	1480
	Plasticity	None
	Function (Hardening, Elastic curve form)	
	Strain rate dependency	None
⊟	Micromec	Endless fiber reinforced plastics
⊟	Matrix	
	Density of the matrix	1093
	E-Modulus	3000
	Poisson's ratio	0.3
	Yield strength	50
	Strength at Break	70
	Failure strain	0.05
⊟	Fiber	
	Fillerlength	20000
	Fillerdiameter	20
	Phi or Psi	φ
	Phi	58
	Psi	71.7
	Fillermaterial	T300
⊟	Orientation	
	Fillerorientationtype	UD
⊟	Strength	
⊟	Strength evaluation	Fiber strength
	XT	2300
	XC	2000
⊞	Fracture	Composite
	Postfracture	None

Matrix properties

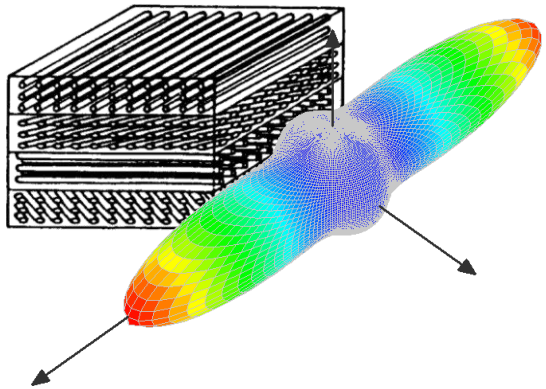
Filler properties

Orientation

Strength

Composites – micro mechanical approach

in VALIMAT



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

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

Typical Design Variables for *MAT_022

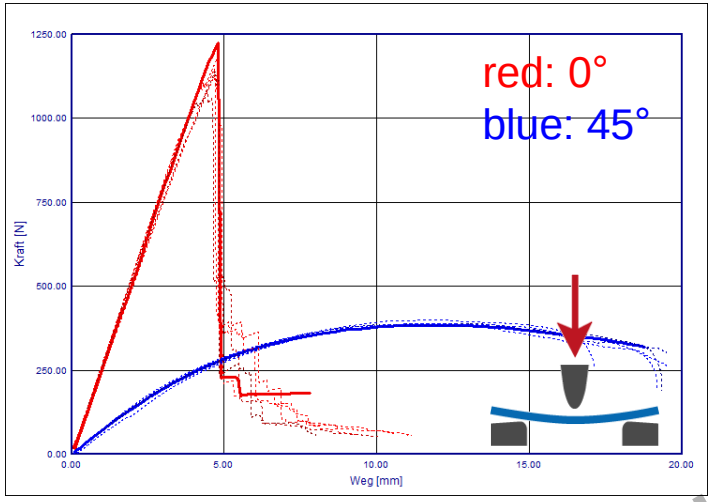
160826_004 | Material | Designvariablen | Layers

Name	Start	const...	from	to	Variance	Condi...	Description
GroupName: 10_elasticity							
c_E11	MMEC	☐	100000	180000	(NULL)		young modulus tensile in 1 direction
c_E22	MMEC	☑	(NULL)	(NULL)	(NULL)		young modulus tensile in 2 direction
c_E33	MMEC	☑	(NULL)	(NULL)	(NULL)		young modulus tensile in 2 direction
c_nue21	MMEC	☑	(NULL)	(NULL)	(NULL)		poisson ration in 21 plane
c_nue31	MMEC	☑	(NULL)	(NULL)	(NULL)		poisson ration in 31 plane
c_nue32	MMEC	☑	(NULL)	(NULL)	(NULL)		poisson ration in 32 plane
c_G12	MMEC	☑	(NULL)	(NULL)	(NULL)		shear modulus in 12 plane
c_G23	MMEC	☑	(NULL)	(NULL)	(NULL)		shear modulus in 23 plane
c_G31	MMEC	☑	(NULL)	(NULL)	(NULL)		shear modulus in 31 plane
GroupName: 51_failure							
fc_R11T	MMEC	☑	(NULL)	(NULL)	(NULL)		
fc_R11C	MMEC	☑	(NULL)	(NULL)	(NULL)		
fc_R22T	MMEC	☑	(NULL)	(NULL)	(NULL)		
fc_R22C	MMEC	☑	(NULL)	(NULL)	(NULL)		
fc_R12	MMEC	☑	(NULL)	(NULL)	(NULL)		

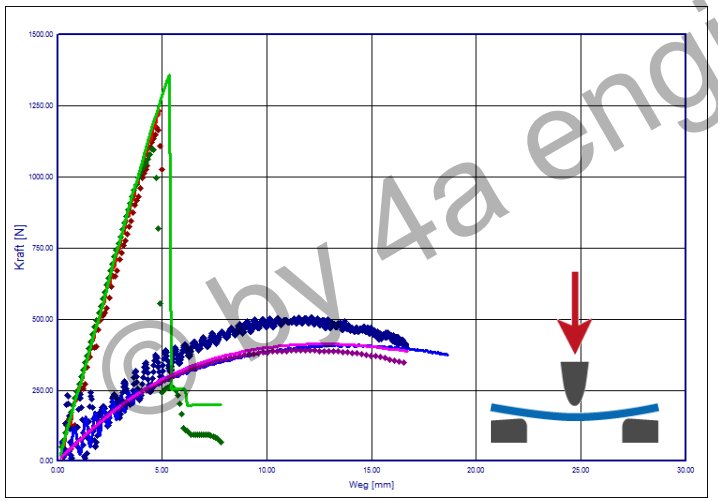
Composites – validation with final material card

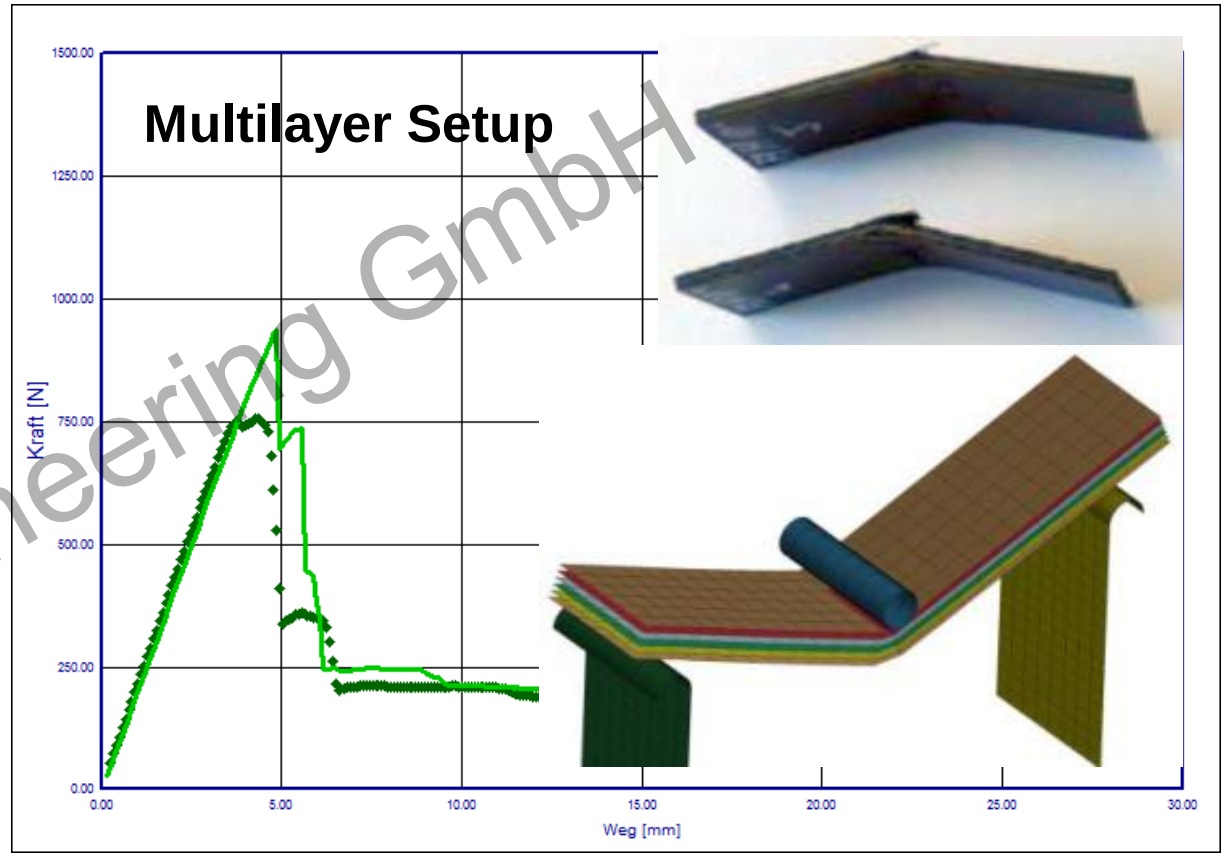
VALIMAT

Orientation



static versus dynamic

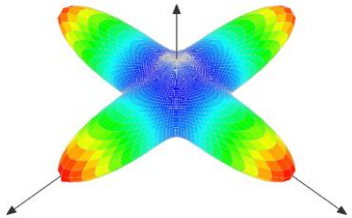




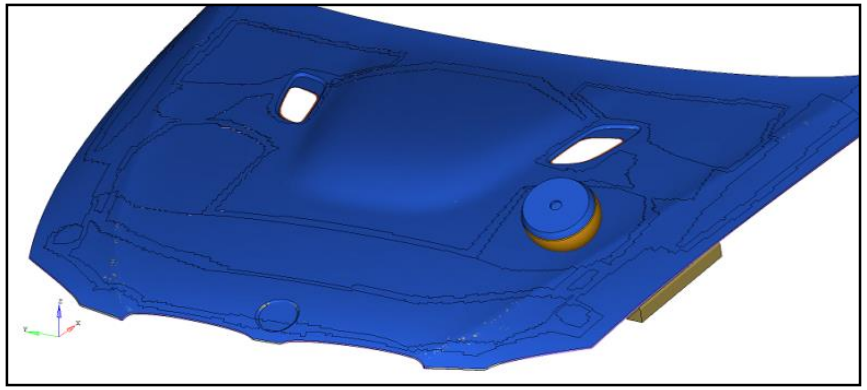
.... test
— simulation

P. Reithofer (4a engineering GmbH) & B. Fellner (MAGNA STEYR Engineering Austria) - Materialcharakterisierung von Composites; 4a Technologietag 2015

Composite – case study



- Front hood
  - Stiffness versus pedestrian safety
- Material card
  - Composite layup with anisotropic material behavior
  - Core material – Honeycomb different compression levels



SOURCE: LINK to PAPER

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

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MICROMEC

FIBERMAP

Thermoplastics

Fiber reinforced Plastics (SFRT & LFRT)

Composites (Carbon)

efficient
dynamic testing

from test to validated
material cards

3D anisotropic
material cards

individual mapping
process information

Summary
Part 2: Modeling of fiber reinforced thermoplastics

Summary

- different models needed for different materials
  - COMPOSITE (higher fiber content) → elastic + damage
  - SFRT, LFRT (medium fiber content) → viscoplasticity also of importance
- Two main approaches
  - Macro scale – composite behavior
  - Micro scale – distinguish between fiber and resin/matrix behavior
- Differences
  - Flexibility in usage (Micro ++)
  - Computational effort (Macro ++)

Summary

- LS-DYNA offers a lot of different material models for
  - thermoplastic materials
  - short and long fiber reinforced thermoplastics
  - classical composites
- all materials show different mechanical response dependent on different aspects like anisotropy, viscosity, temperature, moisture, …
- material characterization must focus on the main behavior and material card generation must reflect that
- tools are needed to handle data and to fit complex failure models

IMPETUS VALIMAT

Thank you for your Attention!

4a summer-school - webinar and training
Material characterization with VALIMAT® and IMPETUS®

SAVE THE DATE
07.07. - 17.07.2020

VALIMAT

IMPETUS

Appendix
Additional overview

efficient dynamic testing

IMPETUS

plastics

engineering

production

excellence in testing

concepts

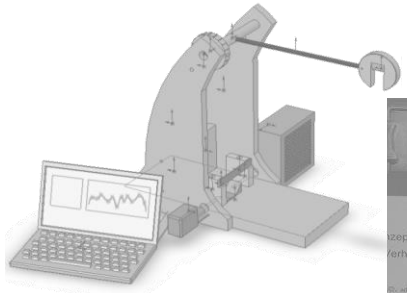
simulation

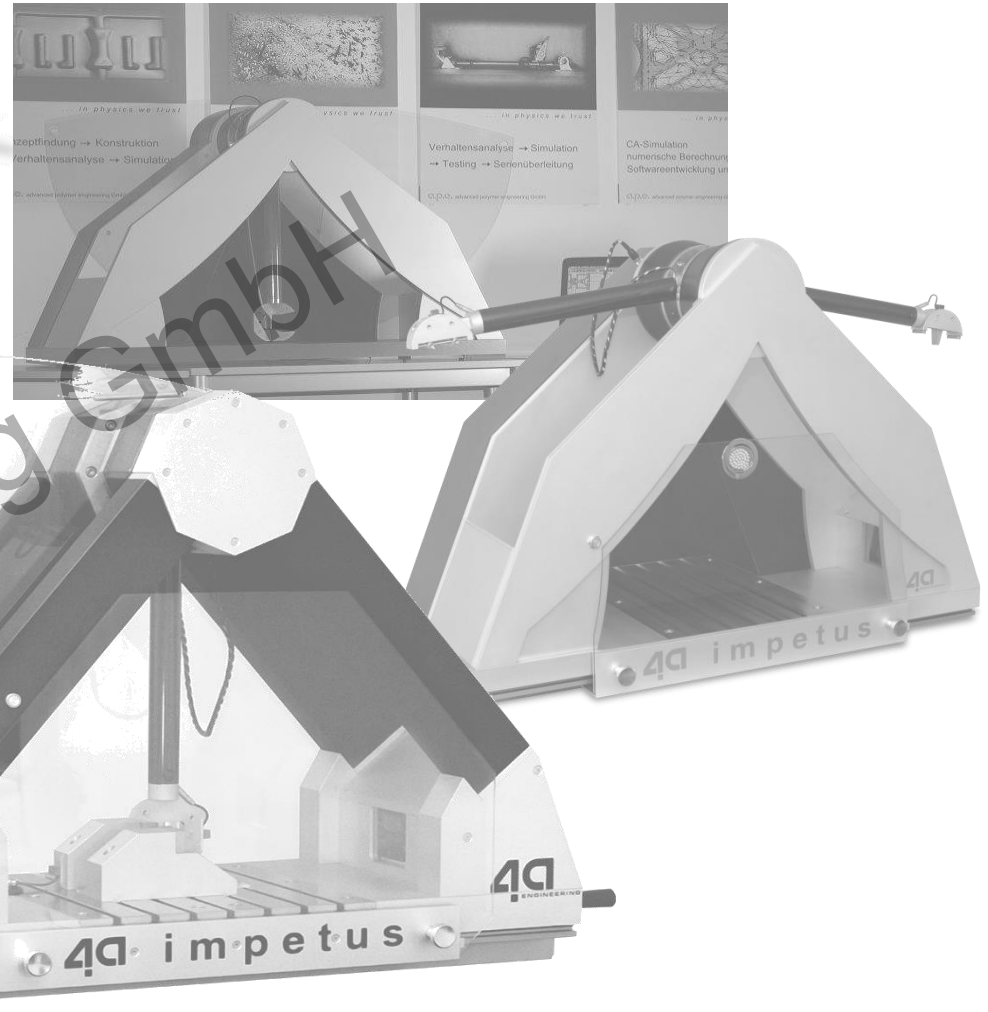
lightweight

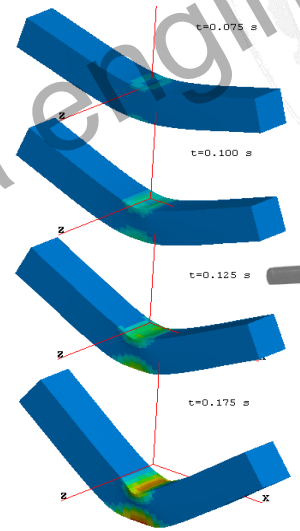
prototypes

Efficient dynamic testing

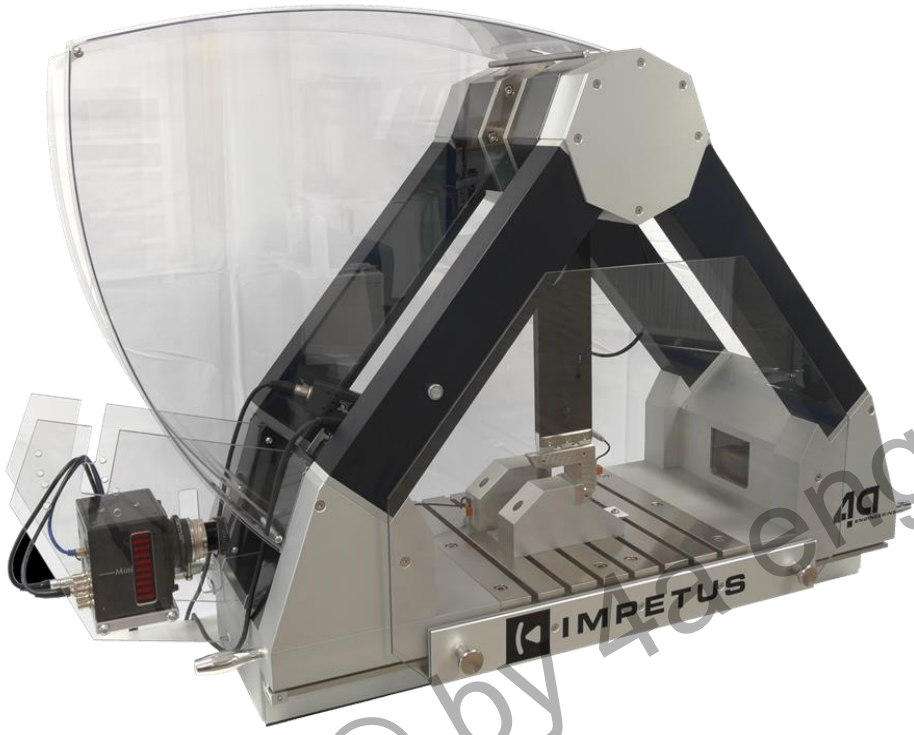
- desktop testing device
- instrumented high-speed testing
  - acceleration → force / displacement
- impact velocity 0.5 – 4.5 m/s







IMPETUS™ data specification



technical specifications

maximum energy	50J
length of swing arm	500mm
mass of swing arm	1.5 - 3.0kg
impact velocity	0.5 - 4.4m/s

weights and dimensions

L x W x H	1400 x 600 x 850mm
mass	165kg

desk load and dimensions minimum required

L x W x H	1500 x 800 x 800mm
minimum load	250kg

electrical supply data

230 VAC 50 Hz	0.5A
115 VAC 60 Hz	1.0A

5V camera trigger

output level high	>2.5V
output level low	<0.5V

Highspeed camera is an optional equipment and can be ordered separately.

Photron High Speed Camera data specification

Photron

FASTCAM	MINI AX200 540K	NOVA S6 800K	NOVA S9 900K	NOVA S12 1000K	
CMOS Image Sensor	1024 x 1024	1024 x 1024	1024 x 1024	1024 x 1024	px
max. fps full resolution	6400	6400	9000	12800	fps
max. Frame Rate	540000	800000	900000	1000000	fps
Light Sensitivity	40000	64000	64000	64000	ISO
L x W x H	94 x 120 x 120	217.2 x 120 x 120	217.2 x 120 x 120	217.2 x 120 x 120	mm
weight	1.5	3.3	3.3	3.3	kg

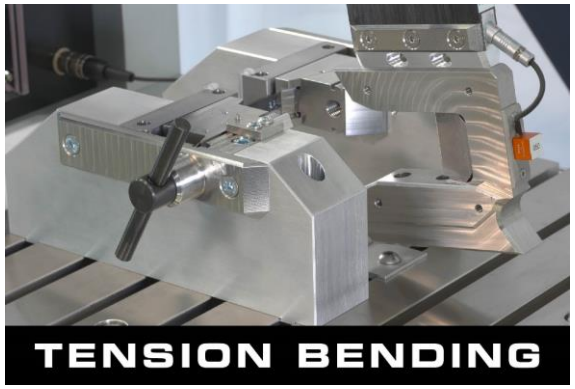
Vision Devices lighting data specification

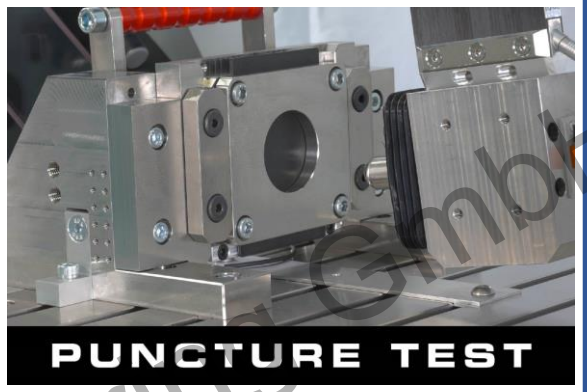
LED VD7000

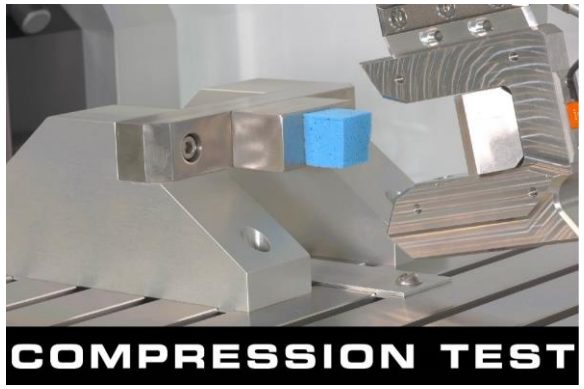
operating voltage	24 - 36	V
rated power	17 - 72	W
Luminous flux	2100	lm
Luminous flux boost	7280	lm
color temperature	6000	K
L x W x H	100 x 46 x 46	mm

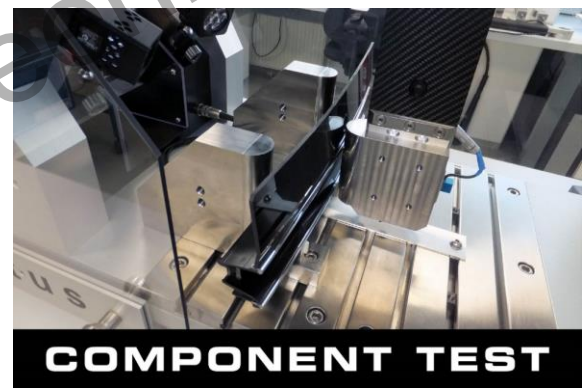
VISION DEVICES

IMPETUS™ - configurations







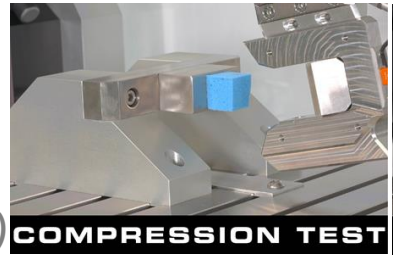
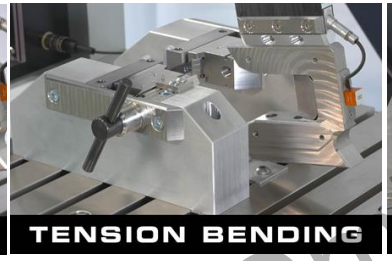
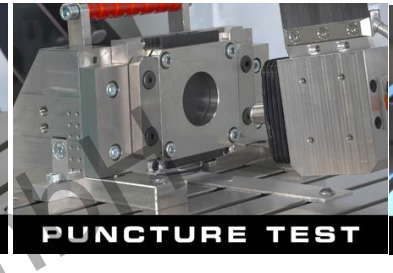


BASIC

STANDARD

PROFESSIONAL

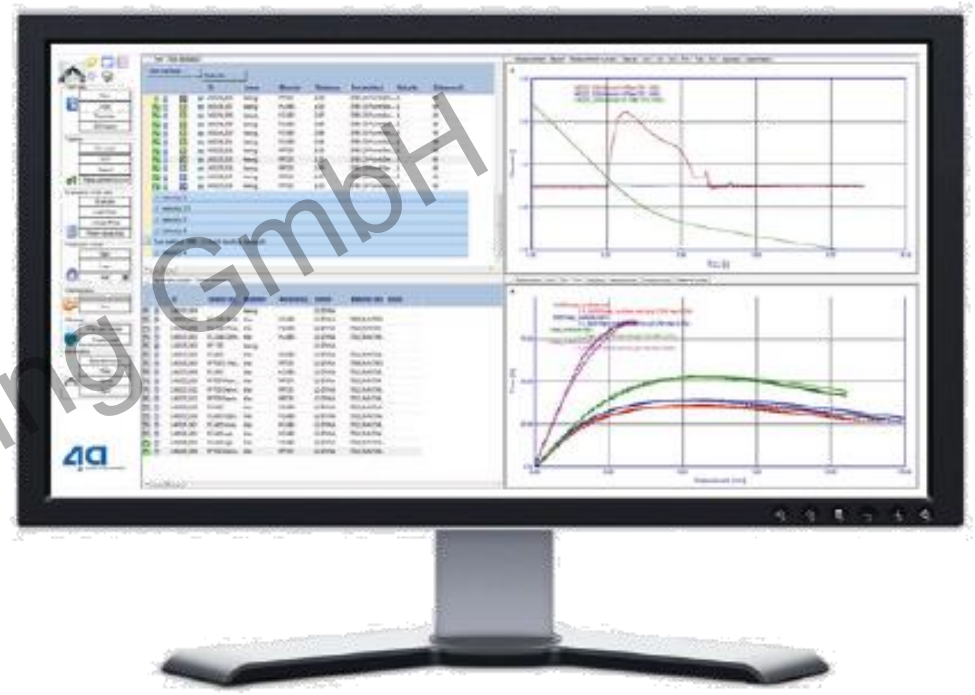
Efficient dynamic testing

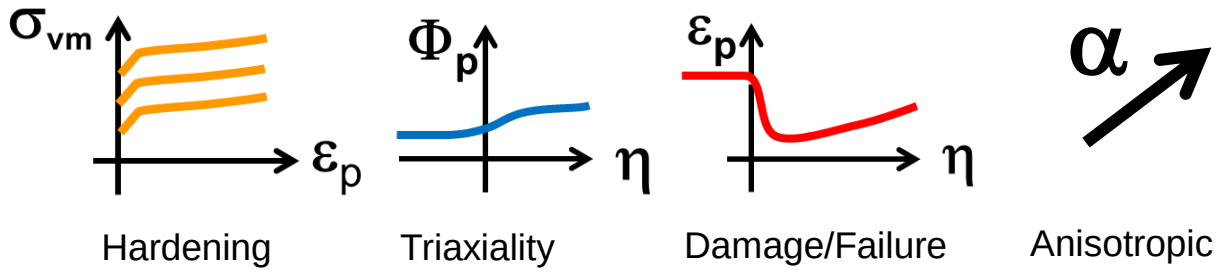
Material *(Typical thickness)*	 COMPRESSION TEST	 3 POINT BENDING	 TENSION BENDING	 PUNCTURE TEST	 TENSION TEST
Plastic *(1 - 4 mm)*		✓	✓	✓	✓
Foam *(20 - 30 mm)*	✓	~			
Composite *(1 - 4 mm)*		✓		✓	
Aluminum *(1 – 2.5 mm)*		✓	✓		✓
Metals *(0.5 – 1.5 mm)*		✓			

From test to material card

VALIMAT

plastics
engineering
production
excellence in validation
concepts
simulation
lightweight
prototypes





Hardening | Triaxiality | Damage/Failure | Anisotropic

Material data generation for simulation

Current Situation

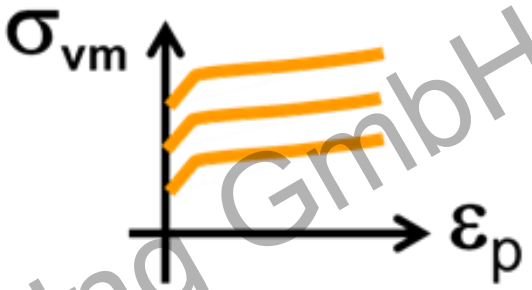
- more and more data
- Not only tension
  - Different loadcases (compression, shear, ….)
- More complex simulation models
  Investigations on failure

NEEDED

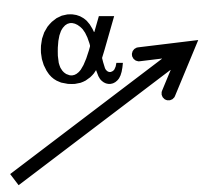
→ Smart USER INTERFACE

→ Optimization

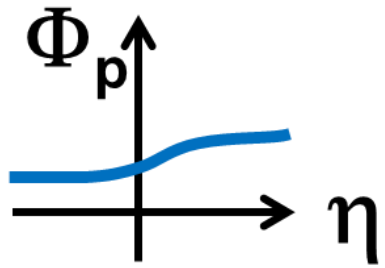
→ DATABASE handling data



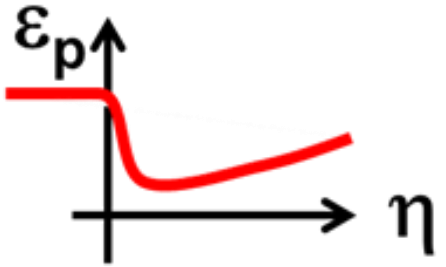
Hardening



Anisotropic



Triaxiality



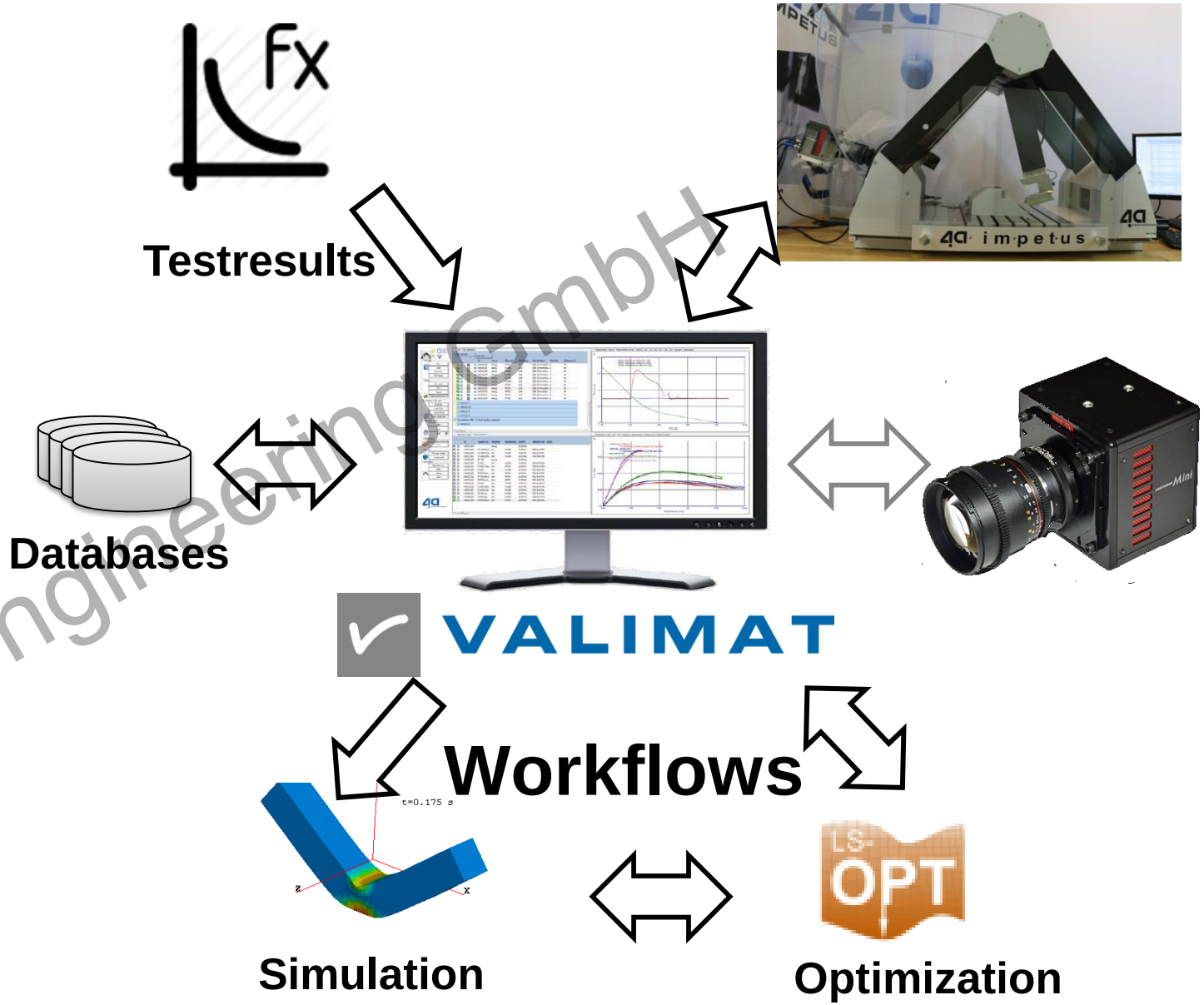
Damage/Failure

From test to material card

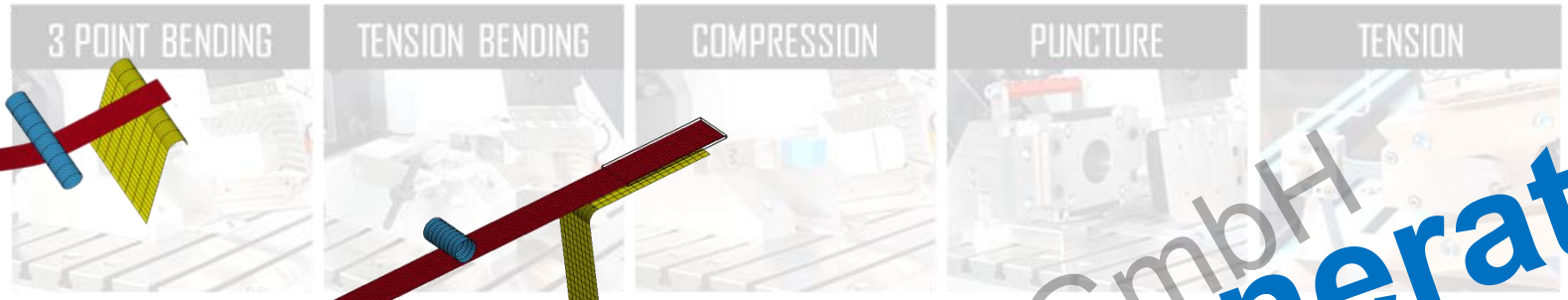
VALIMAT™

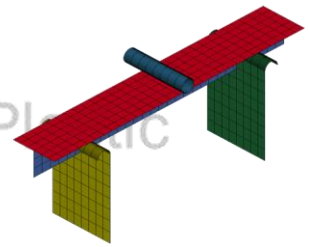
Advantage

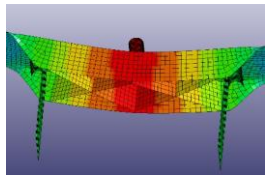
- Handling of bigdata
- Complex models
- Good correlation to simulation



Efficient dynamic testing







Plastic

Foam

Composite

Aluminum

Metals

typical thickness

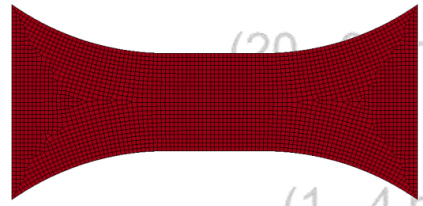
(1 - 4 mm)

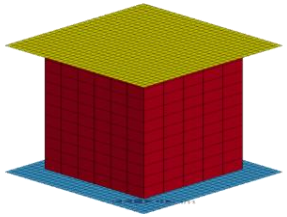
(20 - 2 mm)

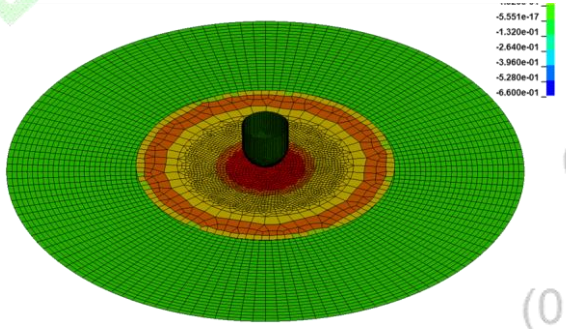
(1 - 4 mm)

(1 – 2.5 mm)

(0.5 – 1.5 mm)







automated FE-model generation

© by 4a engineering GmbH

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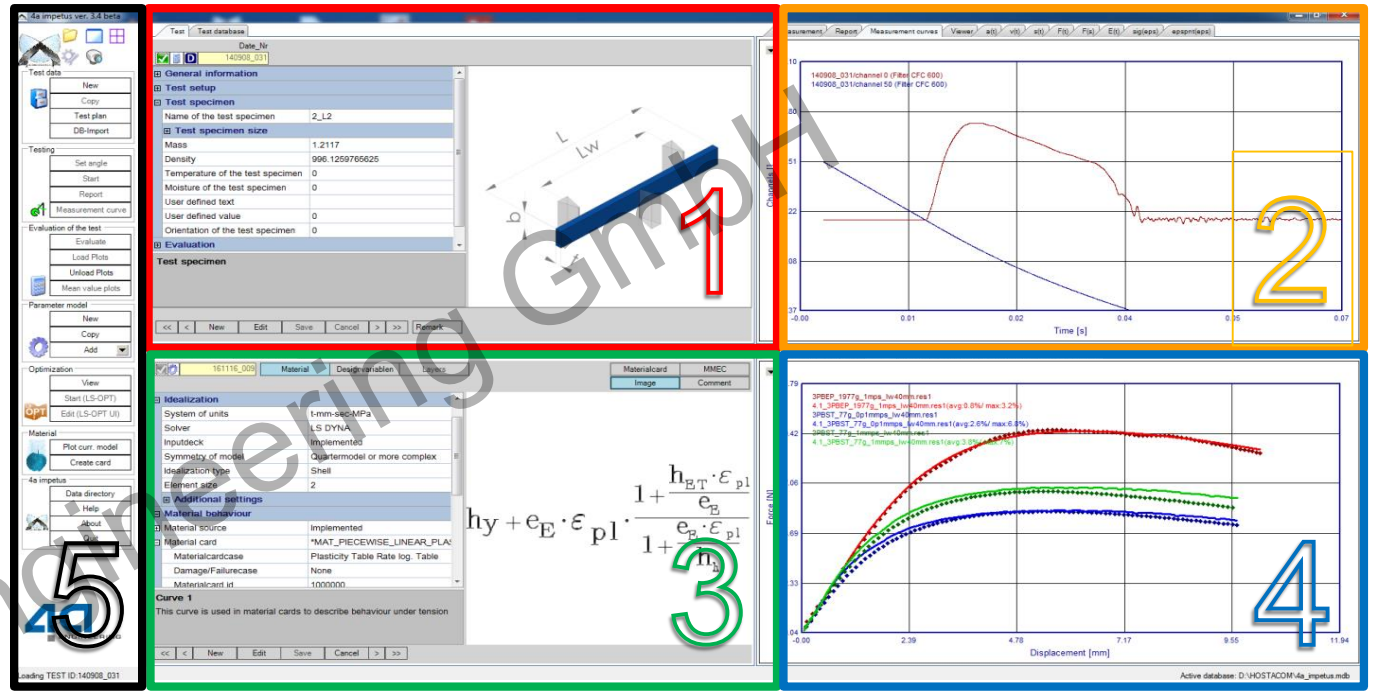
GUI - the graphic user interface is divided into five parts:

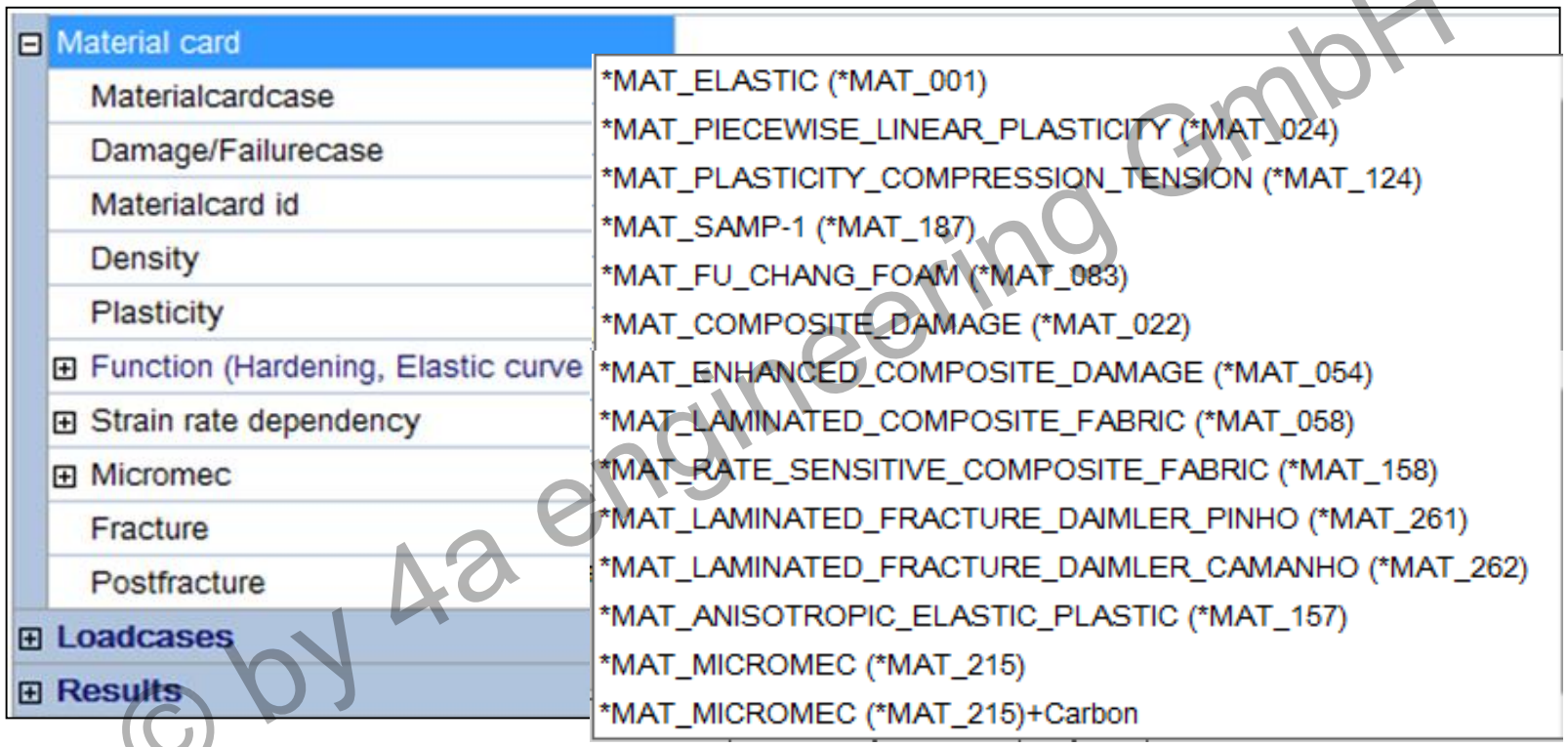


basic menu (left margin, (5))
window top left (1) → test; data base
window top right (2) → measurements; info; measurement results
window bottom left (3) → model parameter; optimization settings
window bottom right (4) → optimization; results of the optimization
the basic menu describes the principal process from the test to the completed material model and allows a simple and fast access of the most important functions.

Material models

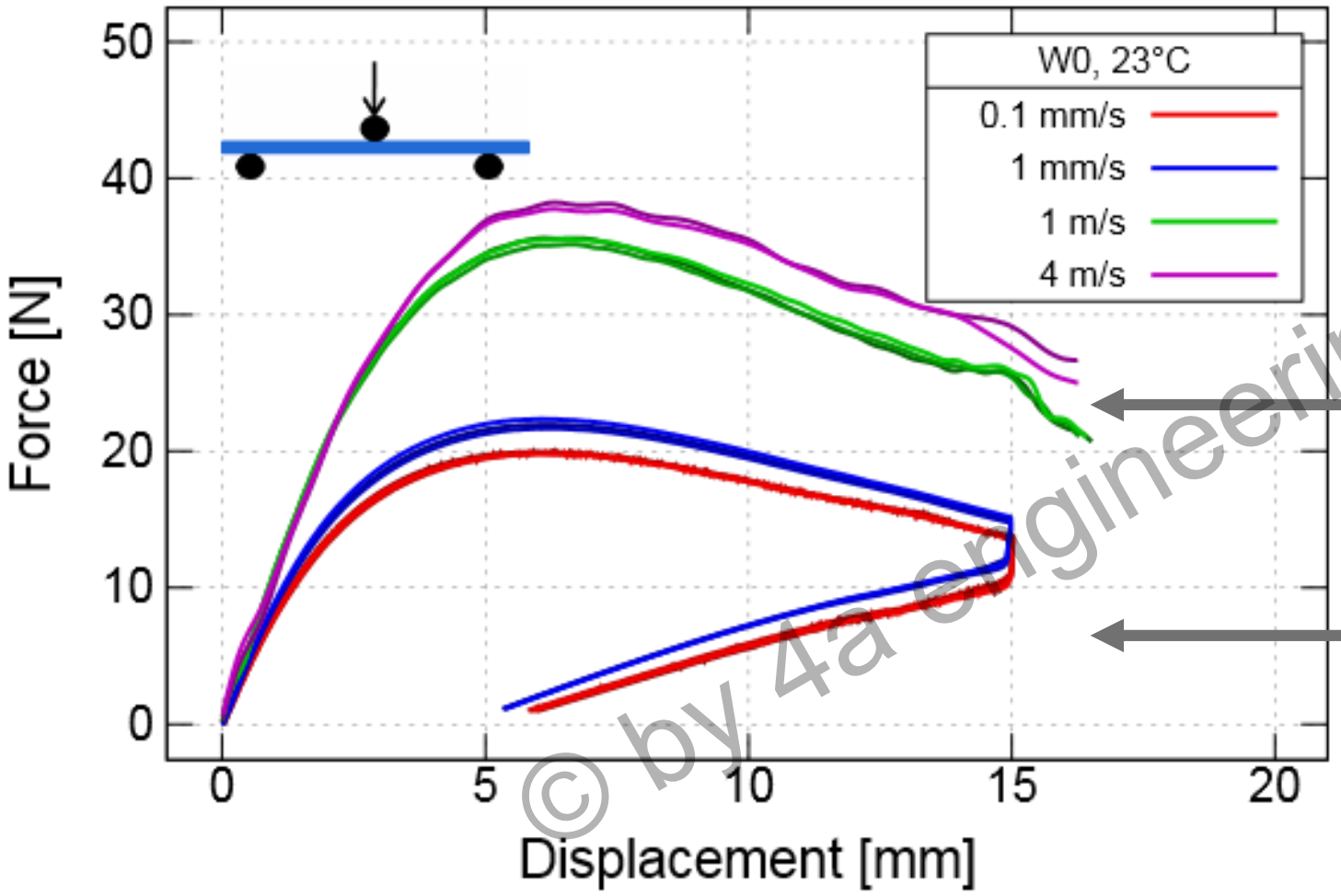
VALIMAT

- Plenty of direct implemented ***LS-Dyna*** material models ***(also Abaqus, PamCrash)***



- ***Whole number*** of LS-Dyna material models is available through ***userdefined material cards***

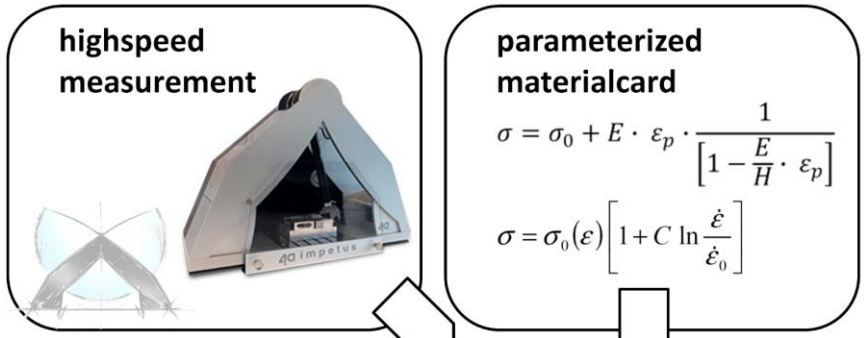
Efficient dynamic testing

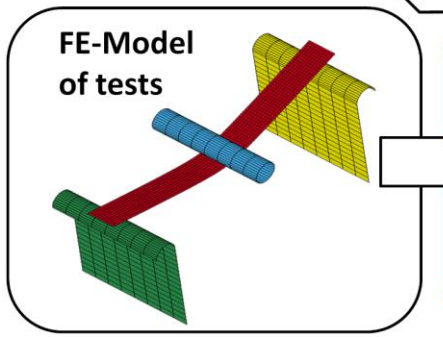


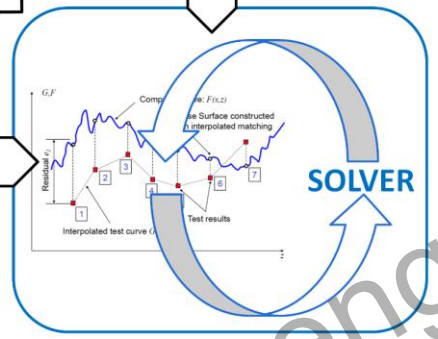
IMPETUS

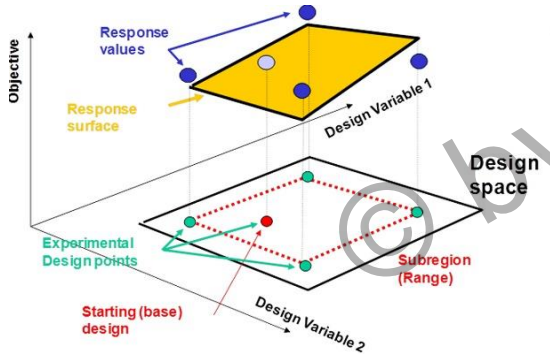
Universal static testing

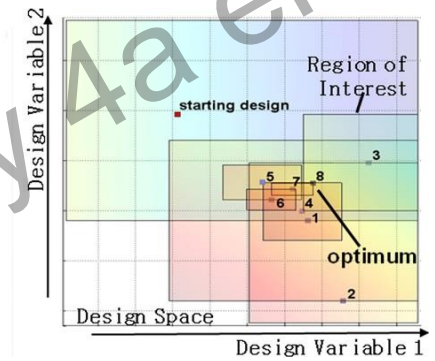
Reverse engineering

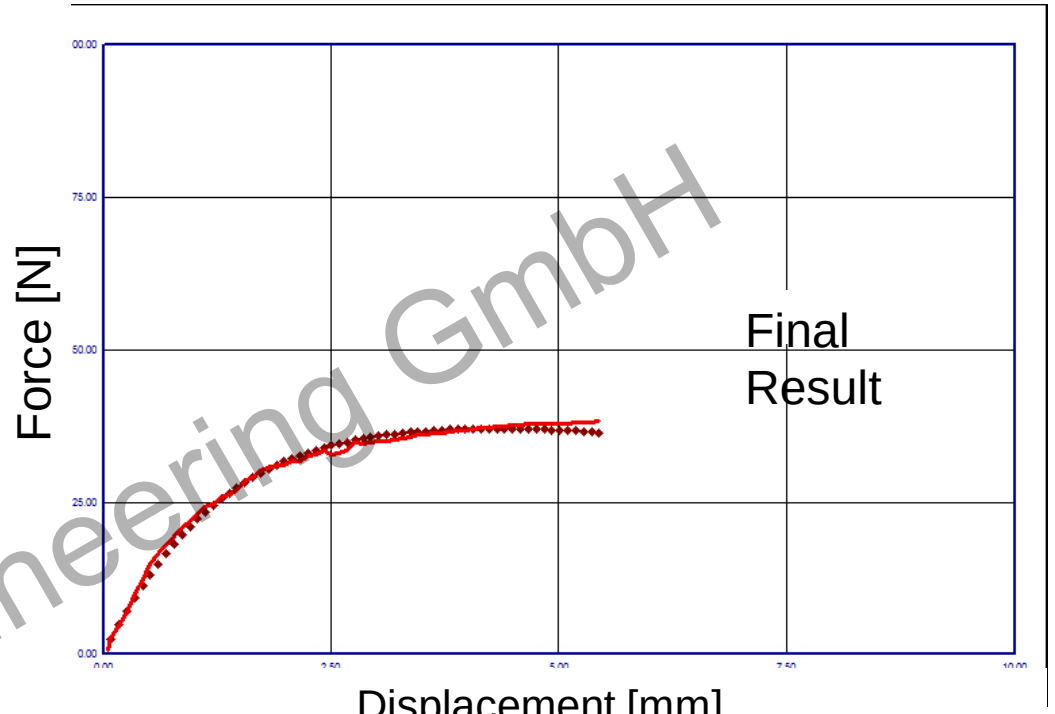






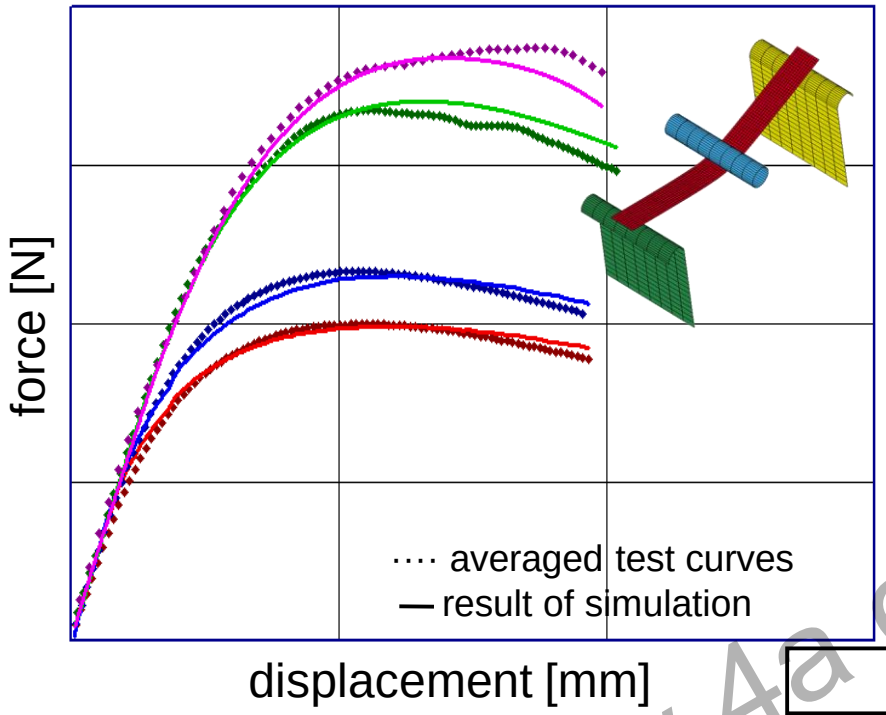


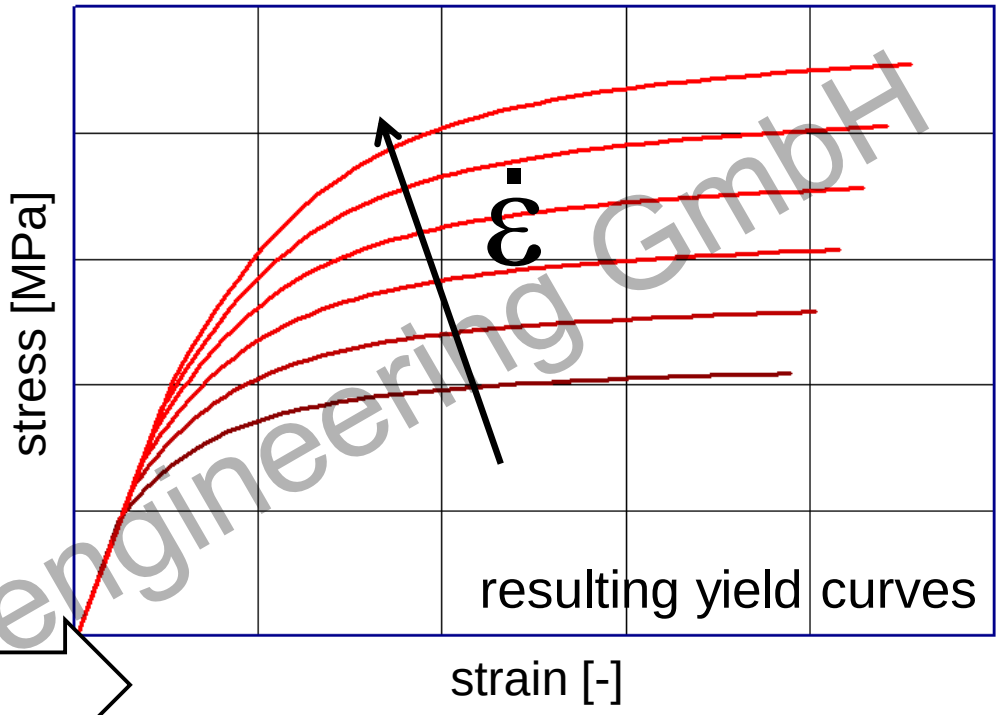




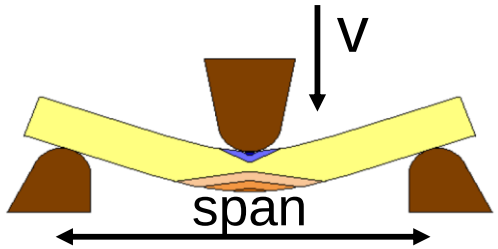
Source: Dynamic Material Characterization Using 4a impetus – PPS Conference 2015, Graz

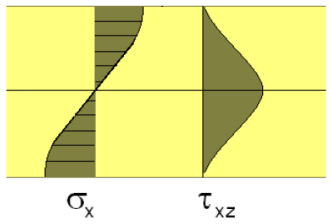
From bending → *MAT_024

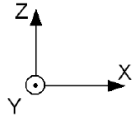




v [m/s]	span [mm]
0.0001	40
0.001	40
1	40
4	40







- Starting parameter
- **Young's Modulus**
- **Yield**
- **Strainrate**
- Asymmetry
- Component

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

VALIMAT

- manage test results
  (import, export, filter, evaluation)
- statistics
- automatic report
- material card generation
- material card validation

for all material types

from test to validated material cards

IMPETUS

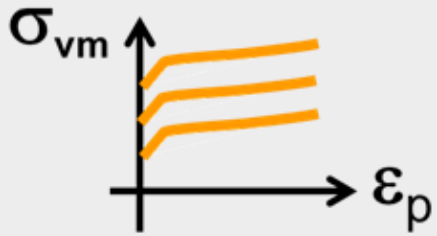
- single pendulum up to 4.5 m/s
- double pendulum up to 8 m/s
- standard test methods
- specialized test methods
- component testing
- advanced measurement

efficient dynamic testing

plastics and composites

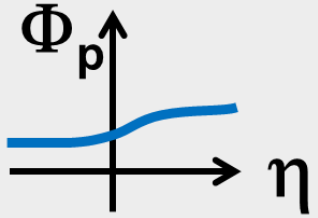
Intelligent reliable solutions for plastics, composites, metals, foams, ...

VALIMAT

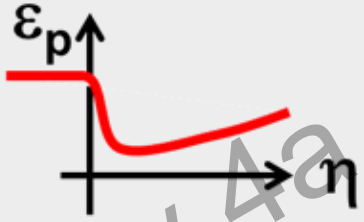


Hardening

Anisotropic



Triaxiality



Damage/Failure

for all material types

from test to validated material cards

IMPETUS

efficient dynamic testing

plastics and composites

IMPETUS http://impetus.4a.at

VALIMAT http://valimat.4a.at

YOUTUBE CHANNEL