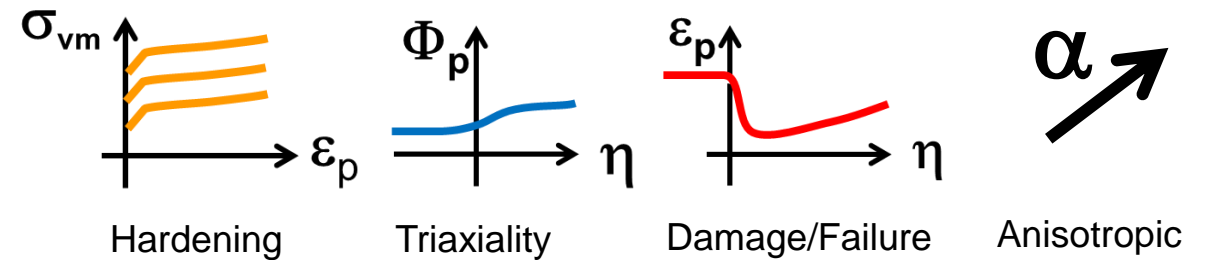


Modeling of isotropic thermoplastic polymers using VALIMAT and IMPETUS

FAW CAE Simulation Technology Forum 13th October 2021

Outline

- Introduction and Motivation
- Overview material and failure models in LS Dyna
- Material behaviour of thermoplastic polymers
- From test to material card
- Comparison of different material models
- Summary





excellence in ...
plastics simulation
testing equipment
lightweight products



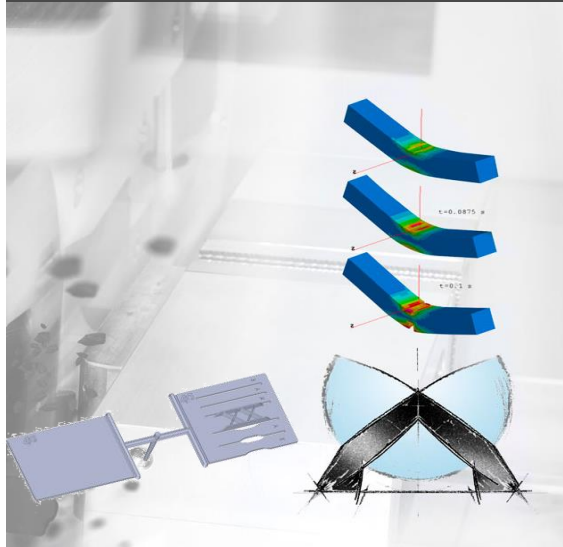
4a-engineering - Business Units

Testing hard- and software



Seamless testing and simulation solution for automated material characterization

Material characterization



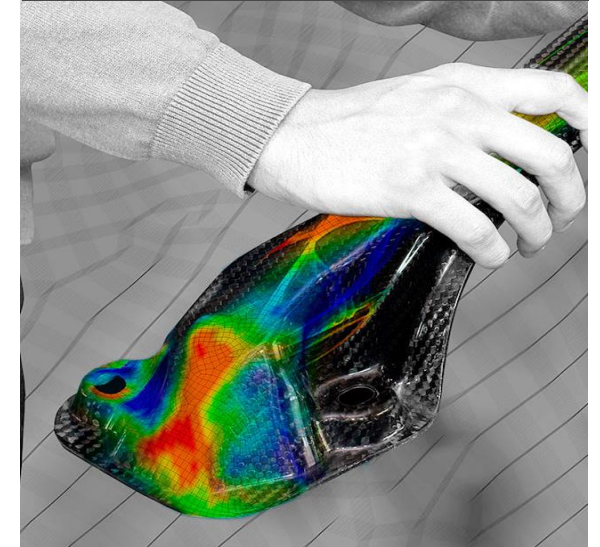
Static and dynamic material characterization from specimen to component validation – all under one roof

Validated material cards



Optimized packages for common material models for LS-Dyna, PamCrash and Abaqus.

Product development



From draft to craft – Engineering, simulation and prototyping

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

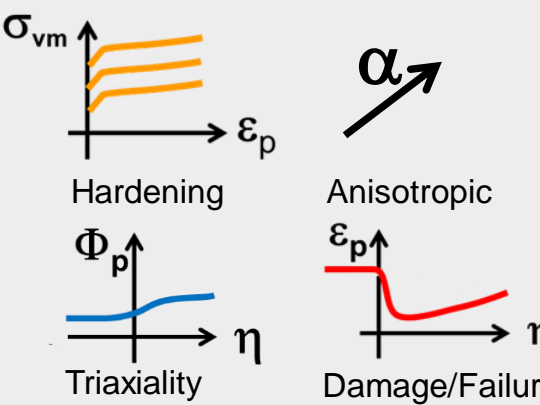
IMPETUS



efficient
dynamic testing

The image shows the IMPETUS 4a dynamic testing machine, a large industrial-scale shaker system. Below the main machine, a schematic diagram illustrates a test setup with a specimen on a base, subjected to a force v, m_p .

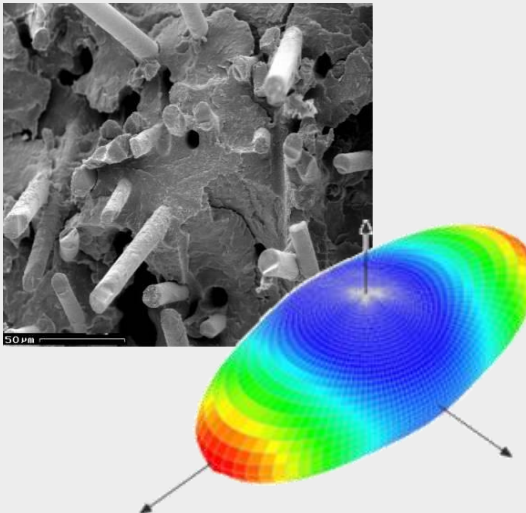
VALIMAT



from test to validated
material cards

The VALIMAT material card displays four graphs: 1) Hardening: σ_{vm} vs ϵ_p showing three parallel curves. 2) Anisotropic: α vs ϵ_p showing a curve that drops and then levels off. 3) Triaxiality: Φ_p vs η showing a curve that rises and then levels off. 4) Damage/Failure: ϵ_p vs η showing a curve that drops and then levels off.

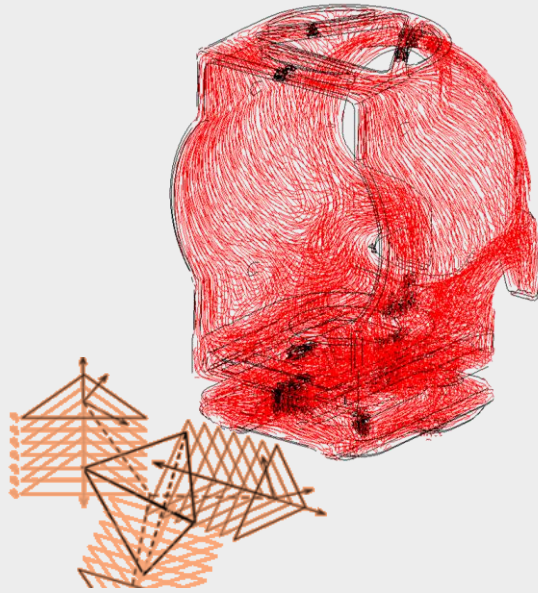
MICROMECC



3D anisotropic
material cards

The MICROMECC material card features a scanning electron microscope (SEM) image of a composite material structure with a 50 µm scale bar. Below it is a 3D visualization of an anisotropic material card, represented as a colorful, multi-axis plot.

FIBERMAP



individual mapping
process information

The FIBERMAP material card shows a 3D visualization of a fiber-reinforced structure, rendered in red and orange, with a corresponding 2D schematic diagram below it.

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

◀ **IMPETUS**

✓ **VALIMAT**

◉ **MICROMECH**

➤ **FIBERMAP**

Foams

Thermoplastics

Fiber reinforced Plastics (SFRT & LFRT)

Composites (Carbon)

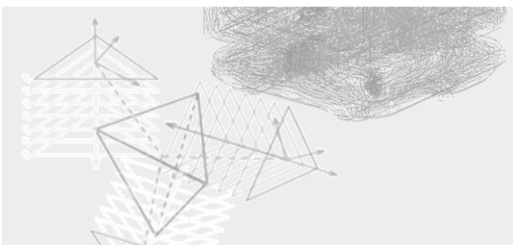
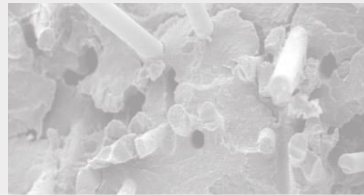
Metals

efficient
dynamic testing

from test to validated
material cards

3D anisotropic
material cards

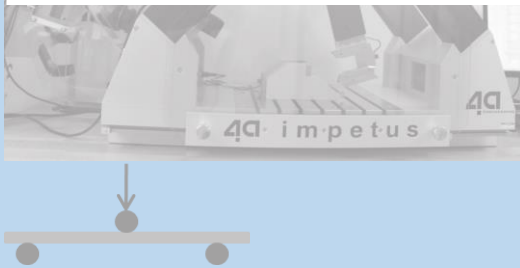
individual mapping
process information



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

 **IMPETUS**

Thermoplastics



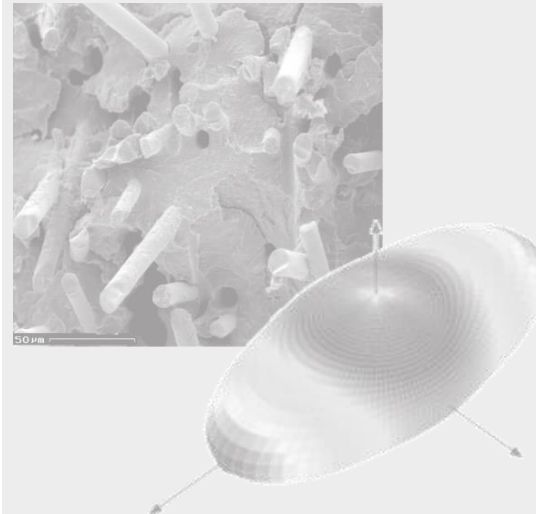
efficient
dynamic testing

 **VALIMAT**



from test to validated
material cards

 **MICROMECH**



3D anisotropic
material cards

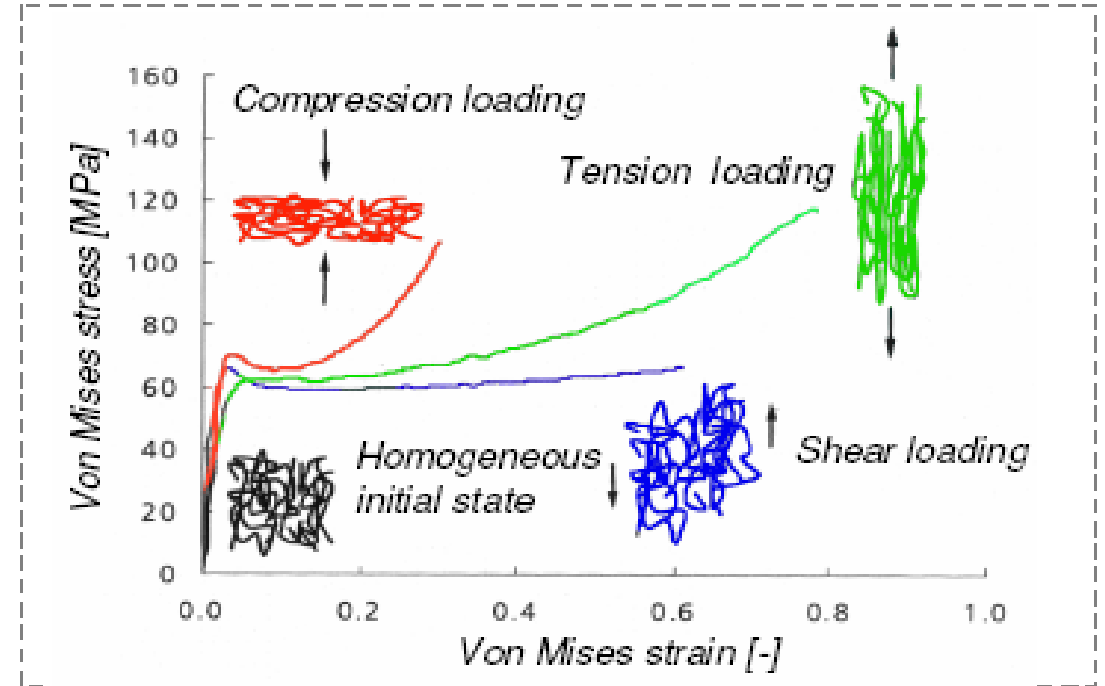
 **FIBERMAP**



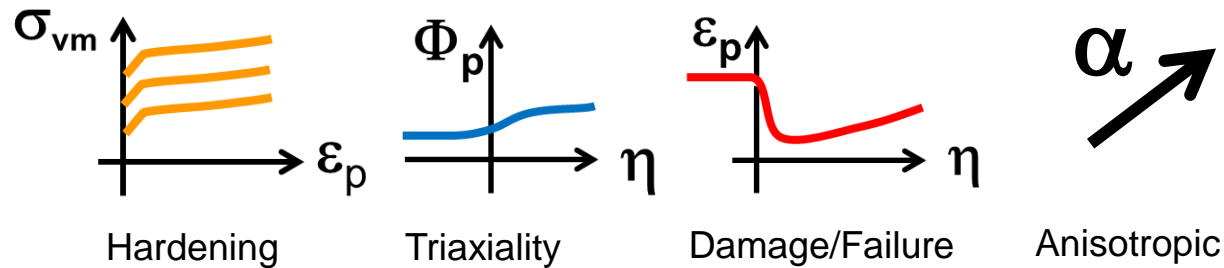
individual mapping
process information

Thermoplastic materials

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

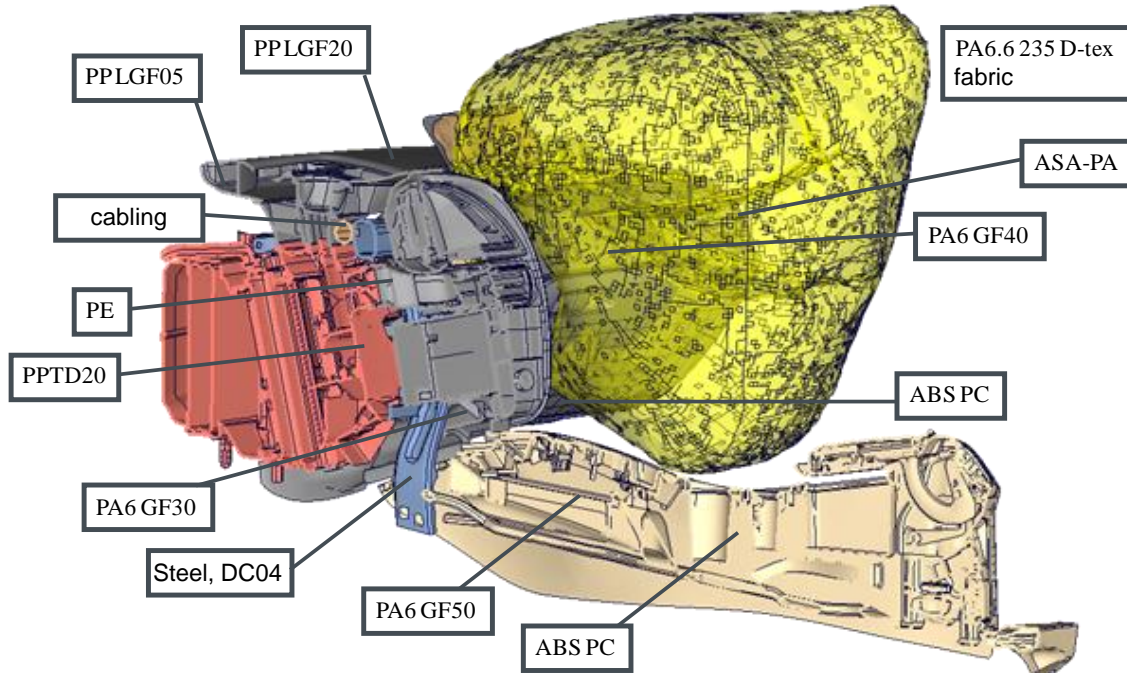


Source: Mechanik der Kunststoffe W. Retting, Hanser Verlag 1991



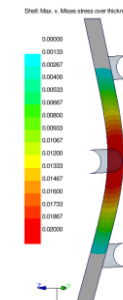
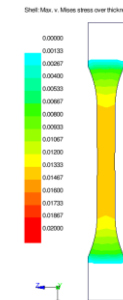
Motivation

material variety

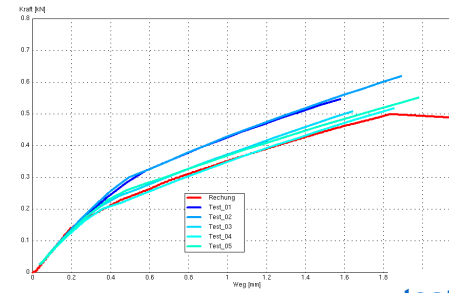


Source: R. Luijckx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG*, 4a Technologietag 2010

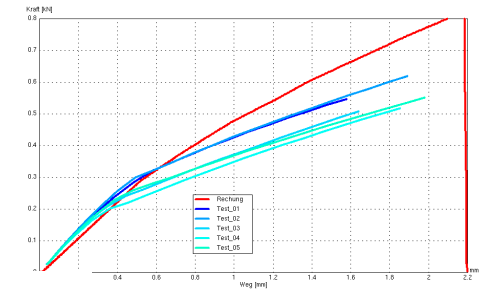
bending load case



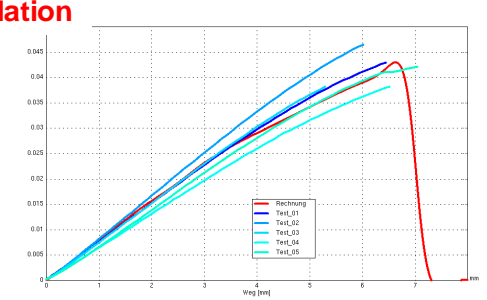
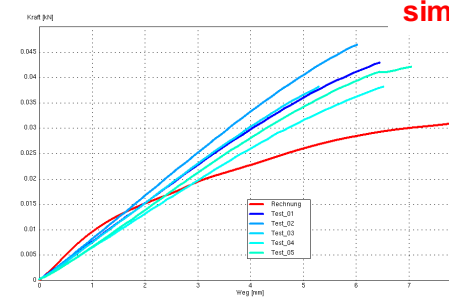
original test curve tension



scaling 1.25

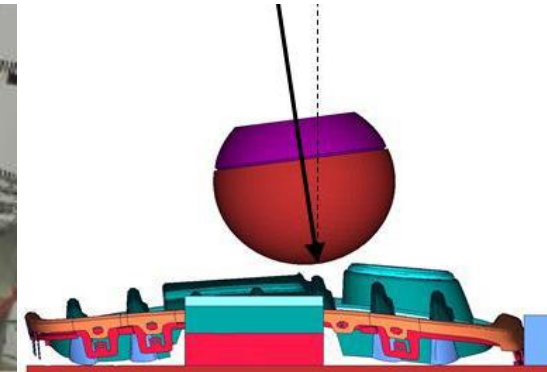
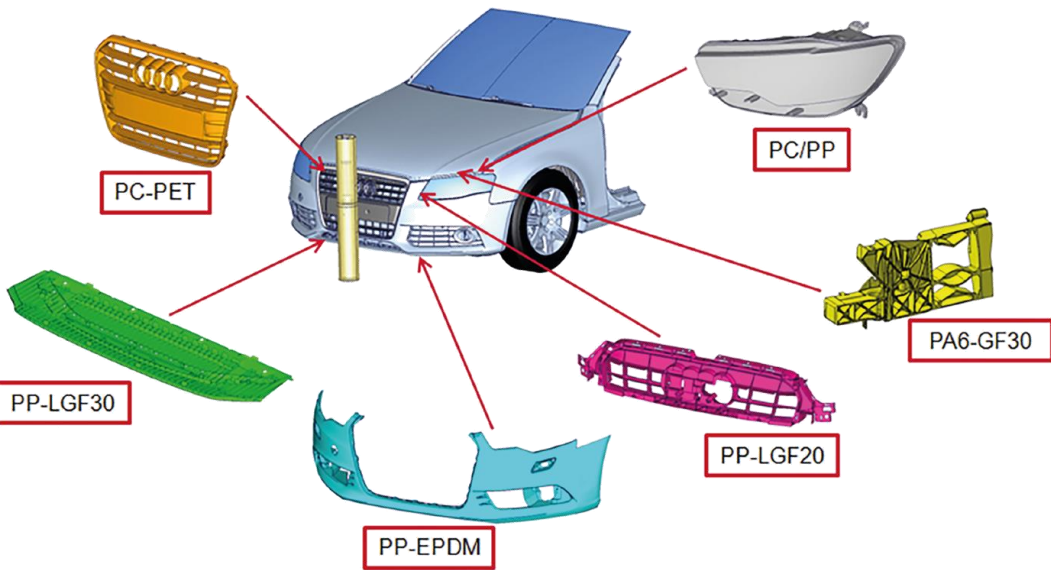
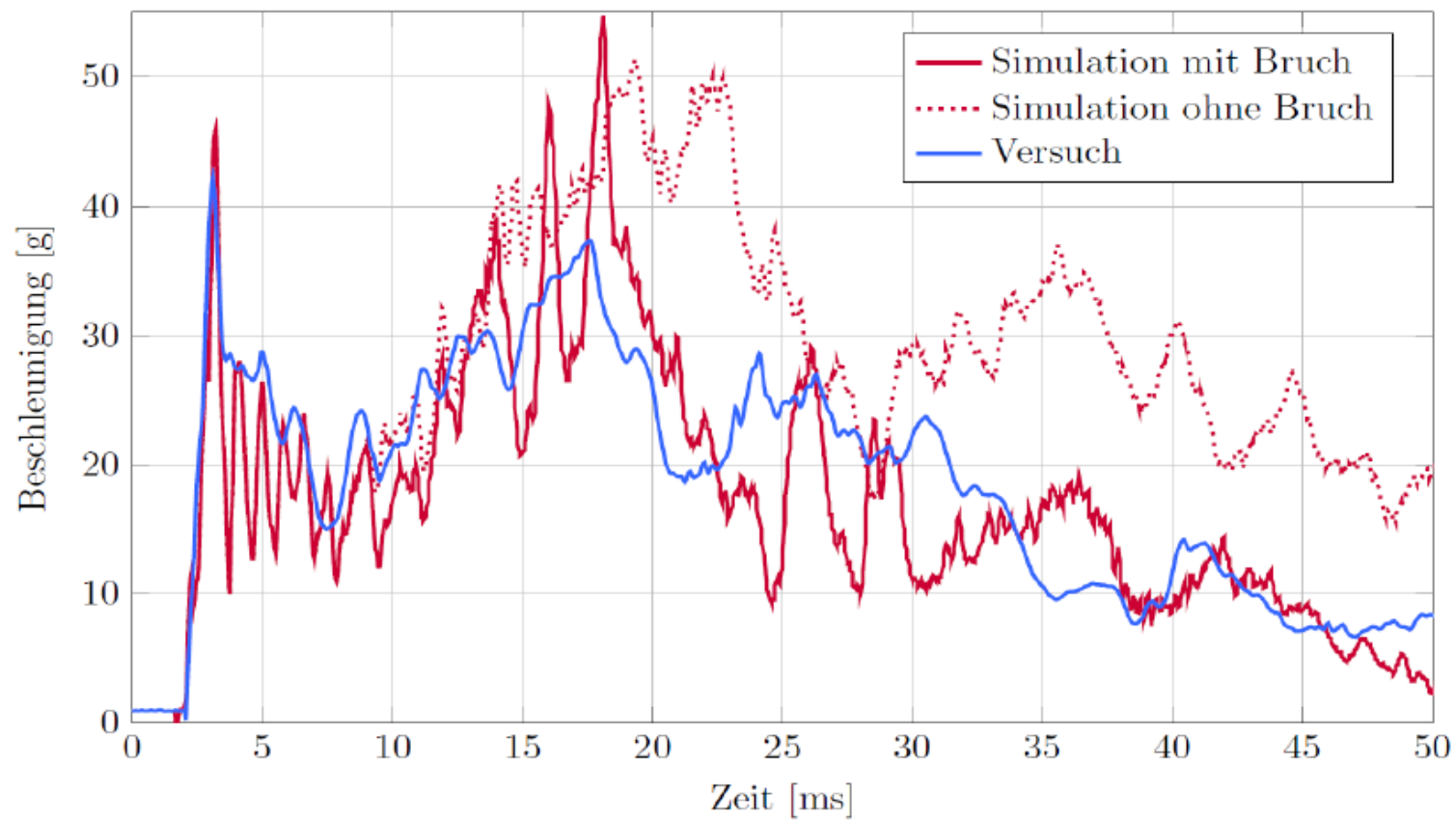
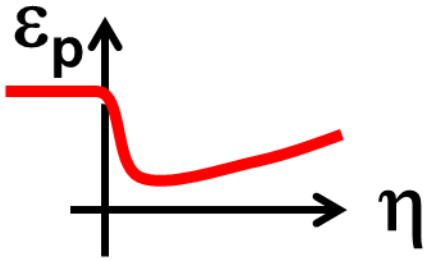


test simulation



Motivation

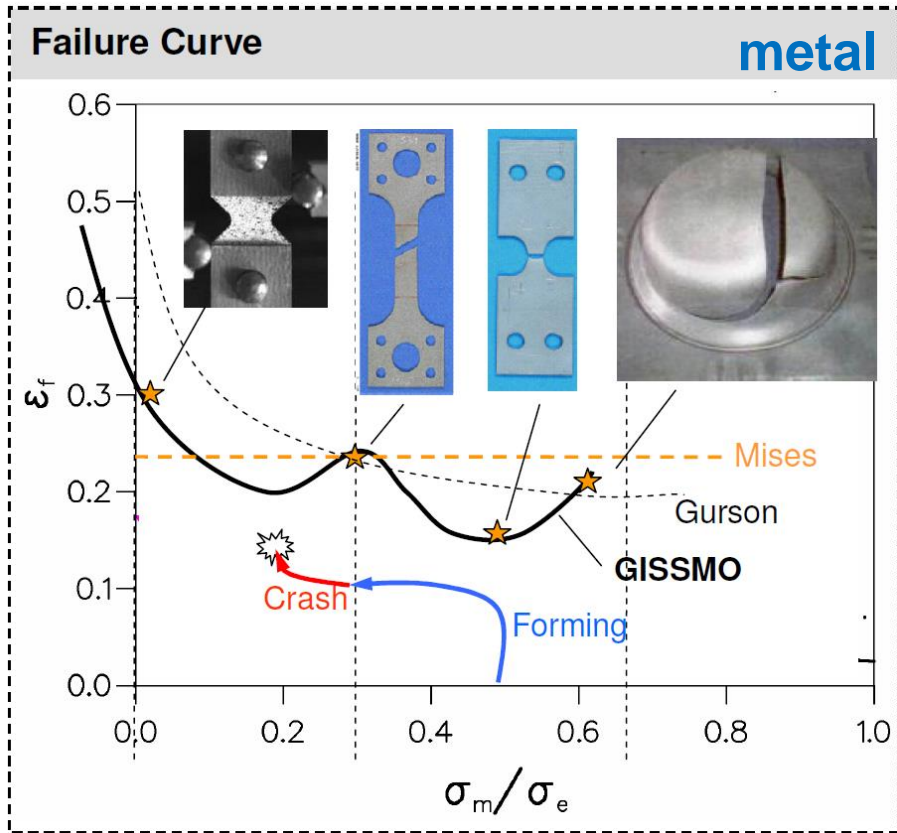
Damage/Failure



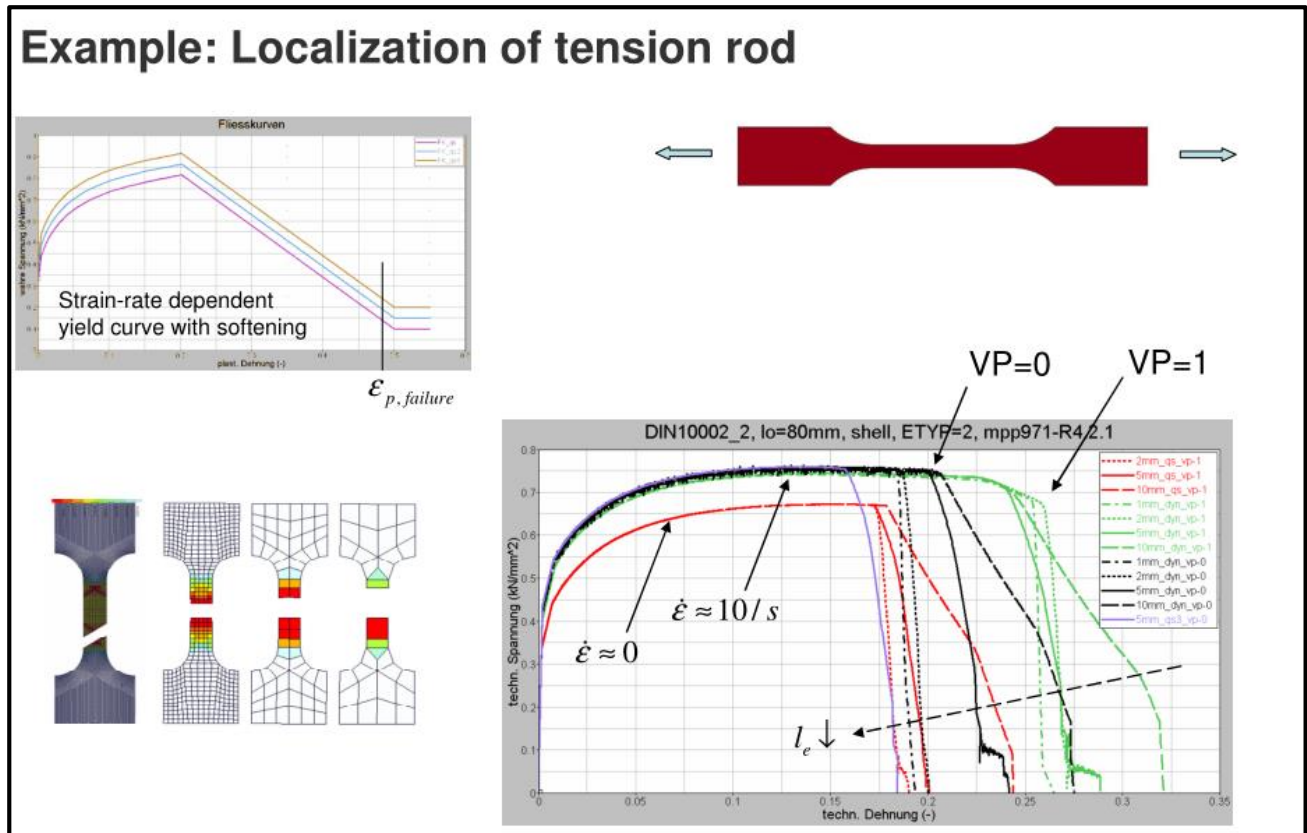
Source: H. Staack, Audi AG: Anforderungsgerechte Material- und Bruchmodellierung für die Fahrzeugsicherheit, TT16 Schladming

Motivation

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

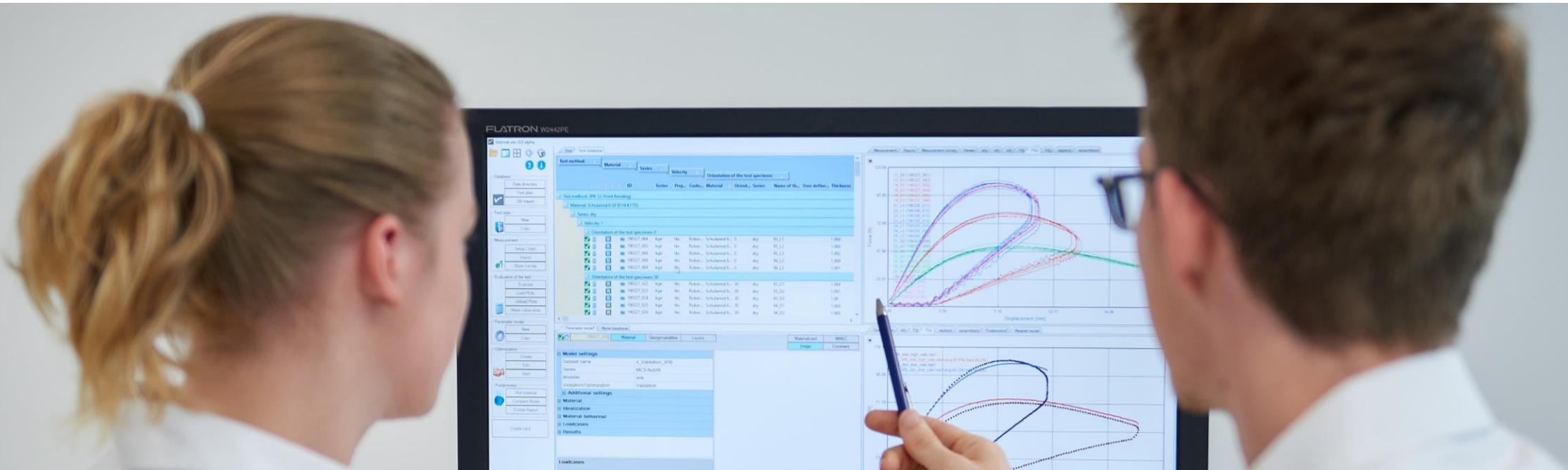


source: F. Neukamm – GISSMO – Material modeling with a sophisticated failure criteria, LS-Dyna Developer Forum 2011, Stuttgart



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**.

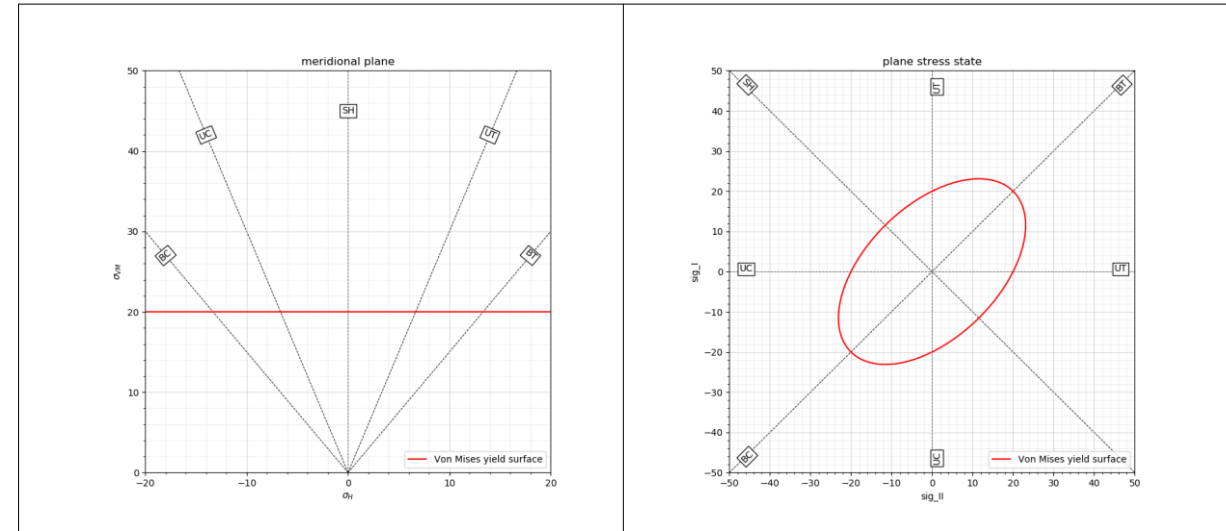
Other interesting material models for thermoplastic polymers are ***MAT_124** and ***MAT_187**.

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

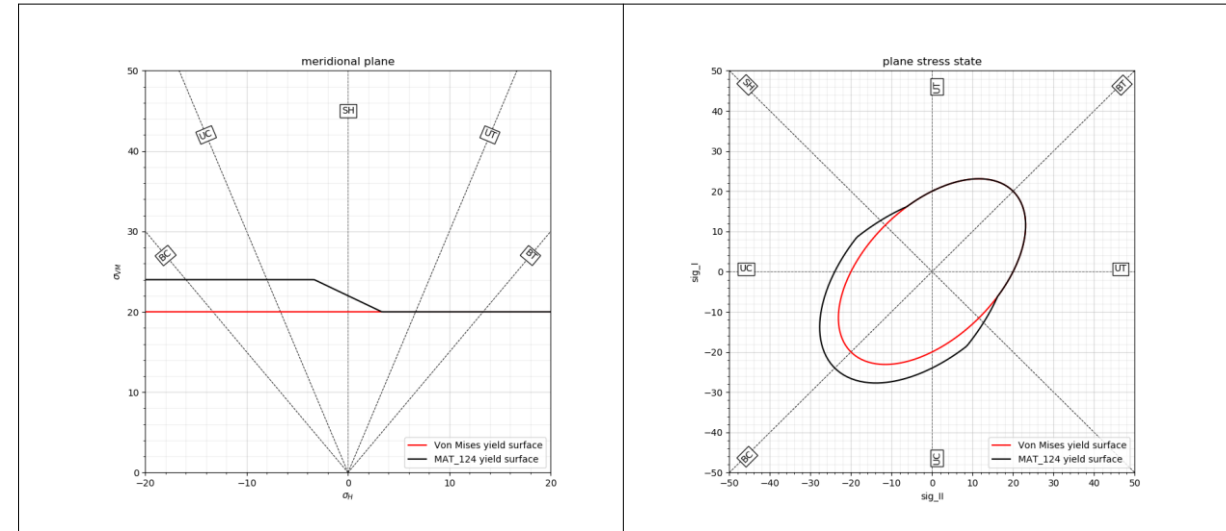
- ***MAT_024 - The workhorse**
 (*MAT_081, *MAT_089, *MAT_123, ...)



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

Commonly Used Material Models For Plastics

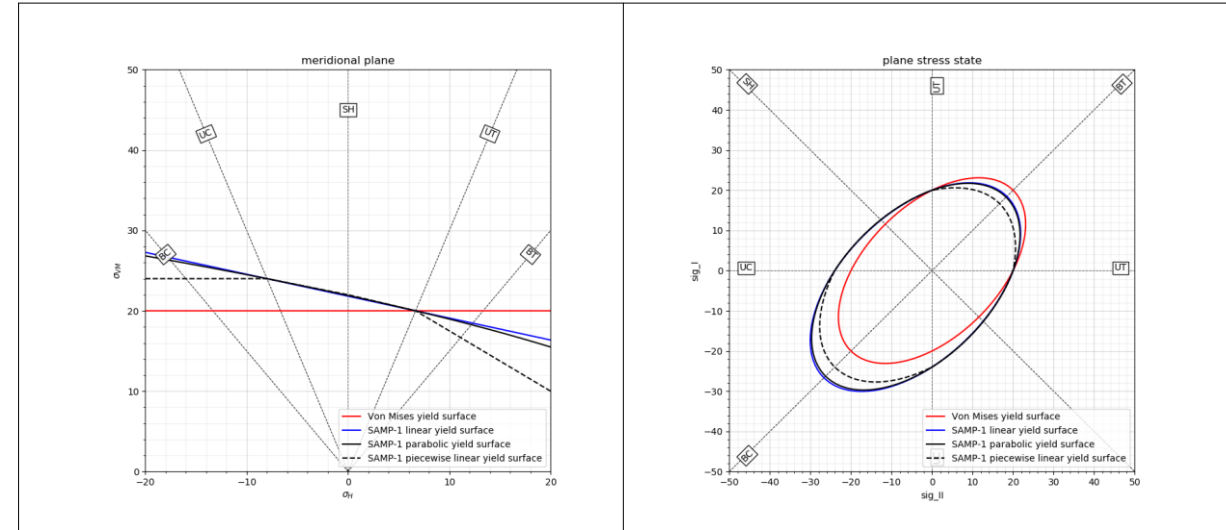
- ***MAT_024 - The workhorse**
(***MAT_081, *MAT_089, *MAT_123, ...**)
- ***MAT_124 - The hidden**



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

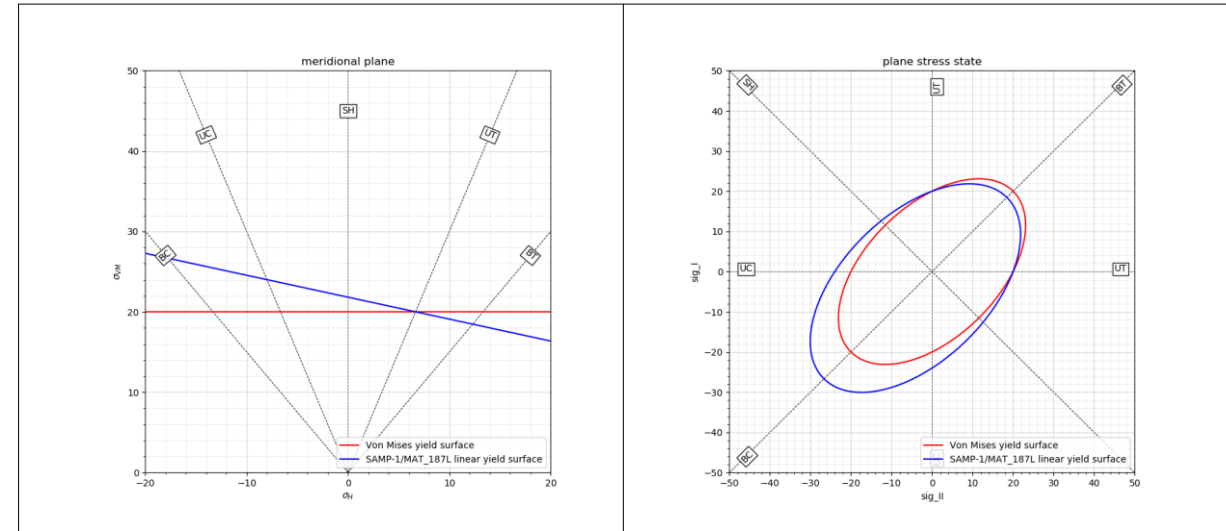
- ***MAT_024 - The workhorse**
(***MAT_081, *MAT_089, *MAT_123, ...**)
- ***MAT_124 - The hidden**
- ***MAT_187 - The plastic expert**



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	✓ $E(\dot{\epsilon})$	✓	✓	✓ $\nu_p(\epsilon)$

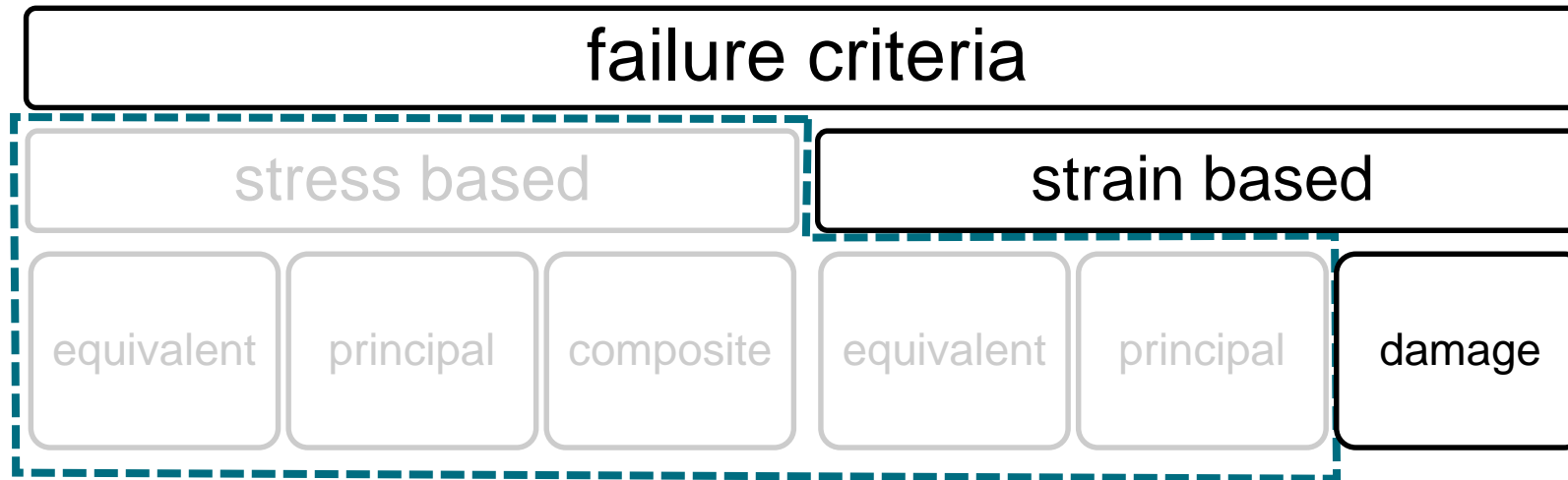
Commonly Used Material Models For Plastics

- ***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	✓ $E(\dot{\epsilon})$	✓	✓	✓ $\nu_p(\epsilon)$
*MAT_187L	linear	✓ $E(\dot{\epsilon})$	✓	✓	✓ $\nu_p(\epsilon)$

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*

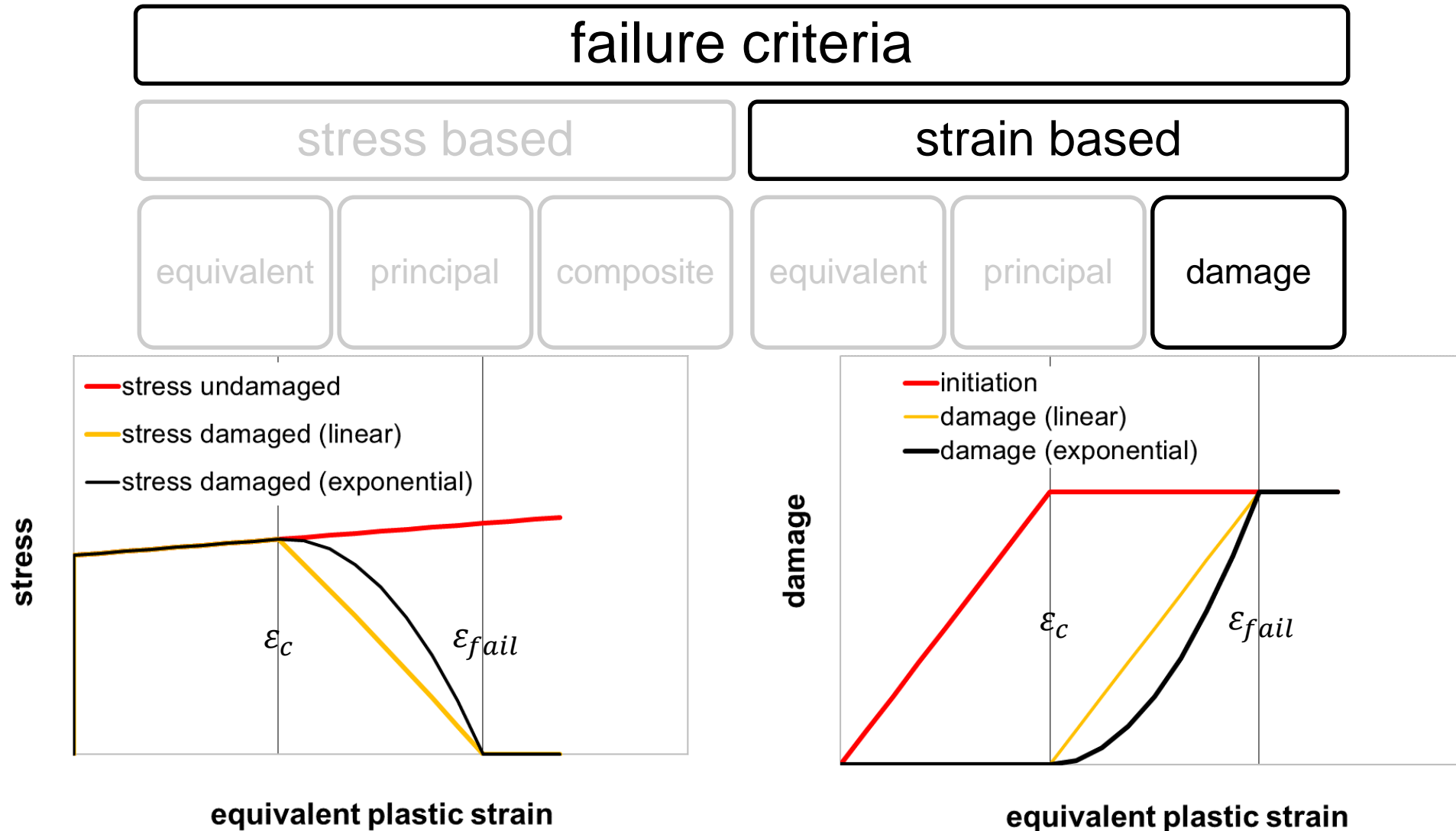
Included eq. pl. strain

****MAT_024***

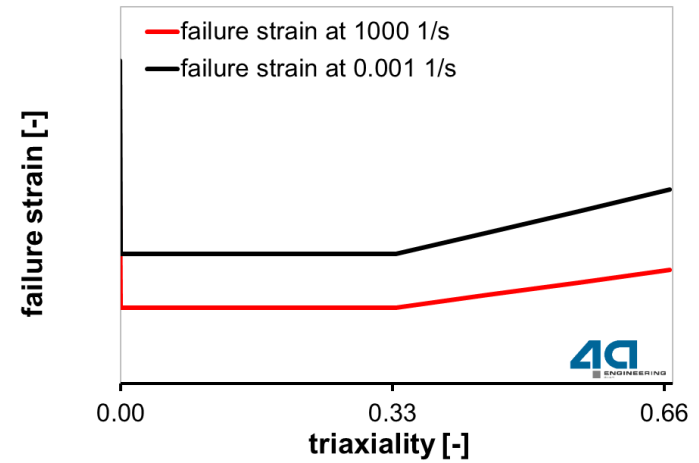
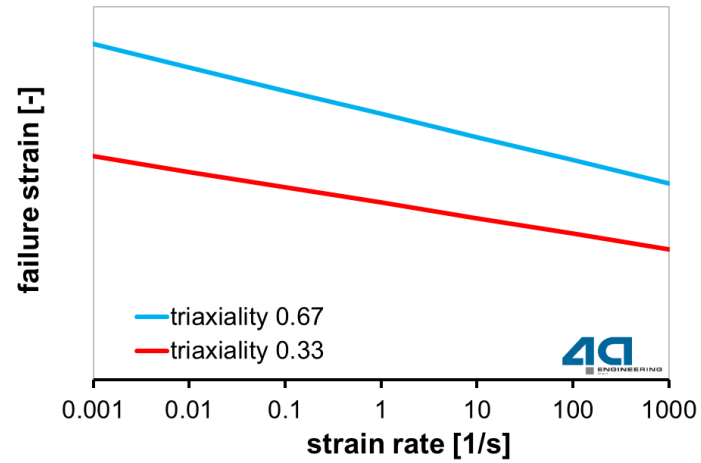
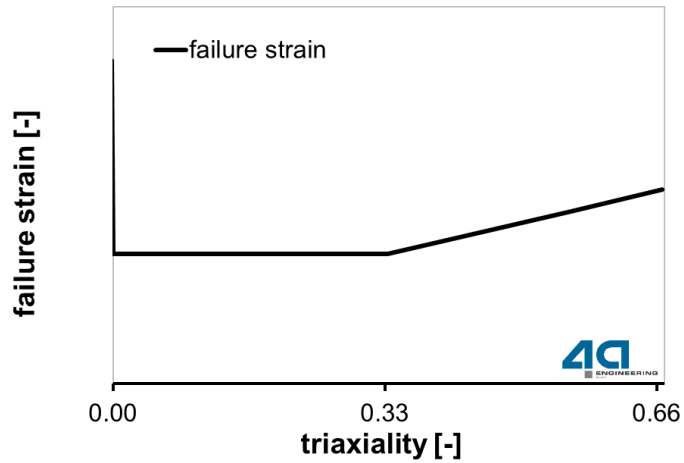
included damage model in

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

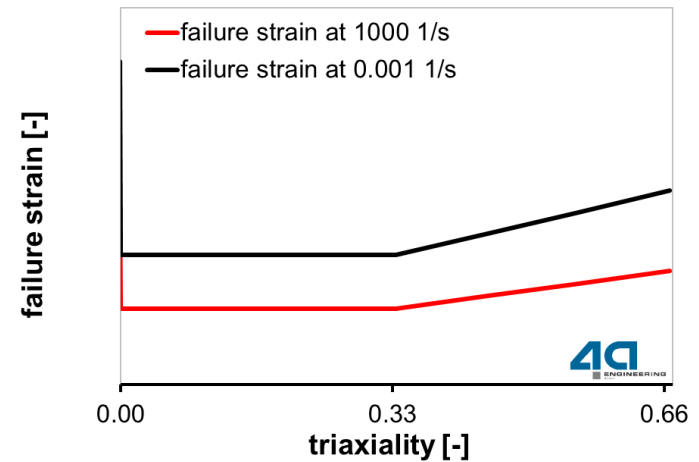
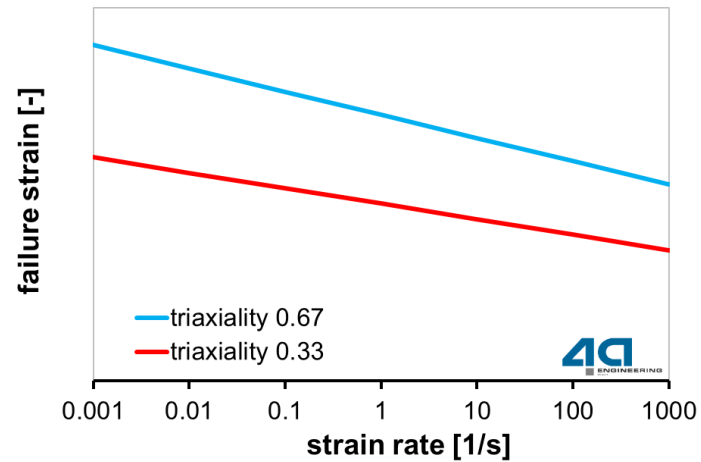
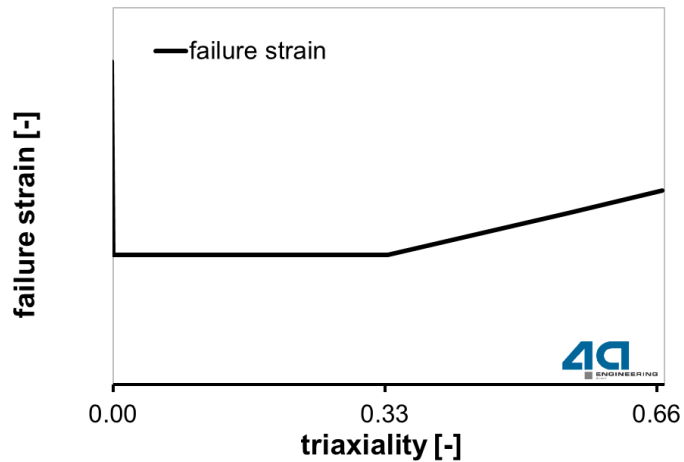
Available failure models – incremental damage formulation



Comparison DIEM-GISSMO visualized

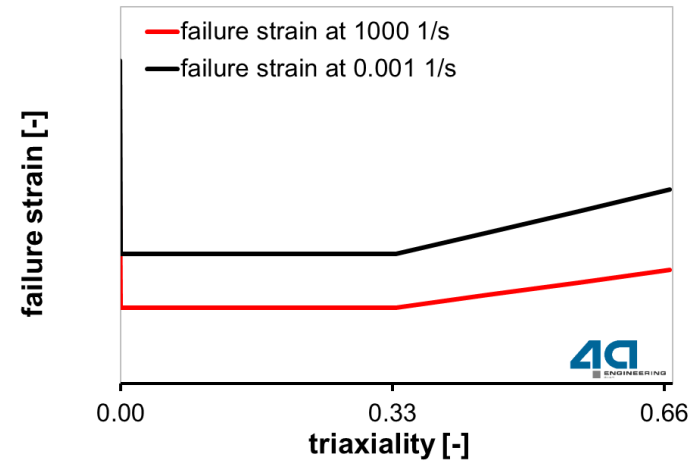
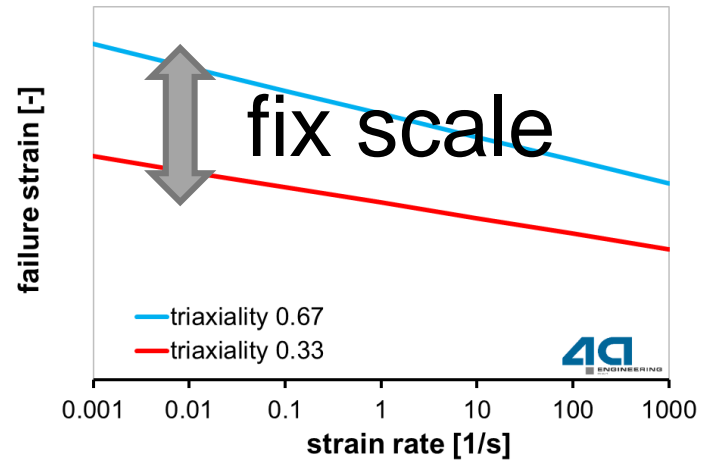
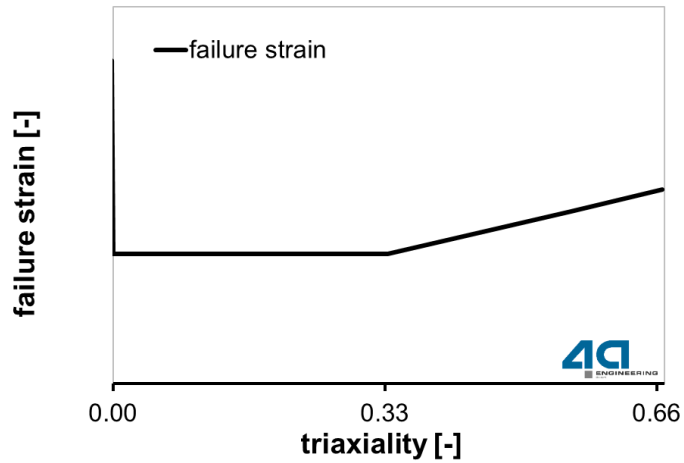


GISSMO

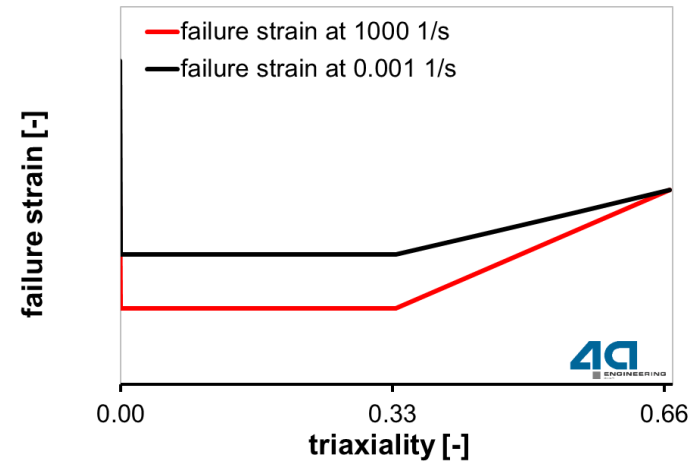
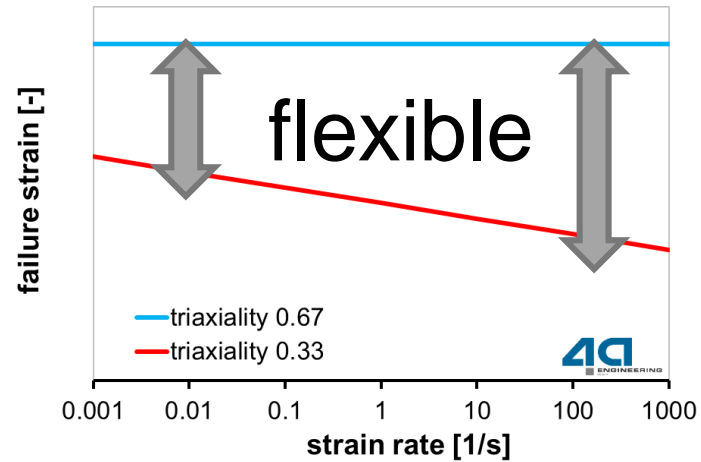
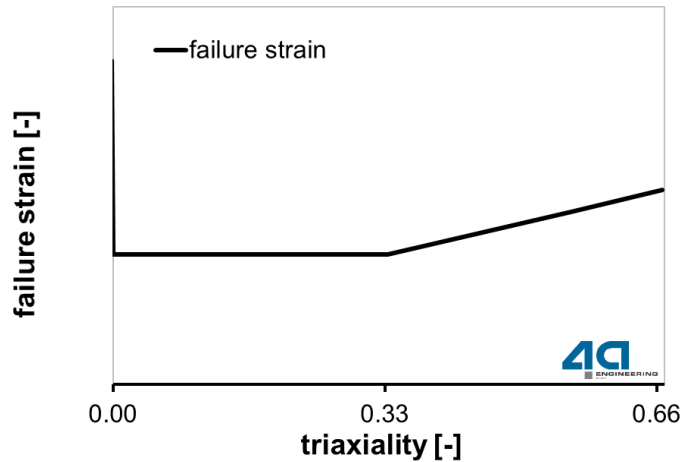


DIEM

Comparison DIEM-GISSMO visualized

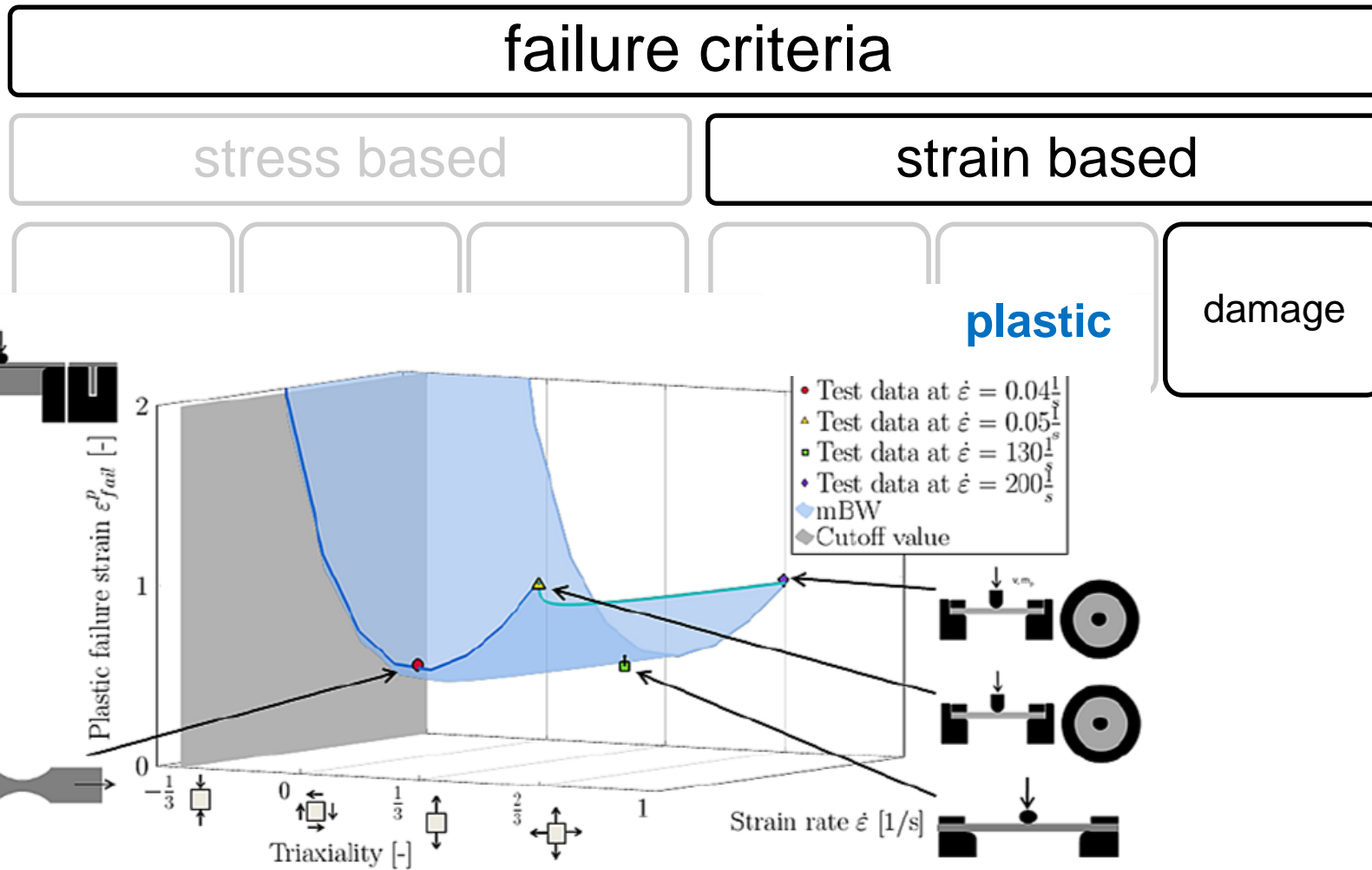


GISSMO



DIEM

Available failure models – typical curves

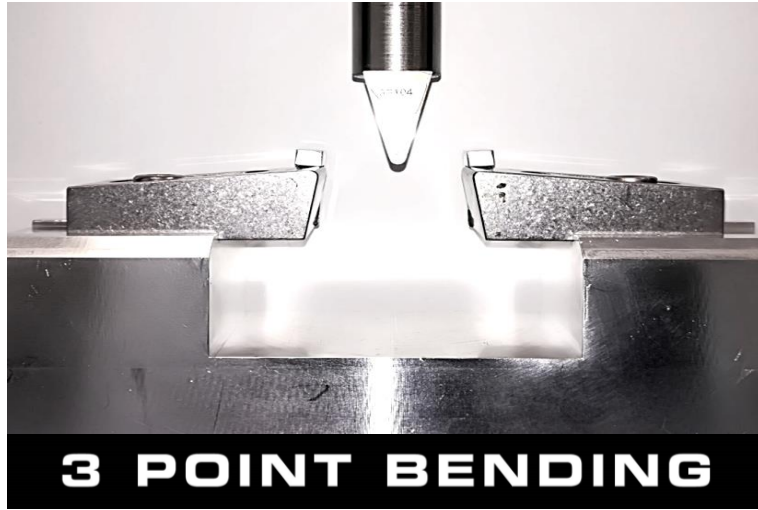


source: H. Staack, - Application oriented failure modeling and characterization for polymers in automotive pedestrian protection, COMPLAS 2015, Barcelona

Let's take a closer look on plastics



Static Testing



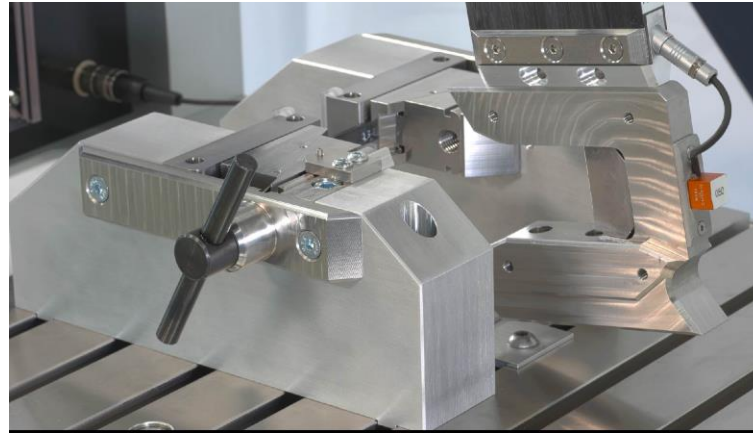
static ~ 1mm/s



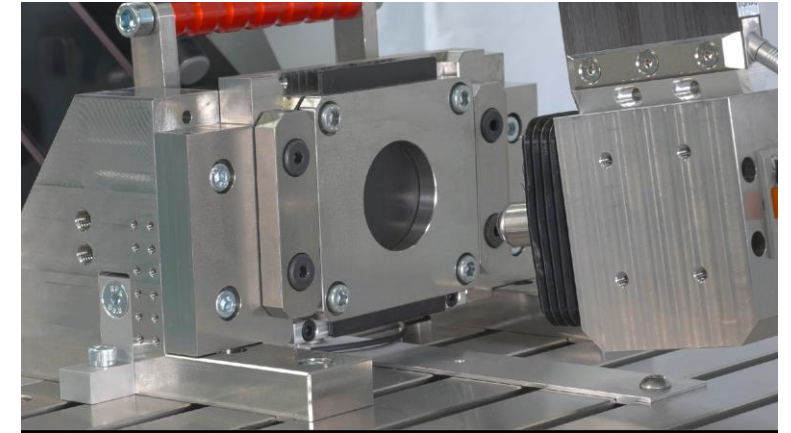
IMPETUS® - efficient dynamic testing



3 POINT BENDING



TENSION BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s



TENSION TEST

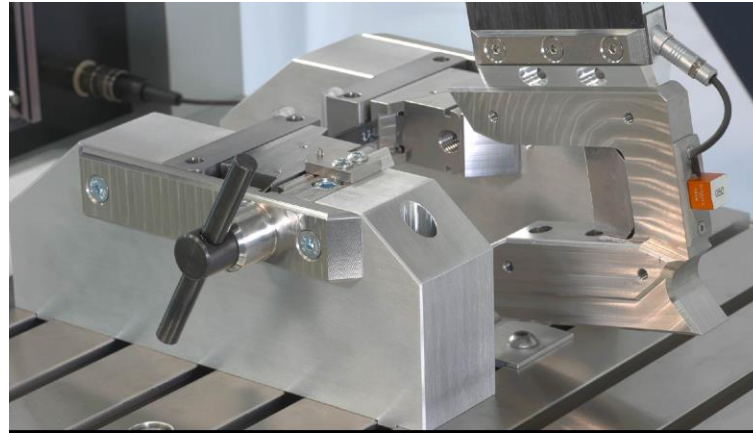


YOUTUBE CHANNEL

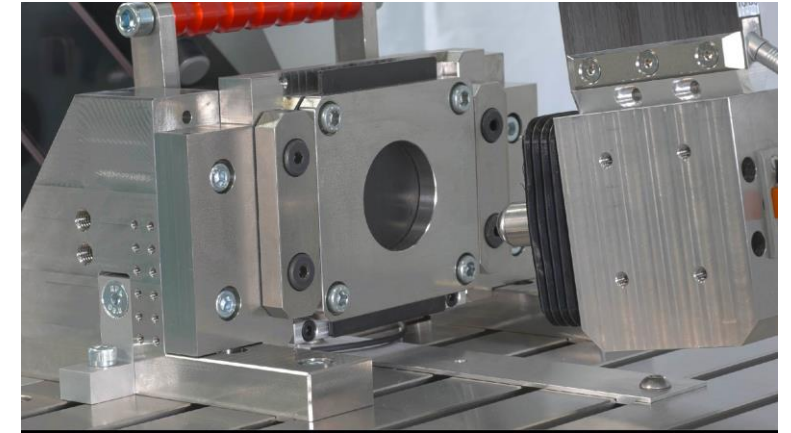
IMPETUS® - efficient dynamic testing



3 POINT BENDING

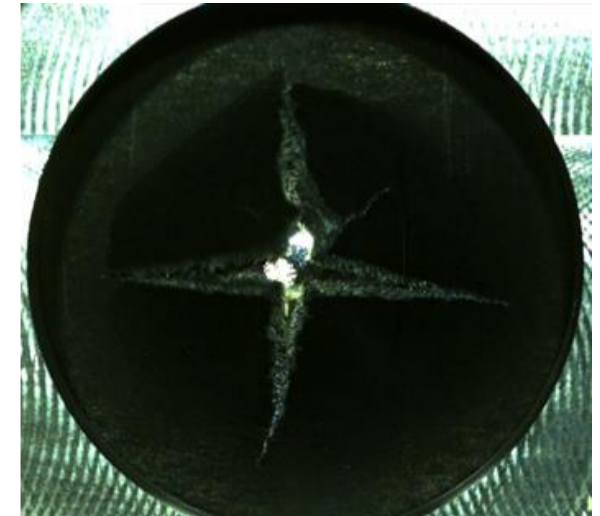
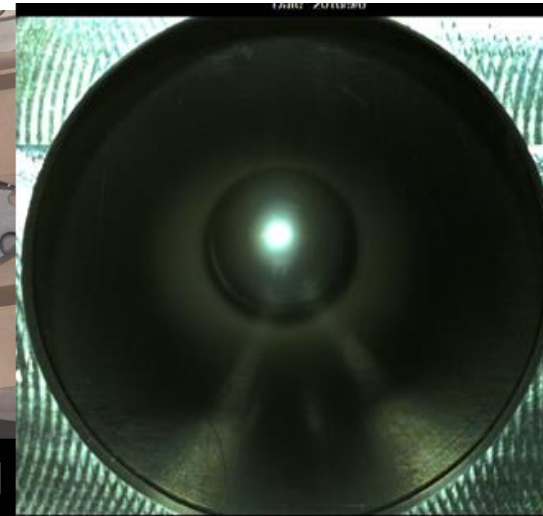
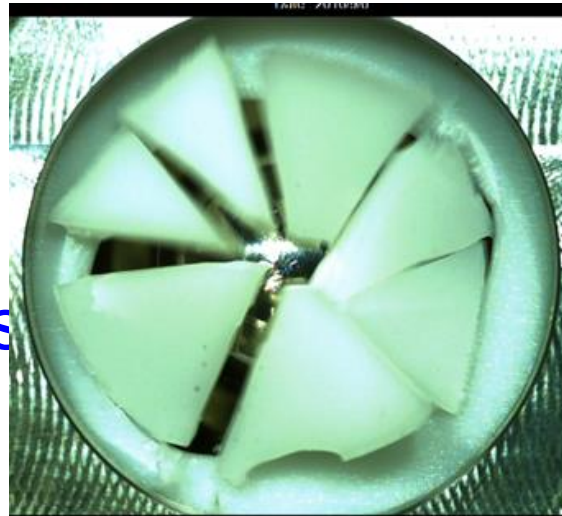


TENSION BENDING

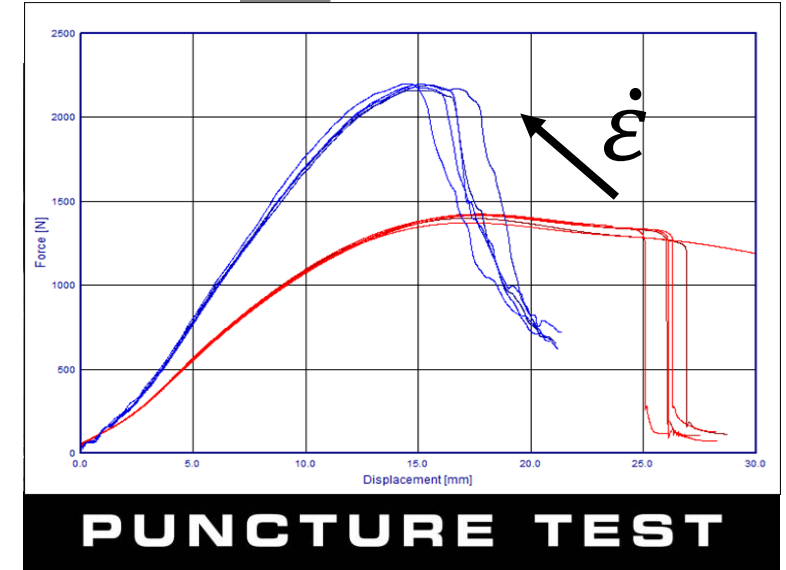
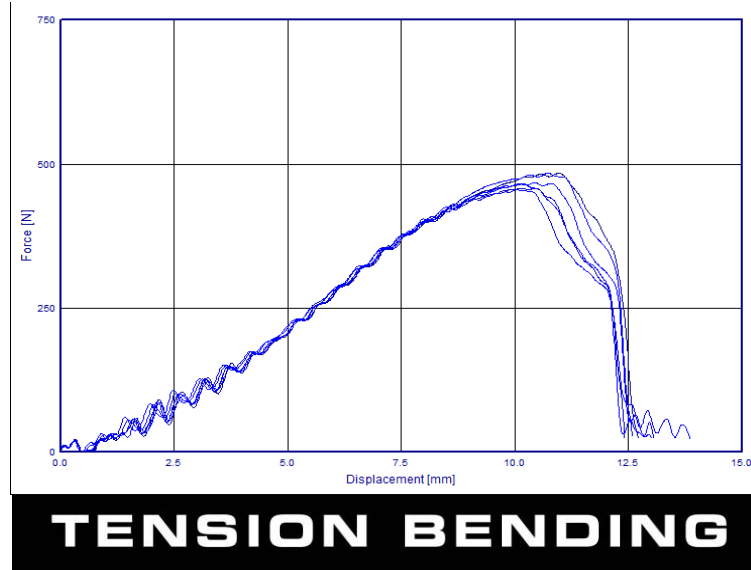
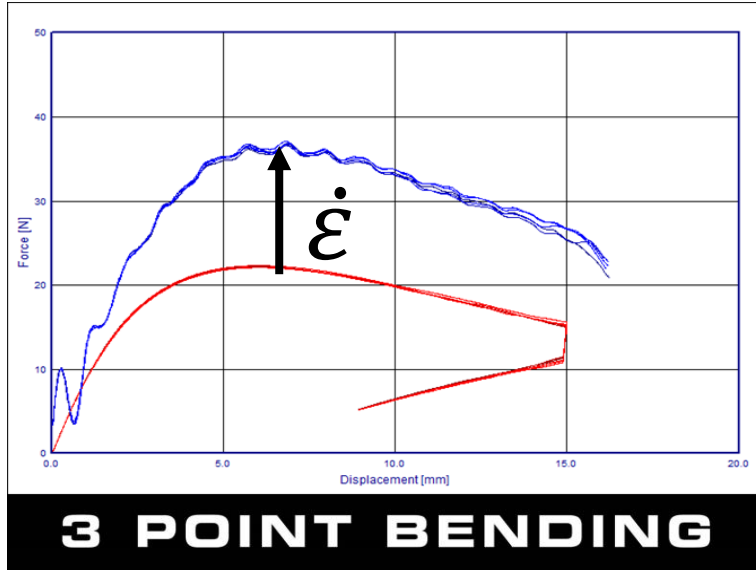


PUNCTURE TEST

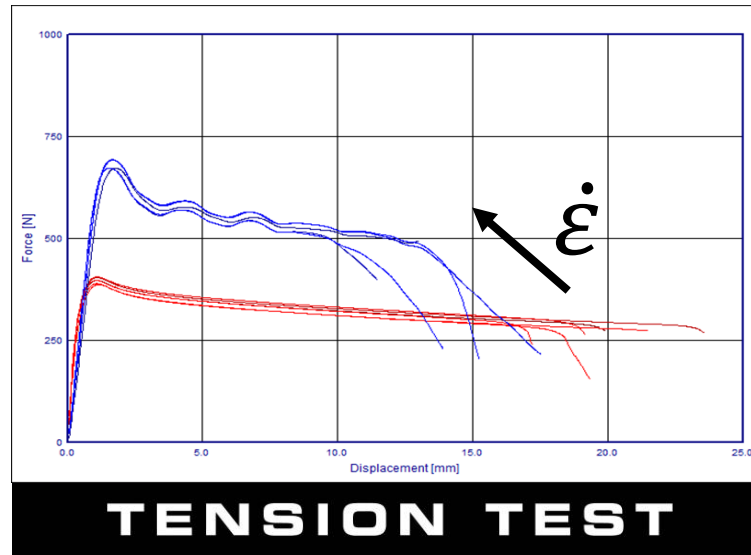
IMPETUS™ ~ 3 m/s



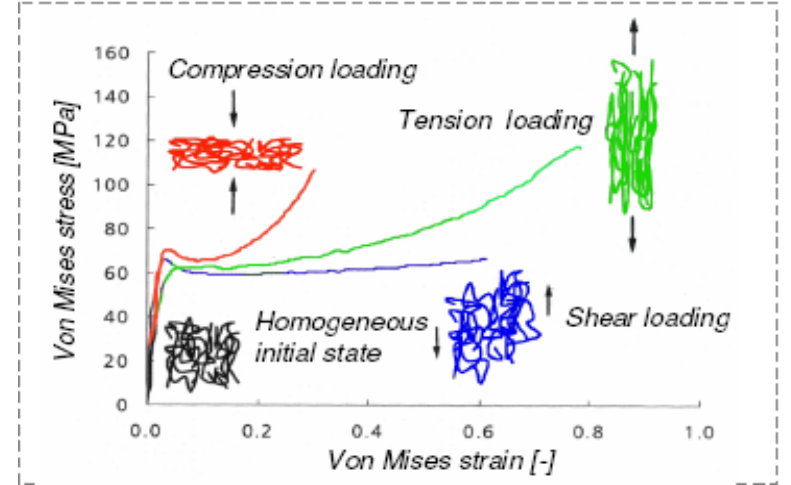
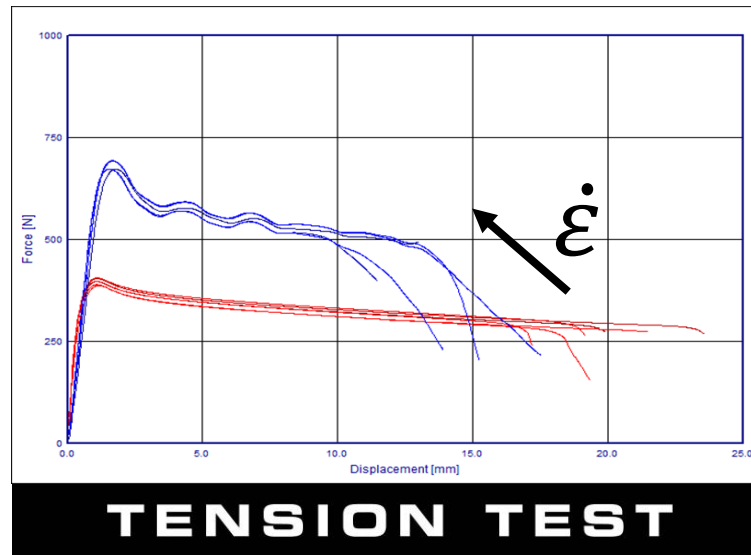
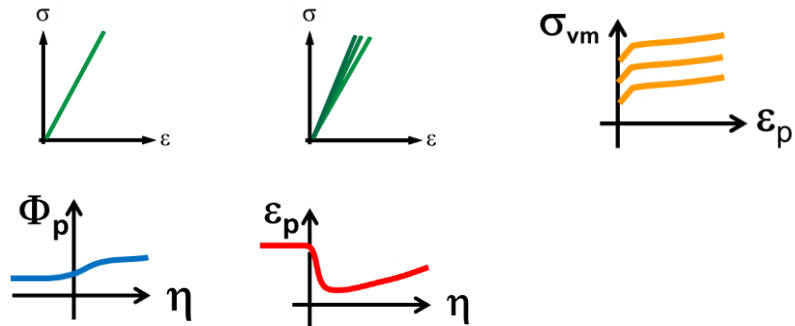
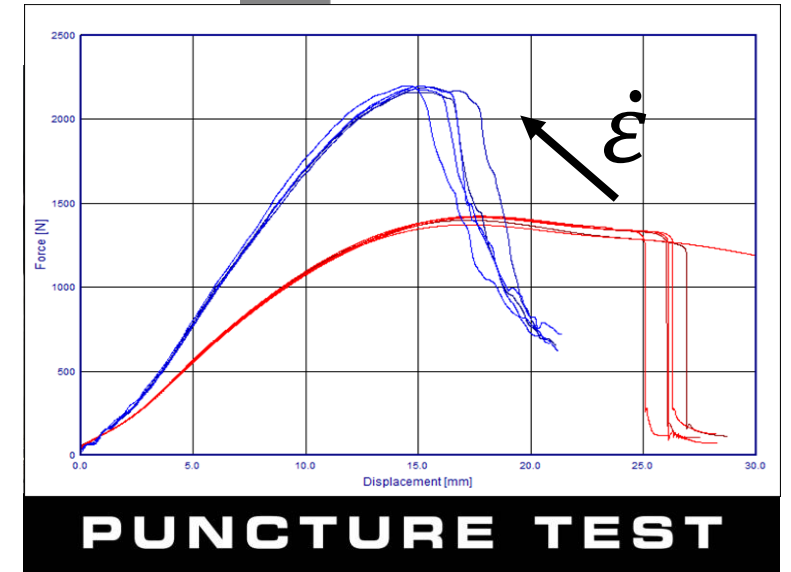
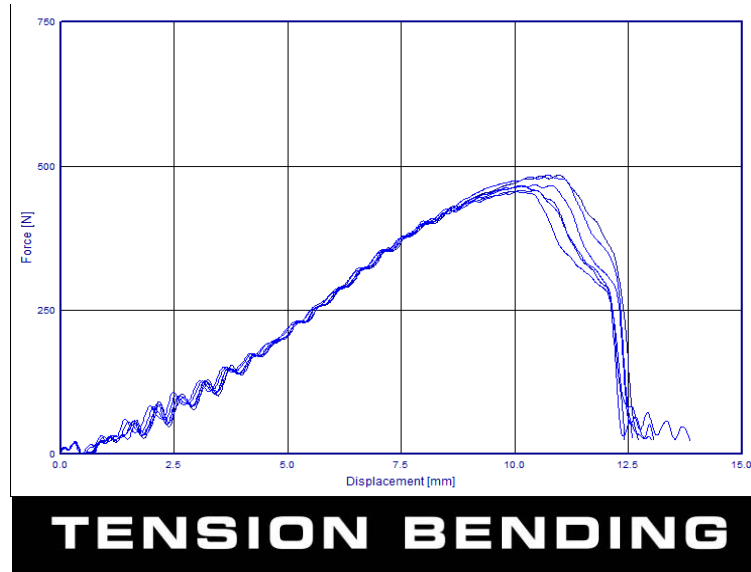
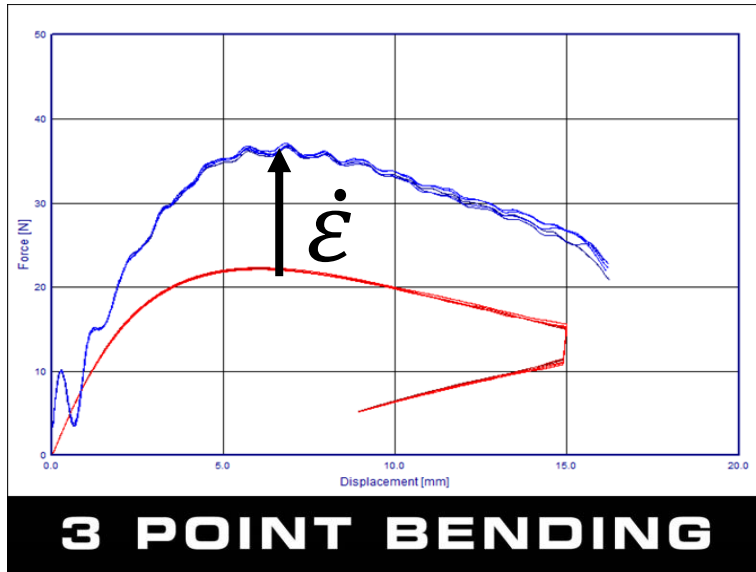
Measurement Results



IMPETUS® ~ 3 m/s
static ~ 1mm/s

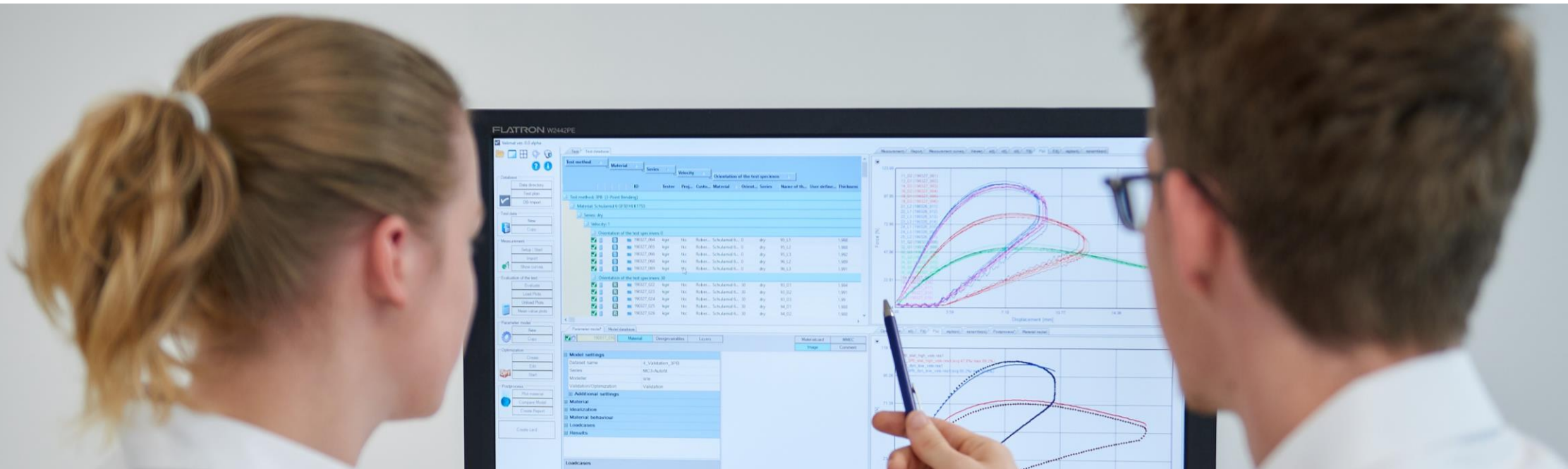


Measurement Results → Material Model



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

From test to material card

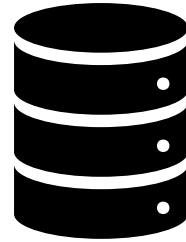




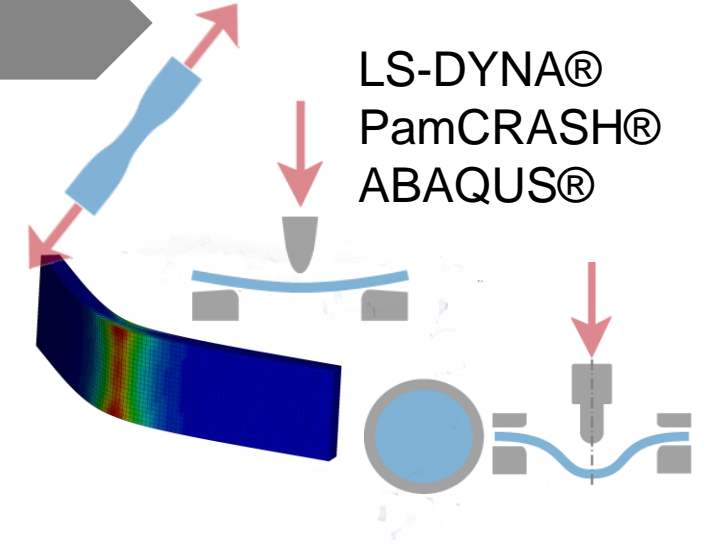
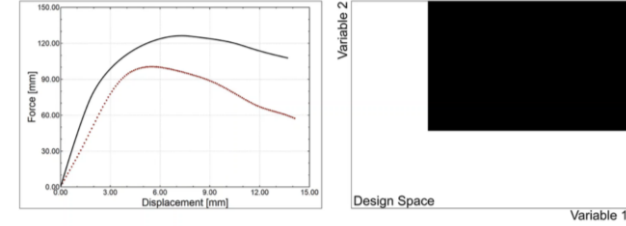
static &
dynamic



VALIMAT



database



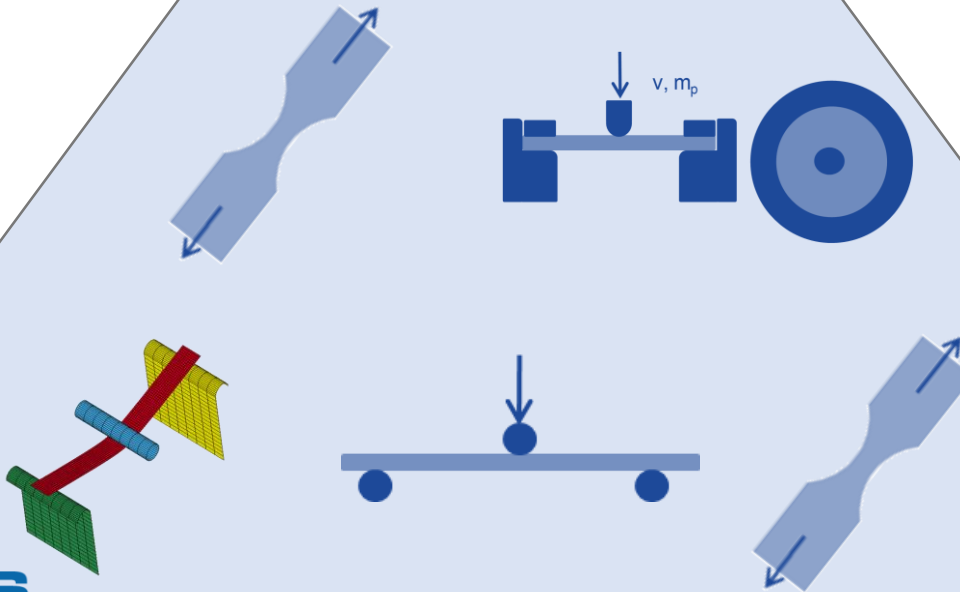
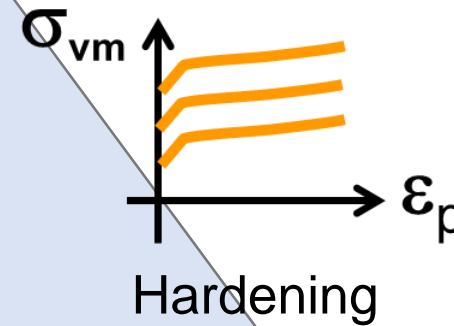
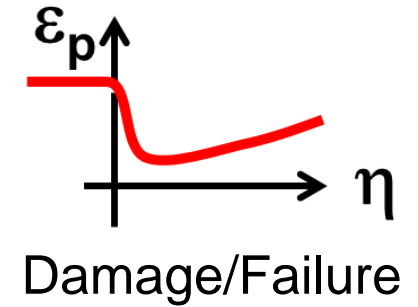
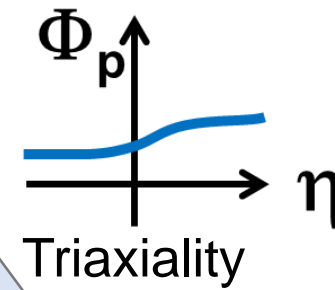
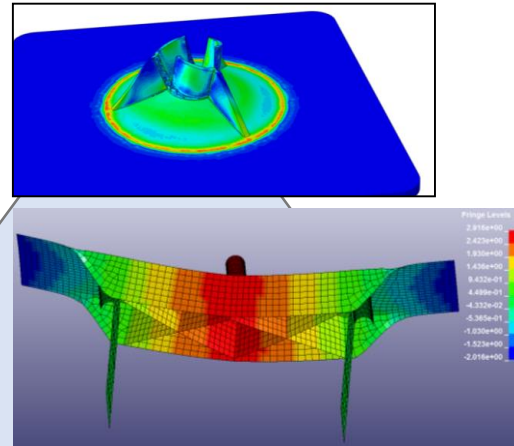
LS-DYNA®
PamCRASH®
ABAQUS®

MCS Monte Carlo Simulation
DoE Design of Experiments
Optimization

From test to material card



Deformation → Failure
 Creep → Static → Crash
 ISOTROPIC → ANISOTROPIC



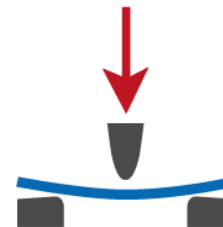
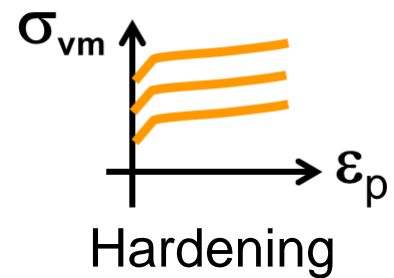
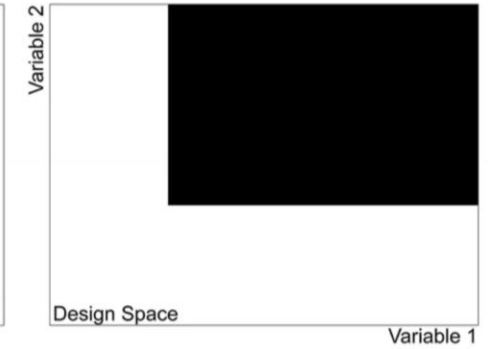
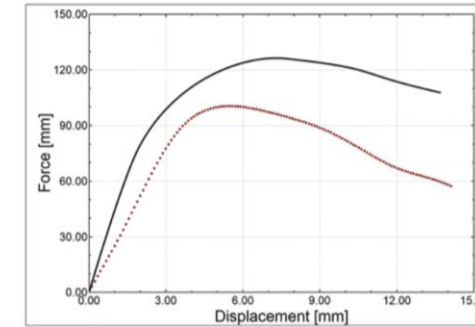
Workflow for Material Card Generation - AUTOFIT



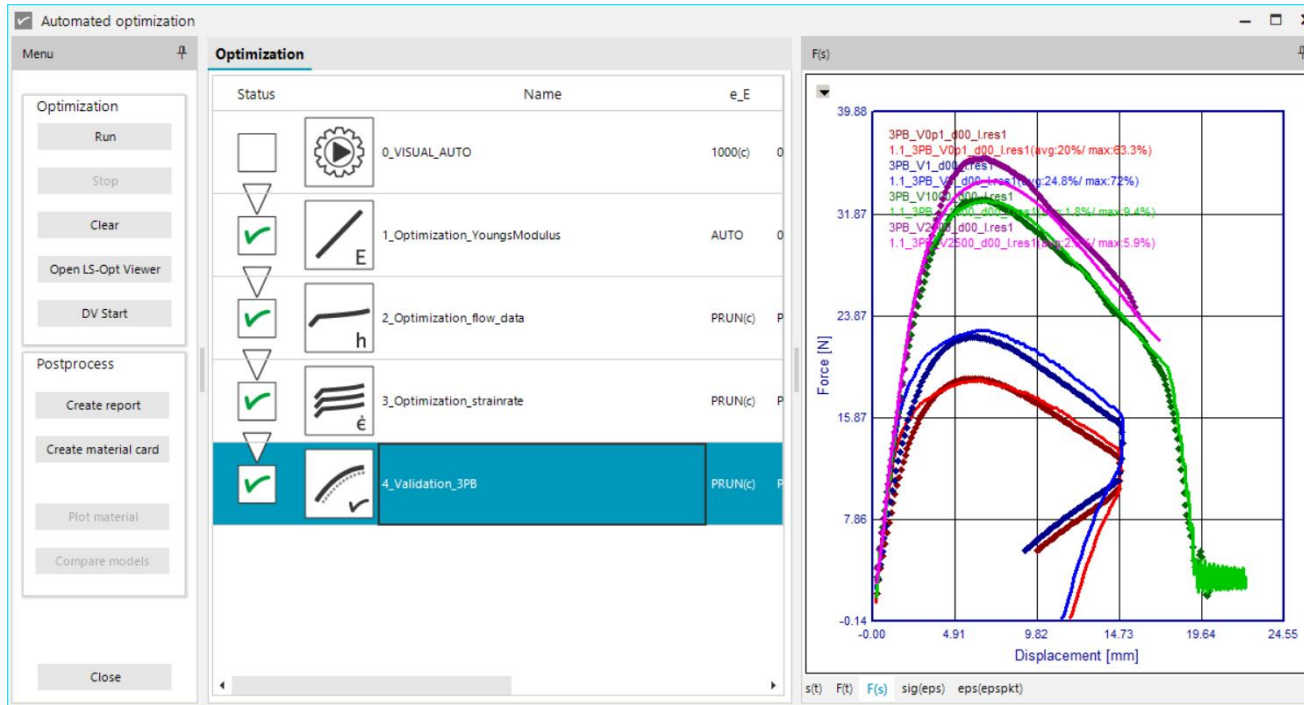
Automated optimization

Status	Name	e_E
	0_VISUAL_AUTO	1000(c)
	1_Optimization_YoungsModulus	AUTO
	2_Optimization_flow_data	PRUN(c)
	3_Optimization_strainrate	PRUN(c)
	4_Validation_3PB	PRUN(c)

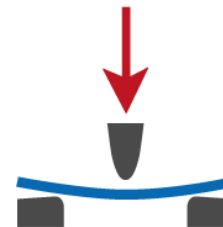
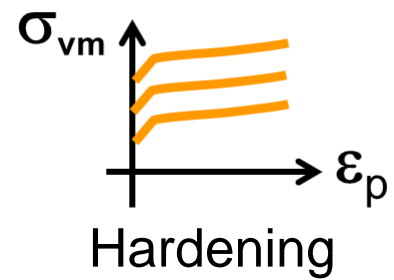
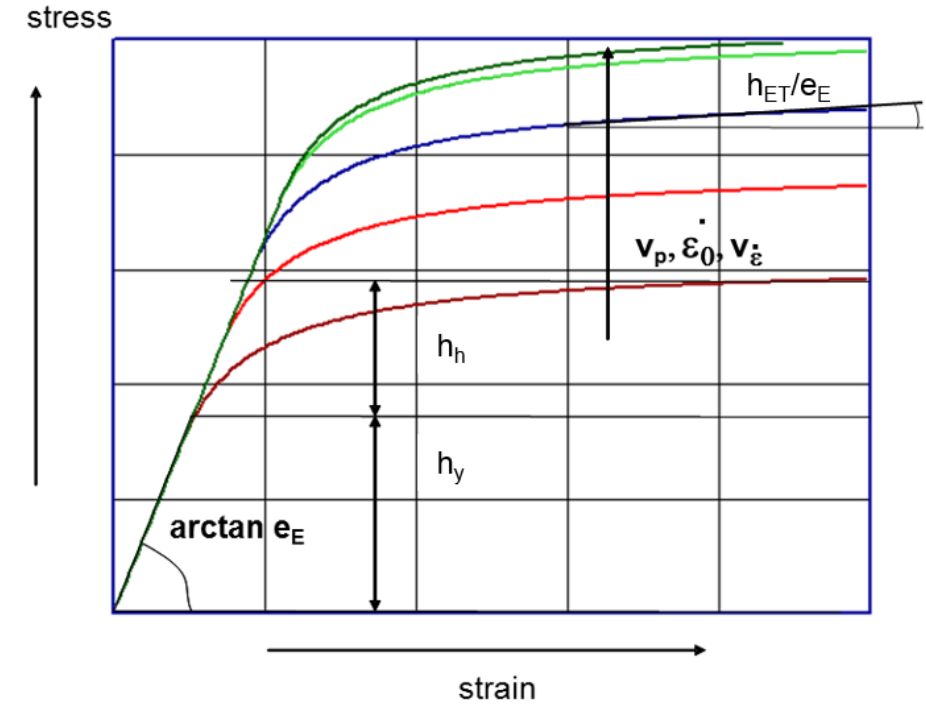
optimization – successive response surface method



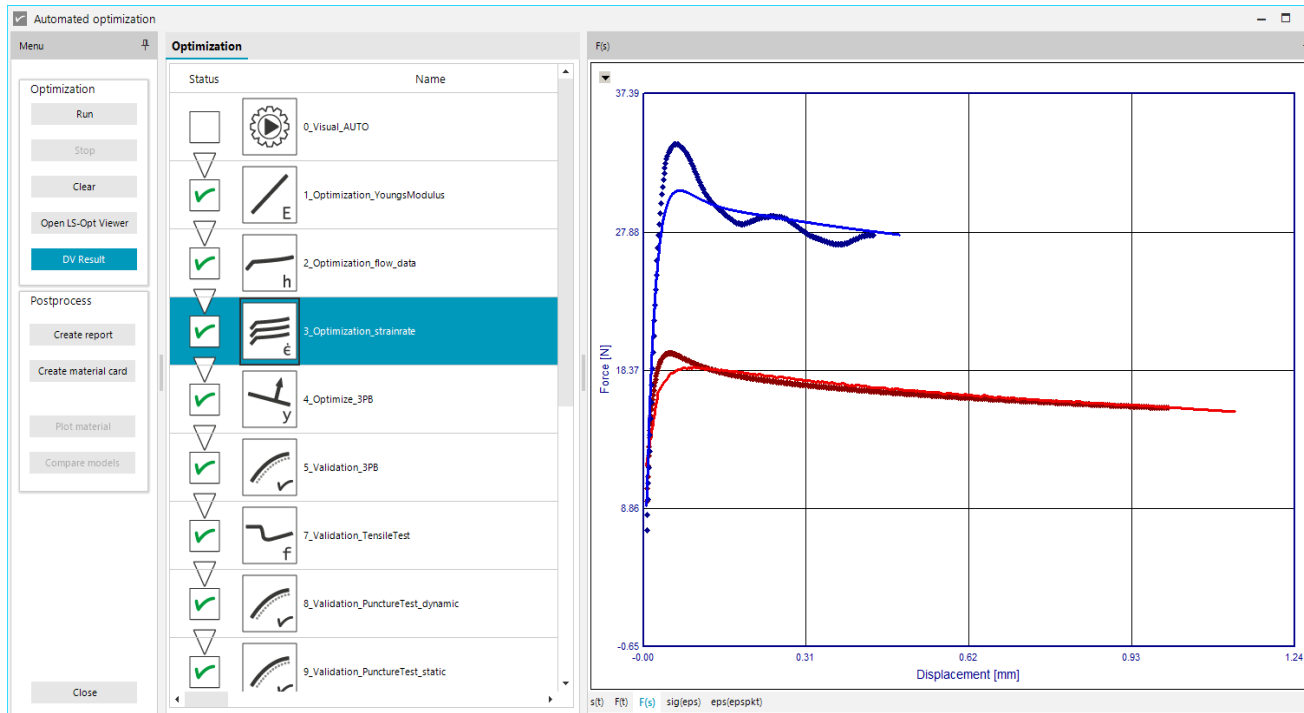
Workflow for Material Card Generation - AUTOFIT



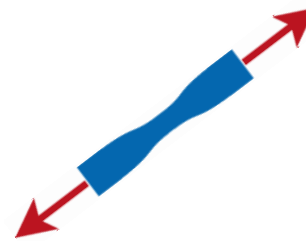
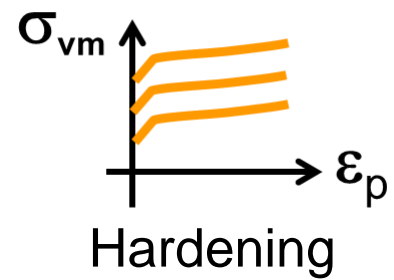
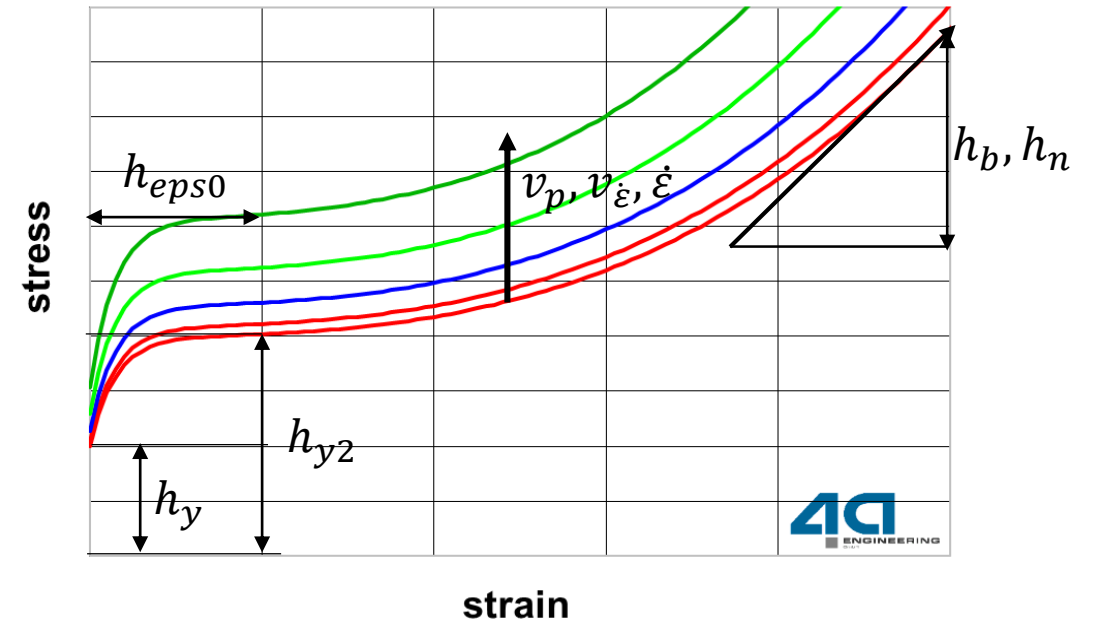
parametrized material card



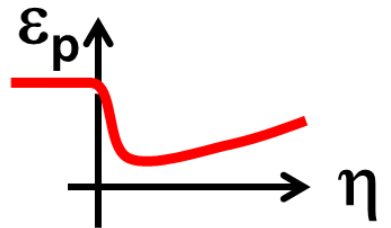
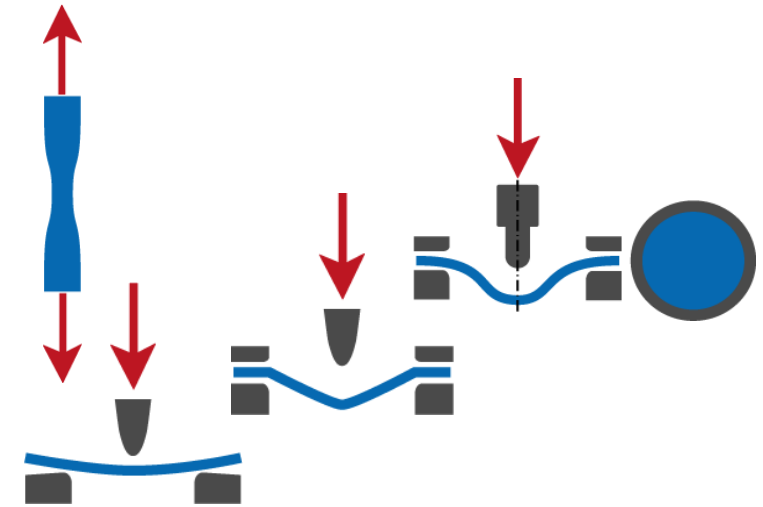
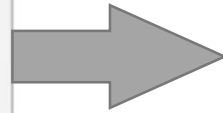
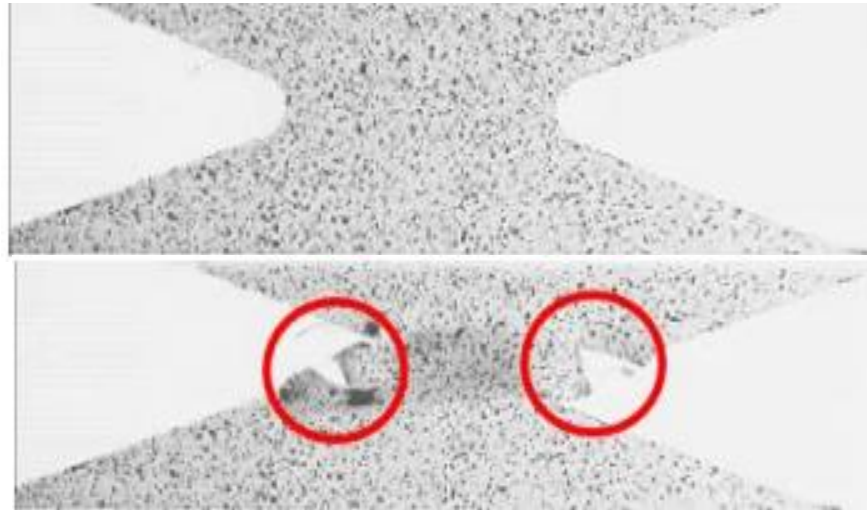
Workflow for Material Card Generation - AUTOFIT



parametrized material card



From test to material card



Damage/Failure

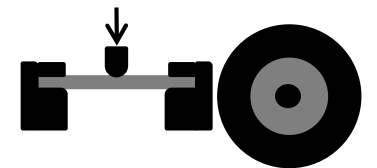
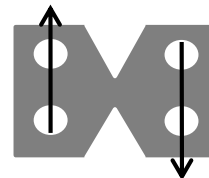
- 0.33

0

0.33

0.66

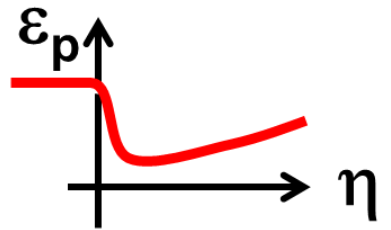
η



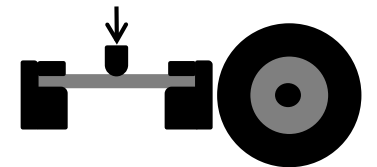
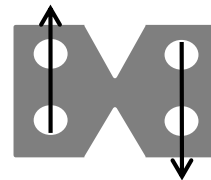
From test to material card



- 0.33 0 0.33 0.66 η



Damage/Failure



Fracture models → *MAT_ADD_EROSION



Parameter model* Model database

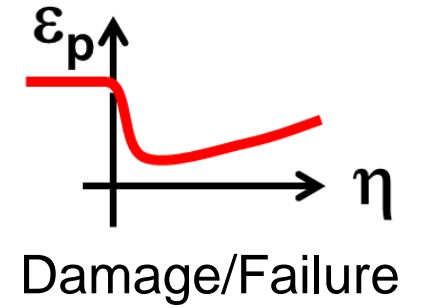
170503_024 Material Designvariables Layers

Materialcard MMEC
Image Comment

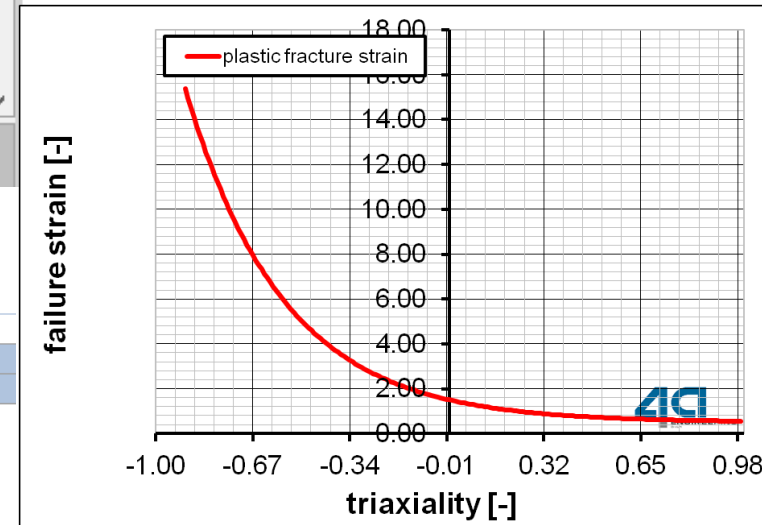
- Material behaviour
 - Material source
 - Elasticity
 - Plasticity
 - Failure/Damage
 - Material card
 - Materialcardcase
 - Damage/Failurecase
 - Materialcard id
 - Density
 - Plasticity
 - Function (Hardening, Elastic curve form)
 - Curve 1
 - Curve 2
 - Strain range upto
 - Sampling points
 - Bias factor
 - Strain rate dependency
 - Strain rate dependency
 - Fracture
 - Ductile Damage Settings
 - Shear Damage Settings
 - FLC Damage Settings
 - Strainrate Settings
 - Postfracture
 - Loadcases
 - Results

Density	-1
Plasticity	vonMISES
Function (Hardening, Elastic cur	
Strain rate dependency	Table
Fracture	Damage
Ductile Damage Settings	Johnson Cook
Shear Damage Settings	None
FLC Damage Settings	plastic equivalent strain
Strainrate Settings	simple criteria
Postfracture	4a picewise linear
Loadcases	Johnson Cook
Casename	mod Xue-Wierzbicki
Tests	Xue-Wierzbicki
Settings optimization	Mohr-Coulomb
Weighting case	1

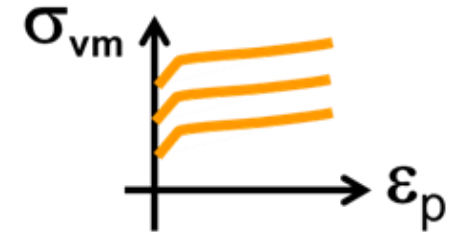
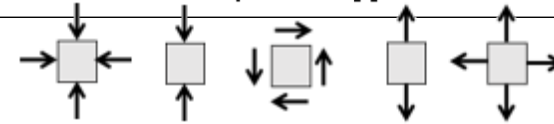
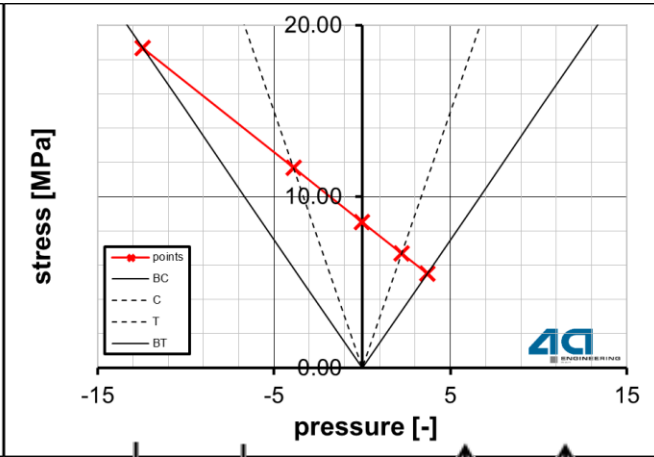
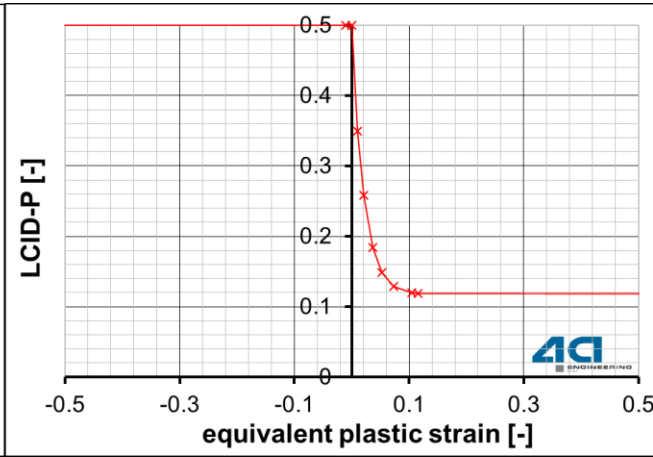
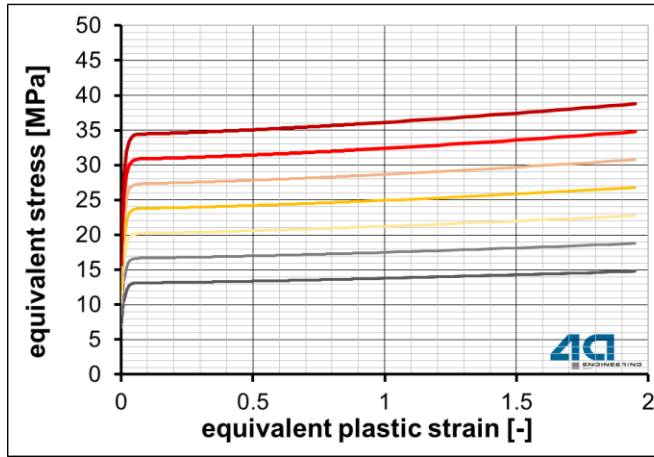
Ductile Damage Settings		
lower triax value		Johnson Cook
upper triax value		mod Xue-Wierzbicki
step size triax	0.33	Xue-Wierzbicki
Shear Damage Settings	None	Mohr-Coulomb
FLC Damage Settings	None	
Strainrate Settings	Johnson Cook	
Postfracture	Fracture Energy (TRIAx)	



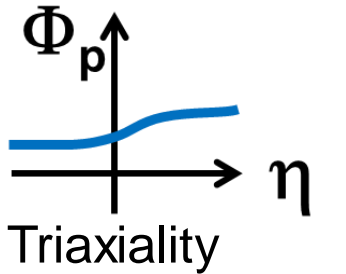
$$f_{d_{JCD1}} + f_{d_{JCD2}} \cdot e^{-f_{d_{JCD3}} \cdot \eta}$$



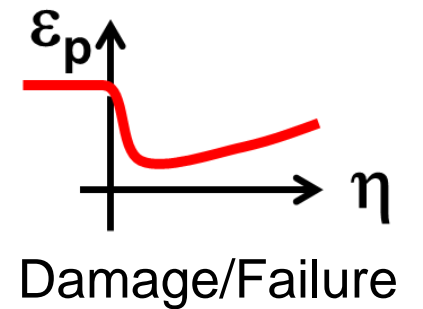
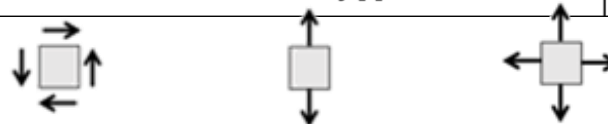
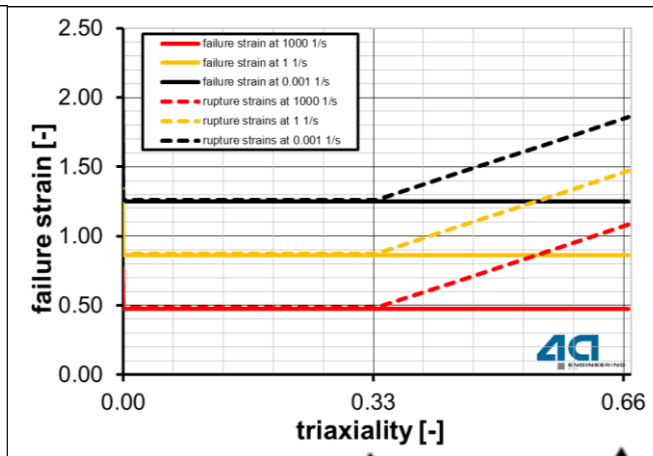
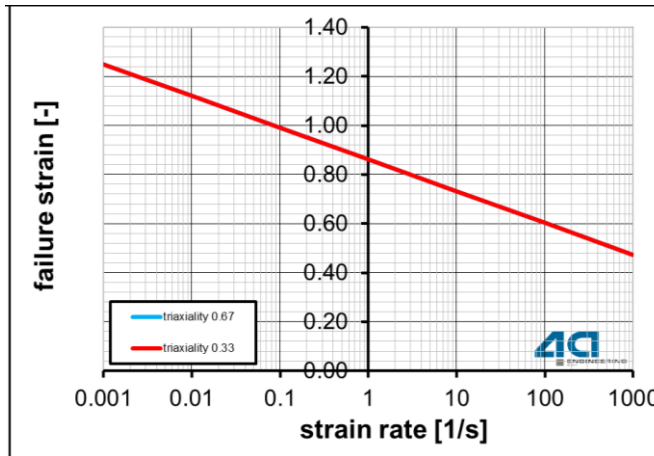
Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT



Hardening



Triaxiality

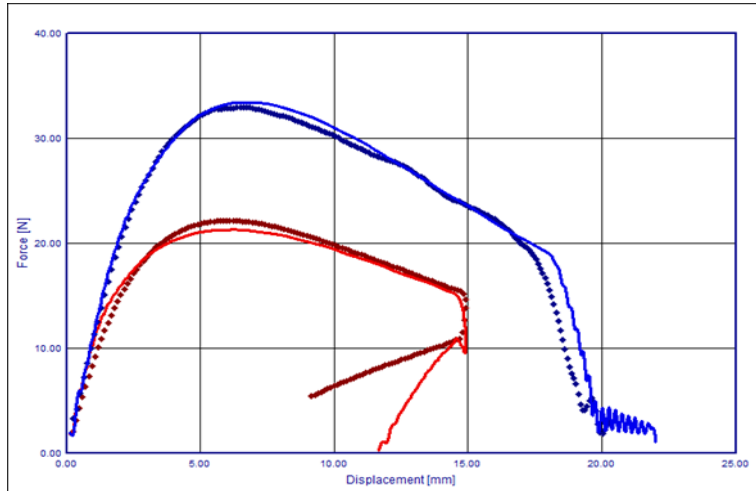


Damage/Failure

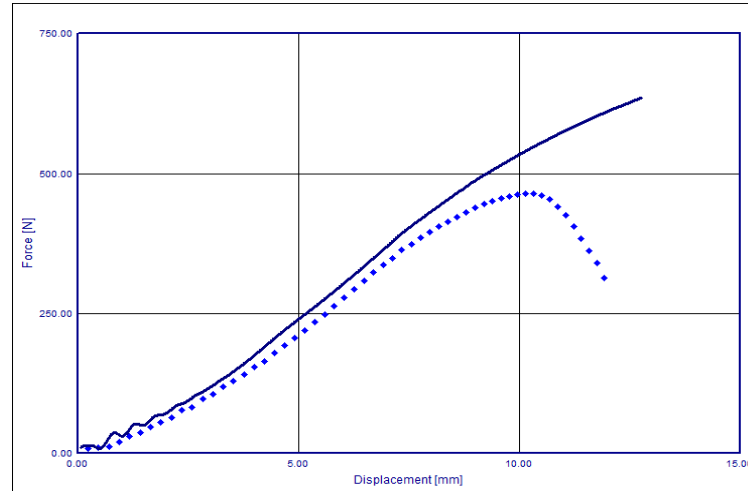
source: Benjamin Hirschmann, master thesis



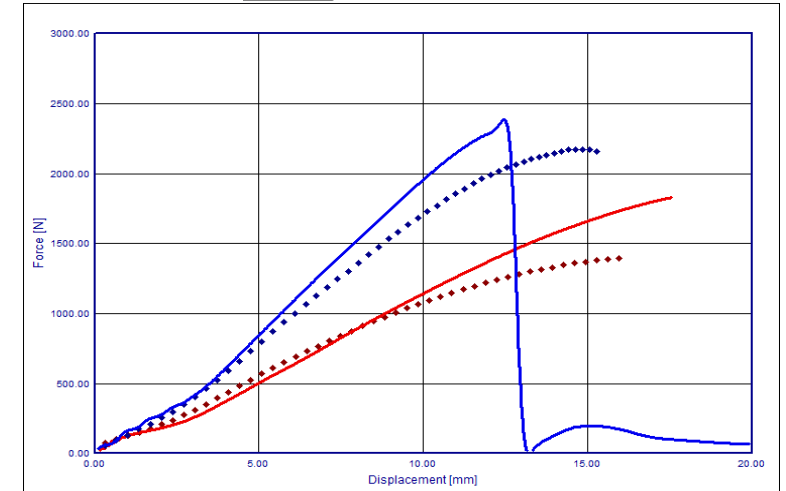
Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT



3 POINT BENDING

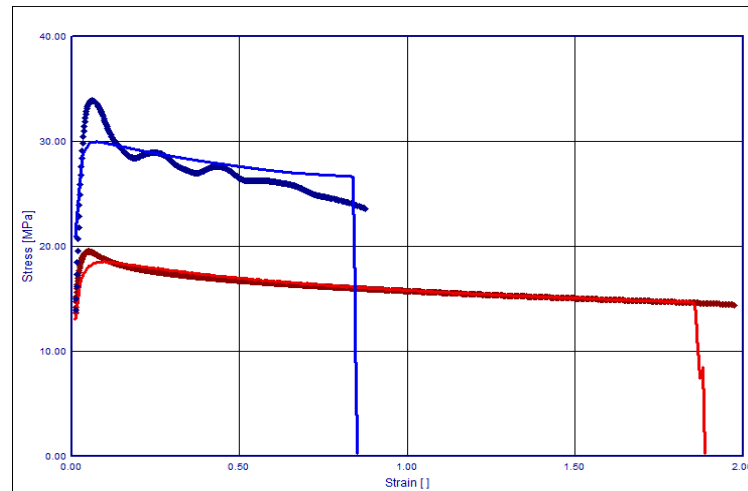


TENSION BENDING

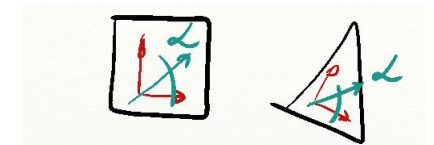


PUNCTURE TEST

IMPETUS® ~ 3 m/s
static ~ 1 mm/s



TENSION TEST

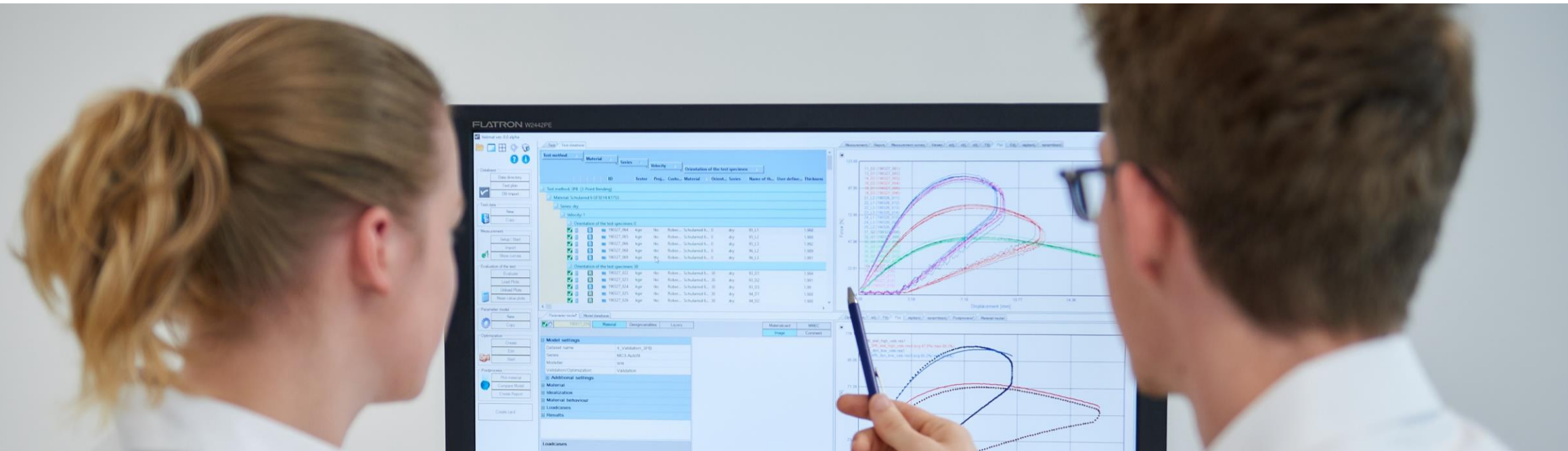


..... averaged test curves
— result of simulation

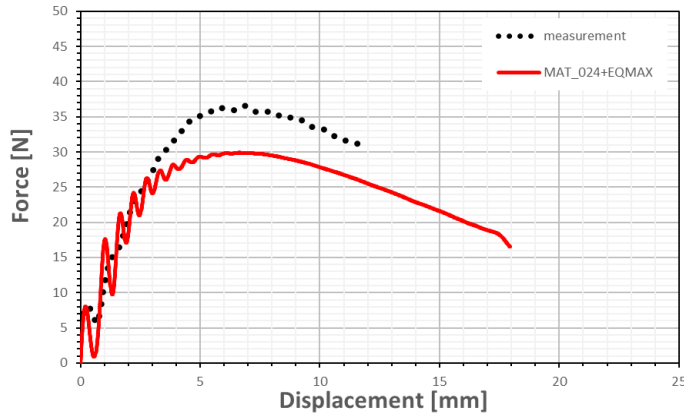
source: Benjamin Hirschmann, master thesis

Comparison different material models

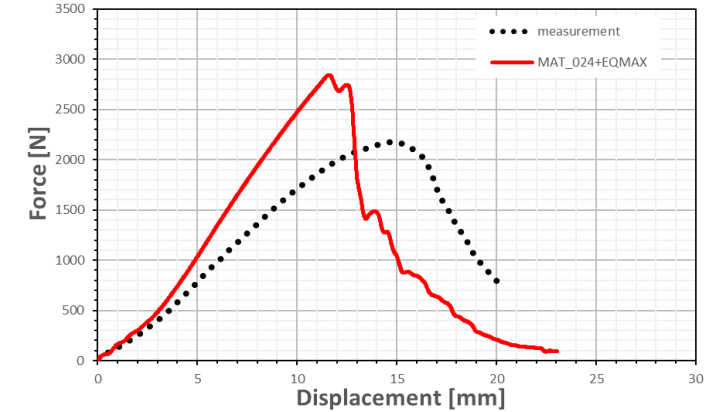
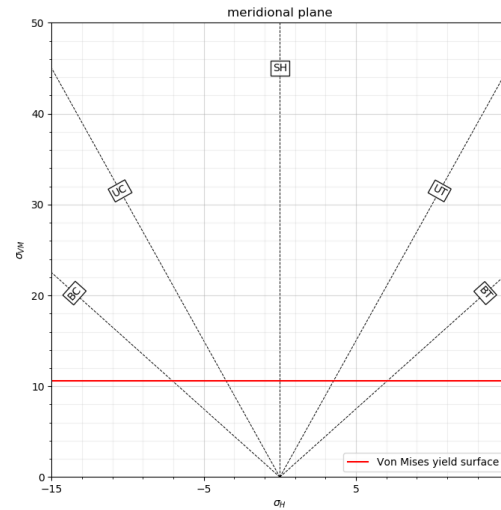
- stability
- numerical cost
 - number of operations in material model → Translation into simulation model (localization, load path,...)
 - relative numerical cost of the material model (measurement model comparison)
- accuracy



Relative Numerical Cost of the Material Model – MAT_024

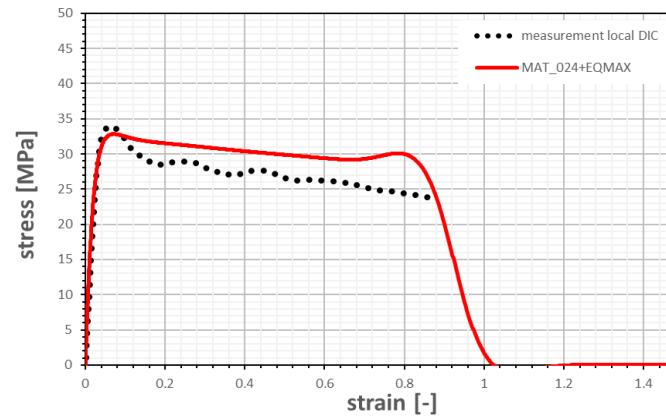


3 POINT BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s

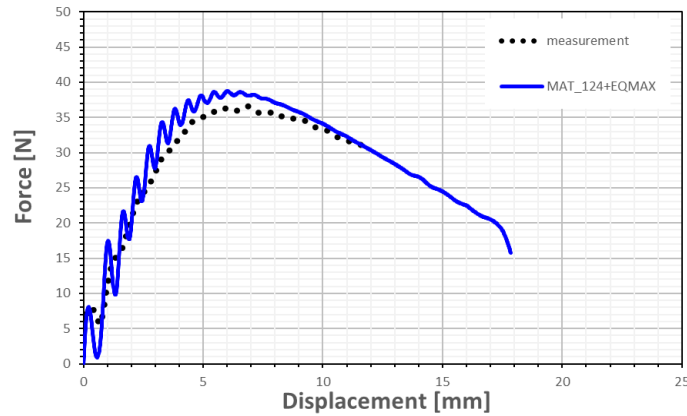


TENSION TEST

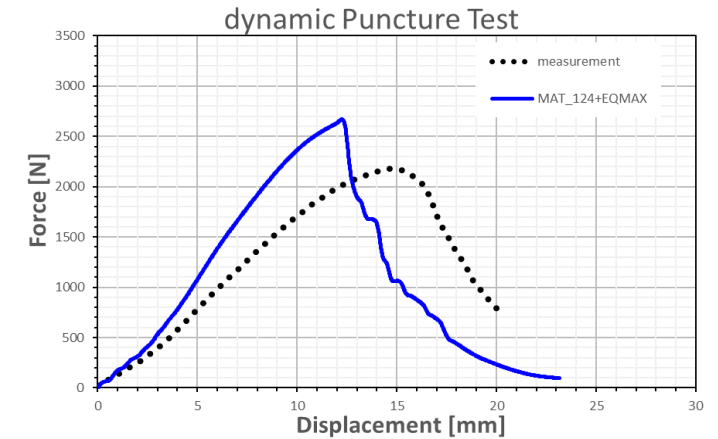
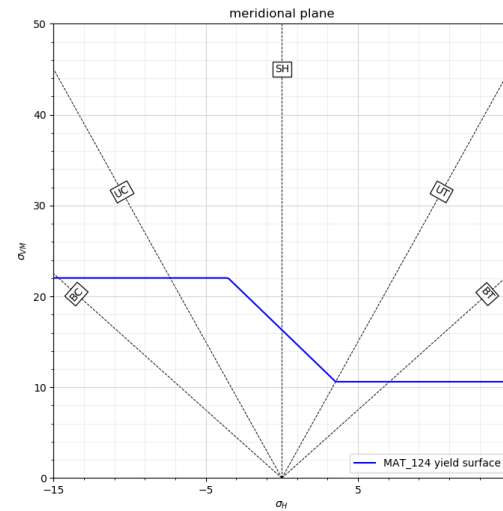
..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_124

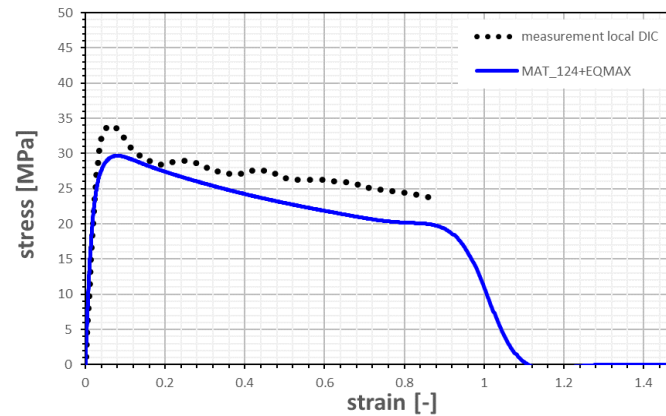


3 POINT BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s

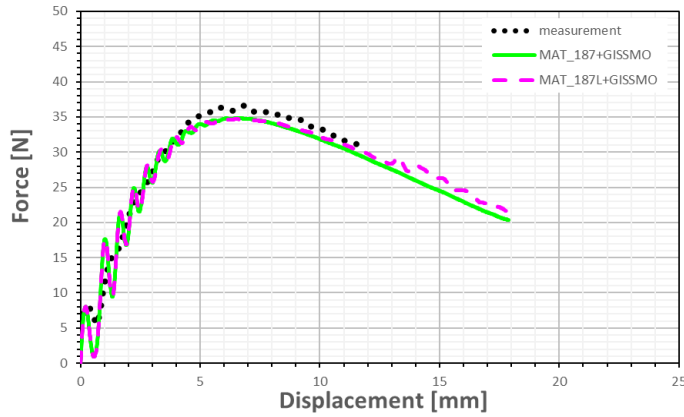


TENSION TEST

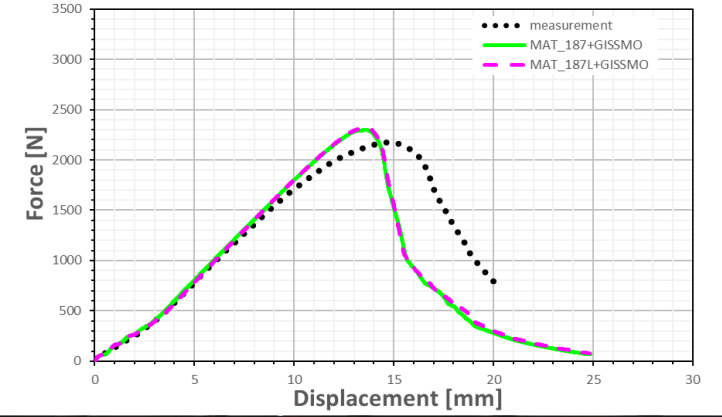
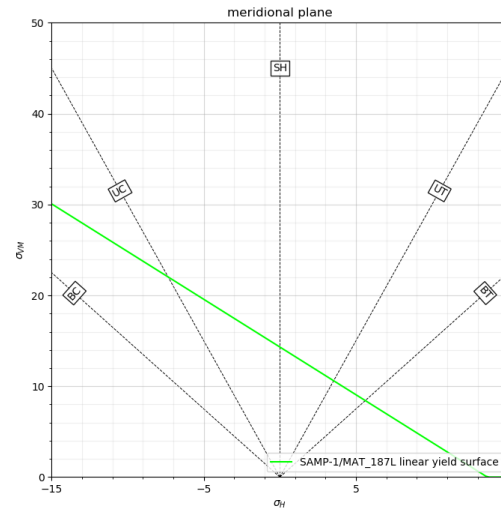
..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_187

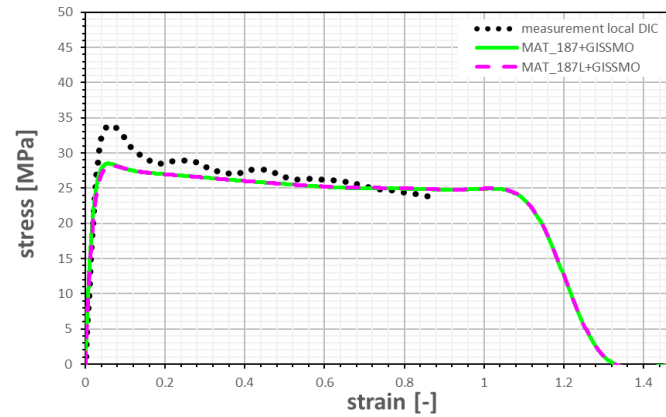


3 POINT BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s

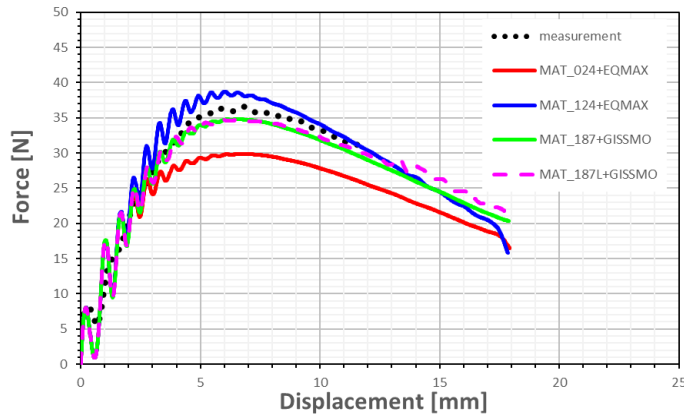


TENSION TEST

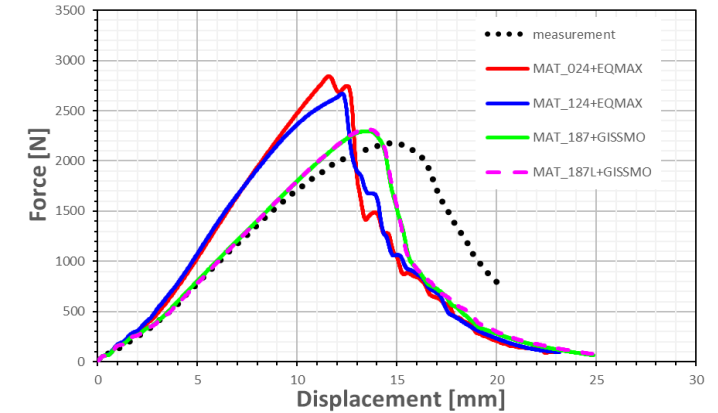
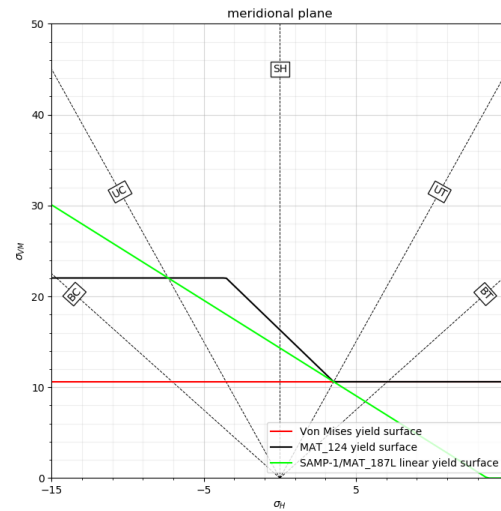
..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model

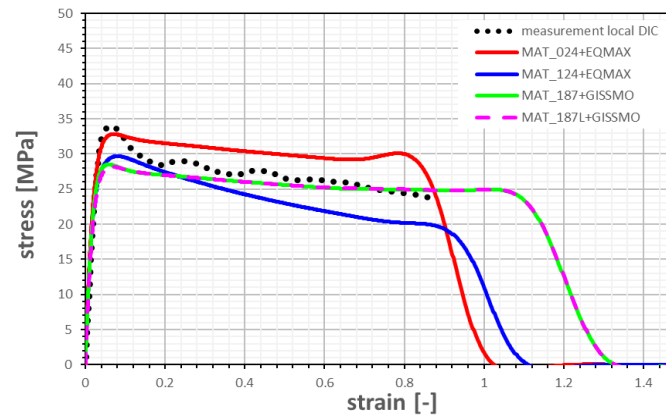


3 POINT BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s

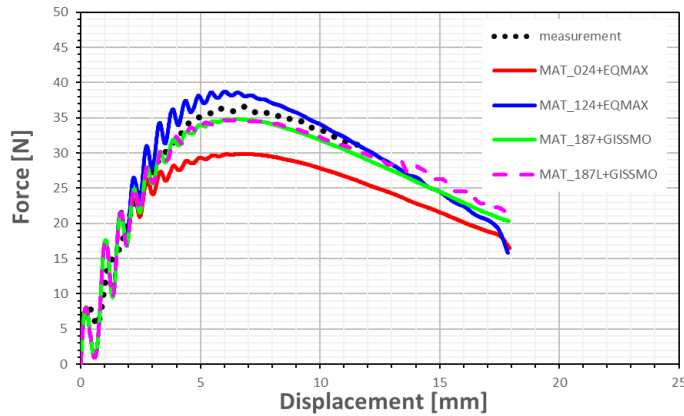


TENSION TEST

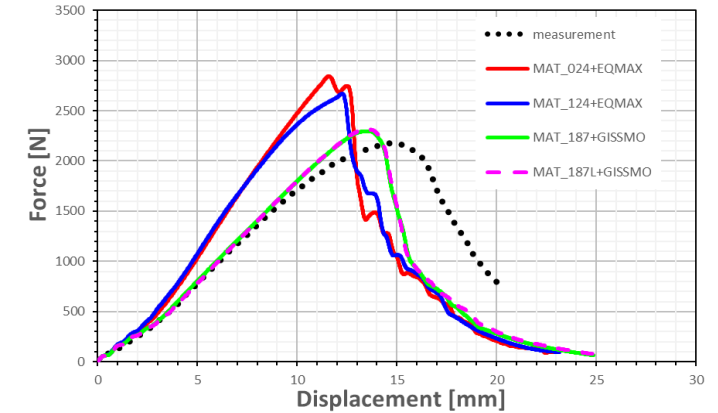
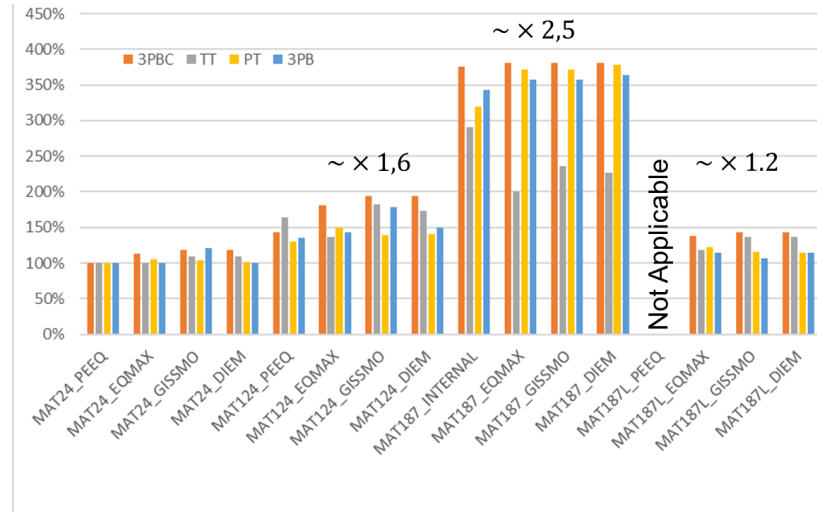
..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model

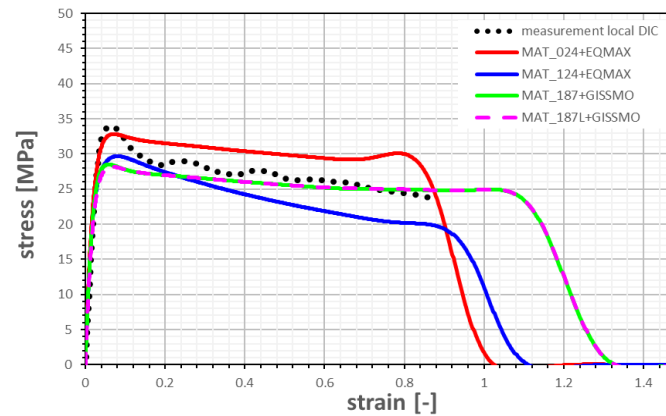


3 POINT BENDING



PUNCTURE TEST

IMPETUS™ ~ 3 m/s

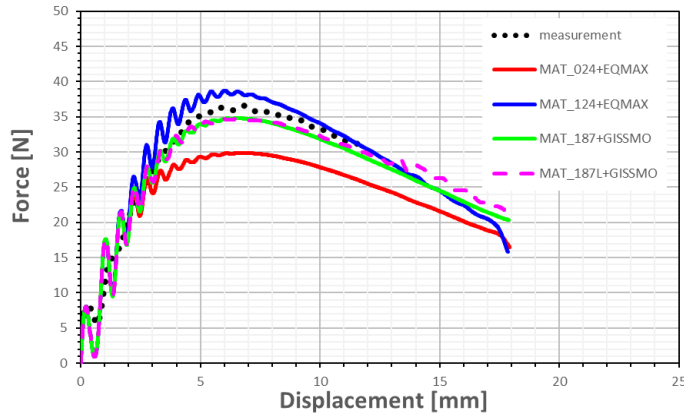


TENSION TEST

..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

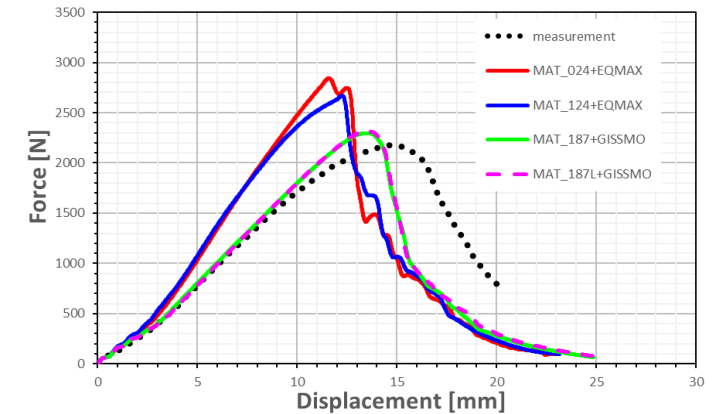
Relative Numerical Cost of the Material Model



3 POINT BENDING

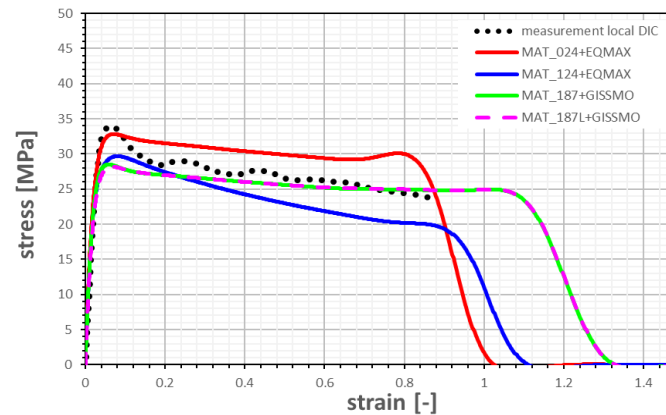
Material model	CPU Time
<i>*MAT_024</i>	1
<i>*MAT_124</i>	1.6
<i>*MAT_187</i>	2.5
<i>*MAT_187L</i>	1.2

CPU Time comparisons



PUNCTURE TEST

IMPETUS™ ~ 3 m/s



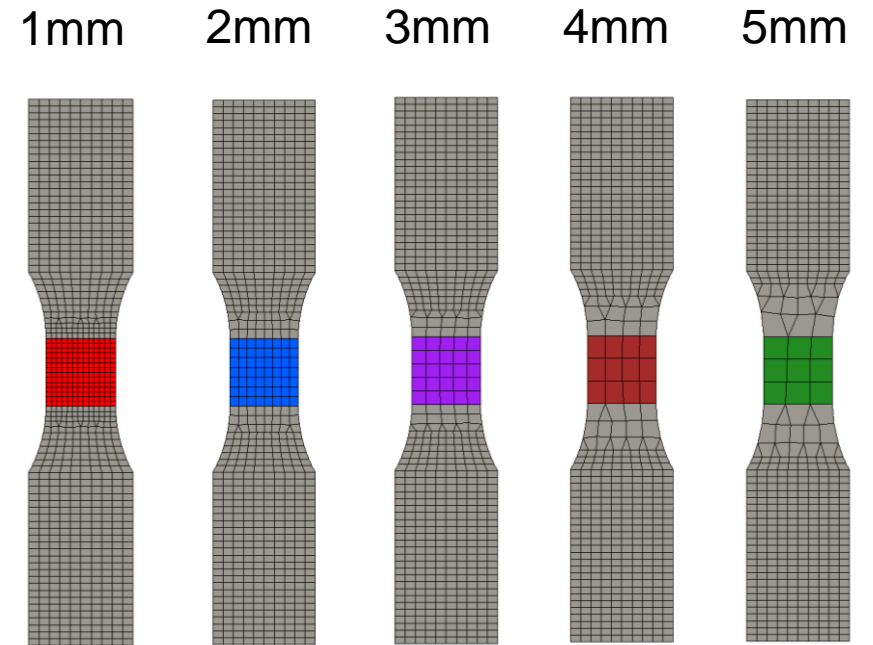
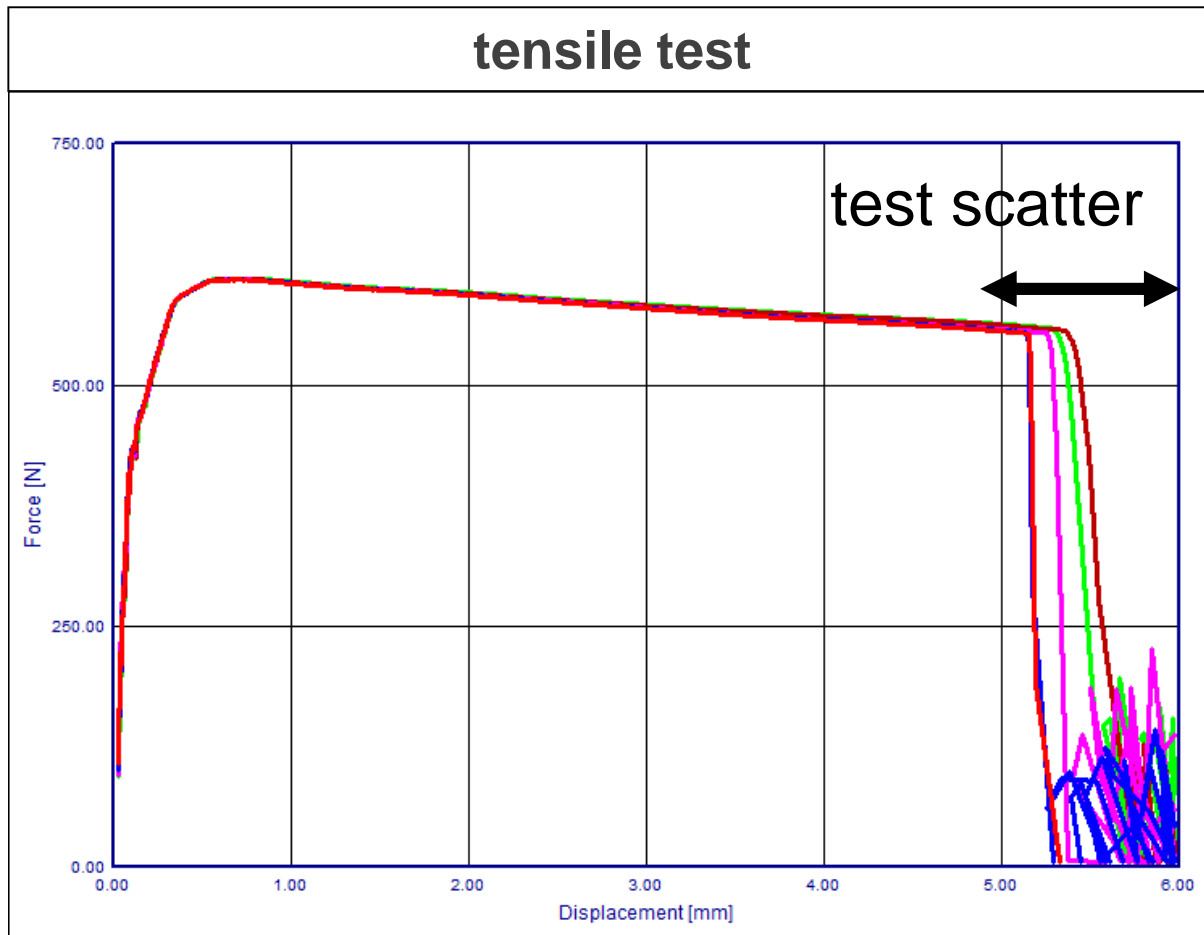
TENSION TEST

..... averaged test curves
 — result of simulation

source: Benjamin Hirschmann, master thesis

Element Regularisation

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



source: Benjamin Hirschmann, master thesis

Summary

Summary: Deformation model

- 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 model

- material characterization in the triaxiality range of 0.33 to 0.66
- GISSMO \neq 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





YouTube CHANNEL

MATERIAL
cards

 **VALIMAT**

more information on our software



α
Anisotropic

Φ_p
Triaxiality

ϵ_p
Damage/Failure

σ_{vm}
Hardening

η

ϵ_p

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 **IMPETUS**



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4advanced Customer Orientation

4advanced Leadership in Technologies

4advanced Motivated & Professional Team

4advanced High Quality Outcome & Success