

# 4a impetus

## Dynamic Material Characterization of Plastics and Composites

P. Reithofer, A. Fertschej, Michael Rollant  
4a engineering GmbH, Traboch, Austria

22<sup>nd</sup> KOREAN LS-DYNA® USERS CONFERENCE 2017  
by THEME Engineering, Inc.



14. September 2017, Seoul

4a engineering GmbH  
Industriepark 1  
A-8772 Traboch  
reithofer@4a.co.at  
++43 (0) 664 80106 601

© 4a engineering GmbH, all rights reserved

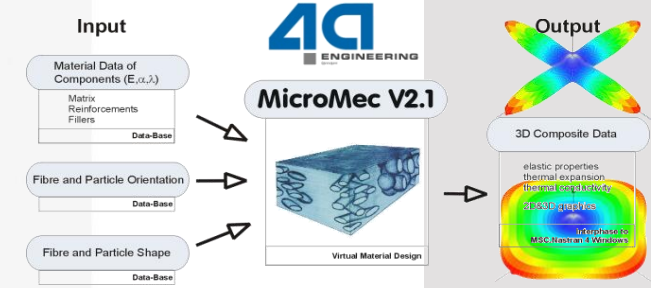
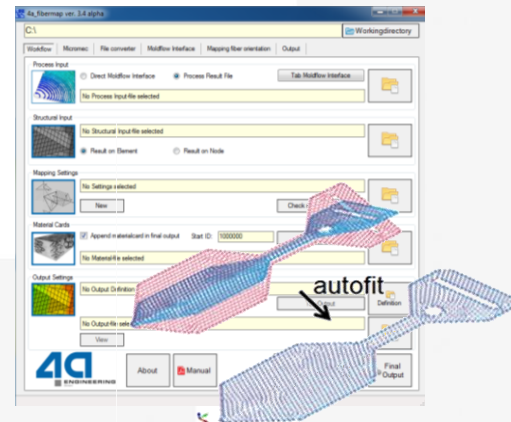
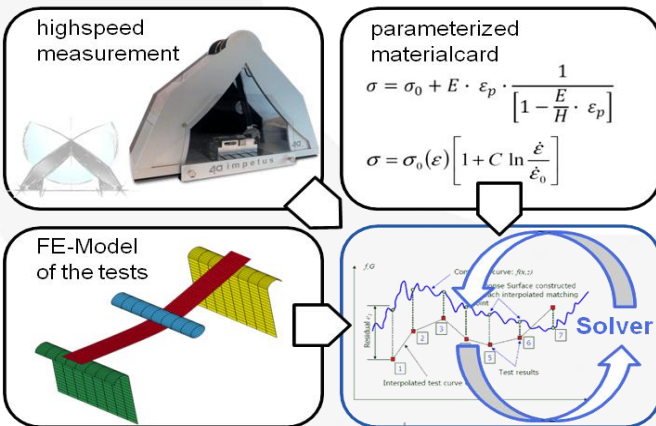
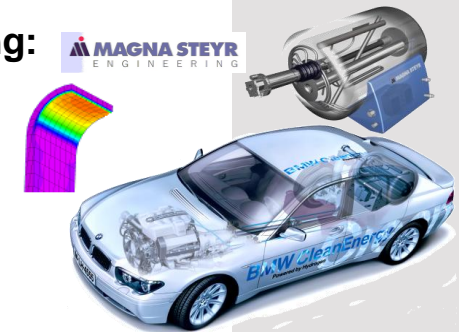
- Introduction 4a engineering & 4a impetus
- material behavior / application
- MPIP - ***Material Parameter Identification Process***
  - ***\*MAT\_024***
  - ***\*MAT\_124/187***
  - ***\*MAT\_157/\*MAT\_215 (\*MAT\_4A\_MICROMECH)***
- case study SFRT/LFRT
- summary

- polymer and materials science
- fiber reinforced plastics and composites
- product development
- numerical simulation methods
- material characterization
- method and software development

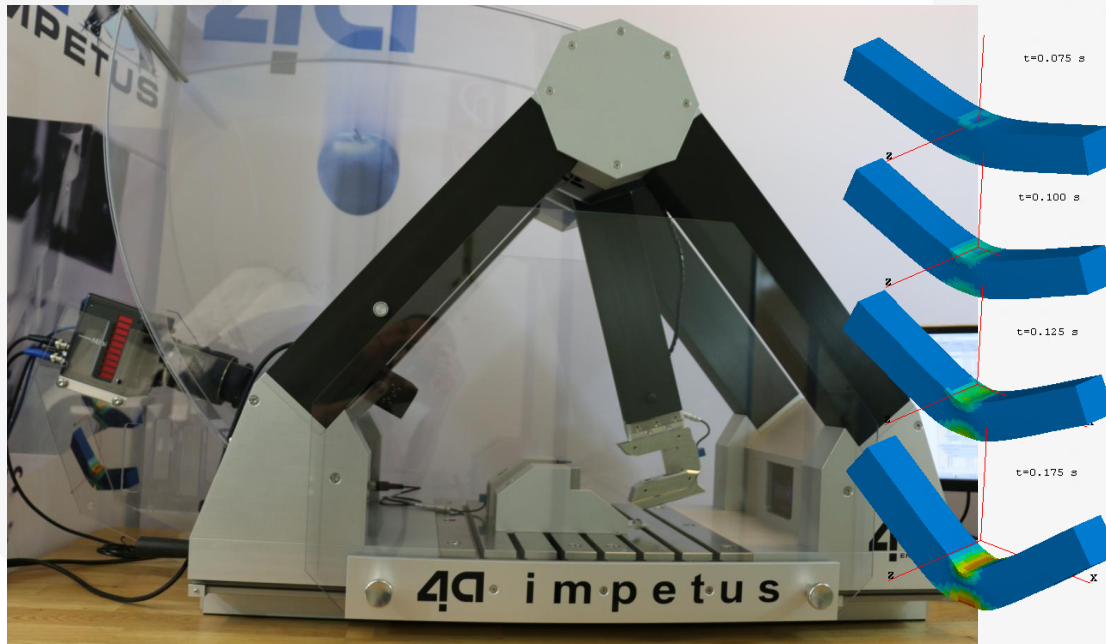
strut bar:



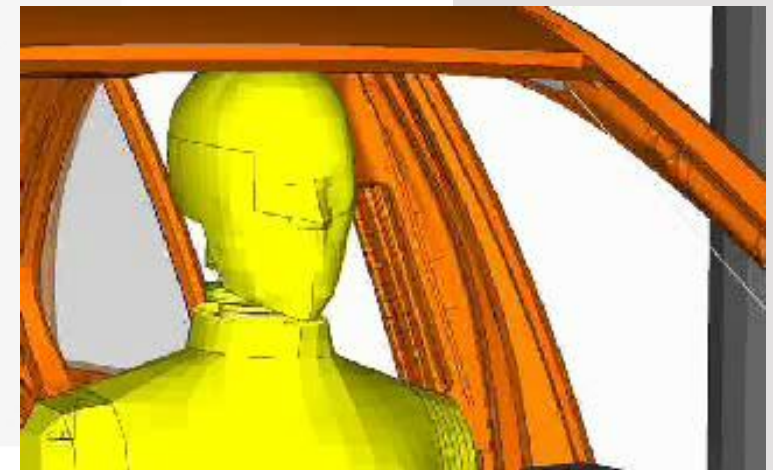
LH<sub>2</sub> – tank mounting:



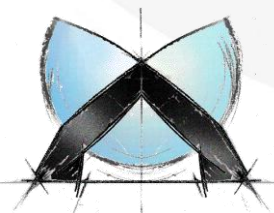
- efficient high-dynamic testing
- crash-behavior of plastics
- material data for simulation



source: <http://gm-volt.com/>



source: [Dynamore](#)

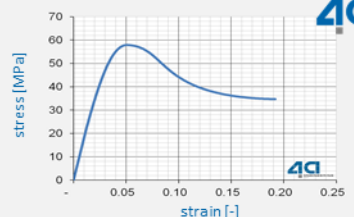


4a impetus - intelligent testing systems  
powered by 4a engineering GmbH

# material behavior / application

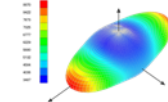
**J2** \*OC(=O)c1ccc(cc1)OC(=O)\*

**Technical semicrystalline thermoplast (general)**  
**PBT**  
 Polybutylene terephthalate

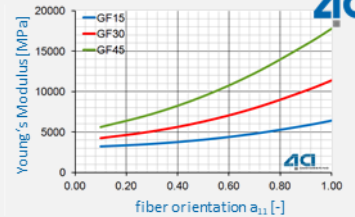


<b>P:</b> 2.1 €/kg	<b>ρ:</b> 1.3 g/cm <sup>3</sup>
<b>E<sub>1</sub>:</b> 2400 MPa	<b>α<sub>1</sub>:</b> 140 · 10 <sup>-6</sup> 1/K
<b>σ<sub>y</sub>:</b> 58 MPa	<b>ε<sub>B</sub>:</b> 120%
<b>T<sub>G</sub>:</b> 30 °C	<b>a<sub>c</sub>:</b> 160(5) kJ/m <sup>2</sup>

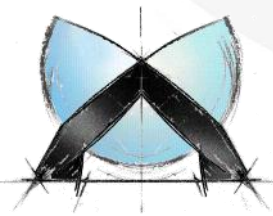
**H2** Young's Modulus [MPa]



**SFRT / LFRT – fiber orientation**  
**PBT GF30**  
 Polybutylene terephthalate short glass fiber reinforced



<b>P:</b> 3 €/kg	<b>ρ:</b> 1.5 g/cm <sup>3</sup>
<b>E<sub>1</sub>:</b> 10000 MPa	<b>α<sub>1</sub>:</b> 25 · 10 <sup>-6</sup> 1/K
<b>σ<sub>y</sub>:</b> 92 MPa	<b>ε<sub>B</sub>:</b> 3%
<b>T<sub>G</sub>:</b> 30 °C	<b>a<sub>c</sub>:</b> 67(11) kJ/m <sup>2</sup>



**4a impetus - intelligent testing systems  
 powered by 4a engineering GmbH**



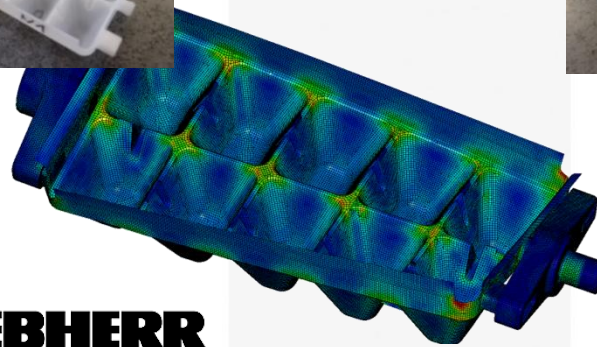
# Material behavior of plastics time dependent behavior



source: <http://mobiwatch.de>



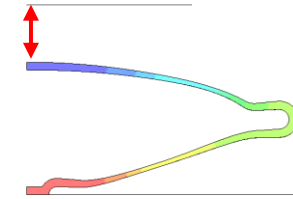
**LIEBHERR**



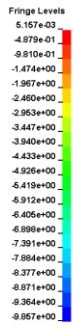
**FLEXIMA**  
feel the comfort.at

3 Tage

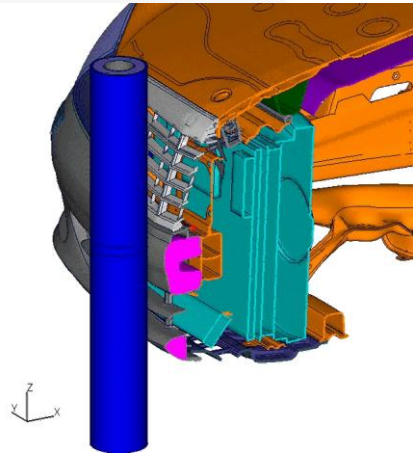
9.8 mm



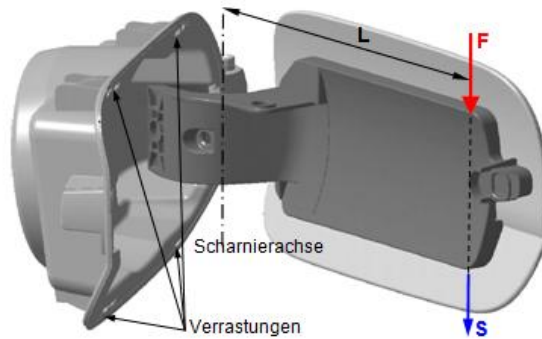
source: [Wimmer\\_TT\\_2012](http://Wimmer_TT_2012)



$\mu$ s      ms      s      min      h      d      w      y



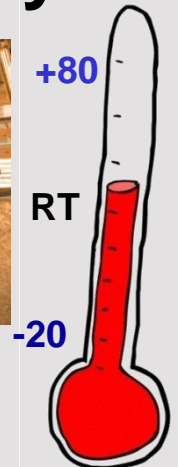
source: [Kolling\\_TT\\_2010](http://Kolling_TT_2010)



source: [Gramling\\_TT\\_2012](http://Gramling_TT_2012)



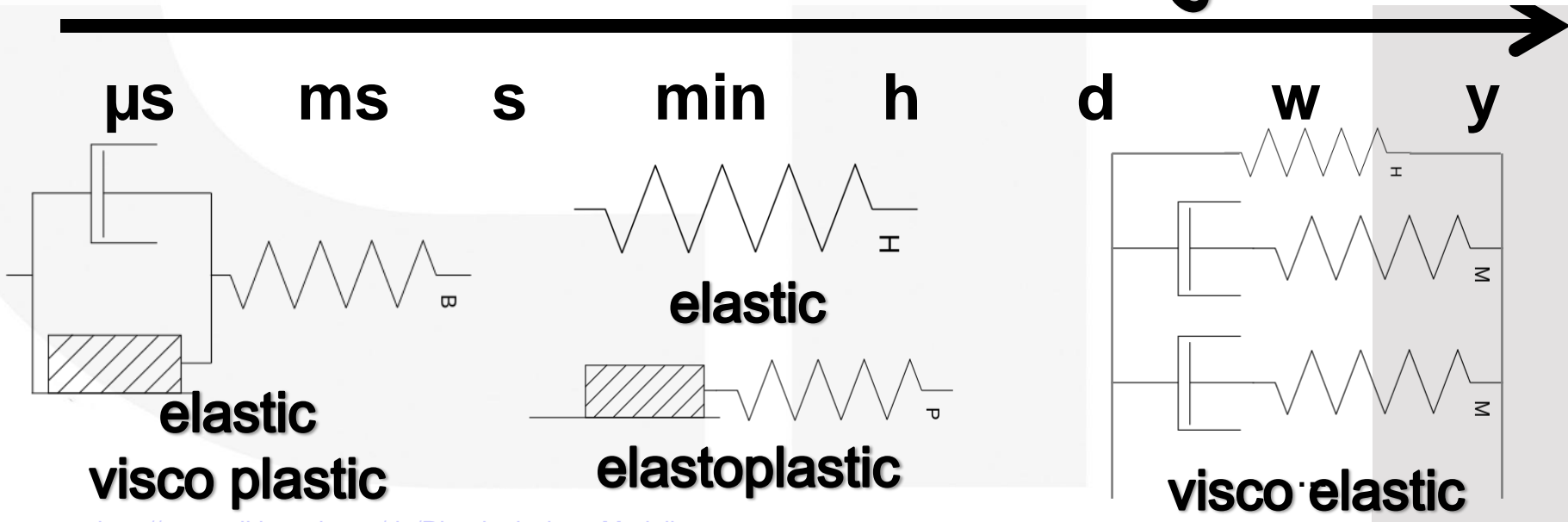
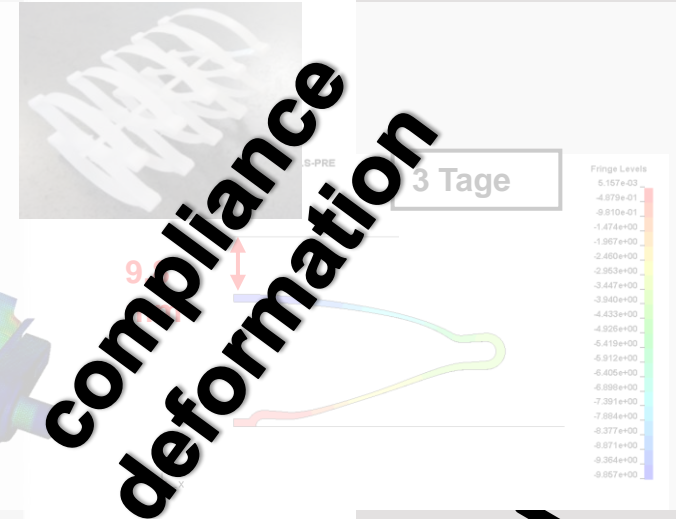
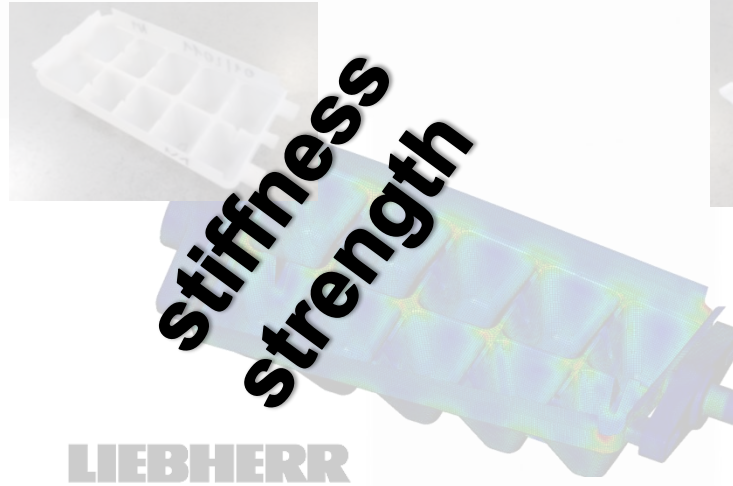
source: <http://www.rad-ab.com/tag/opel-astra/>



# Material behavior of plastics

## time dependent behavior

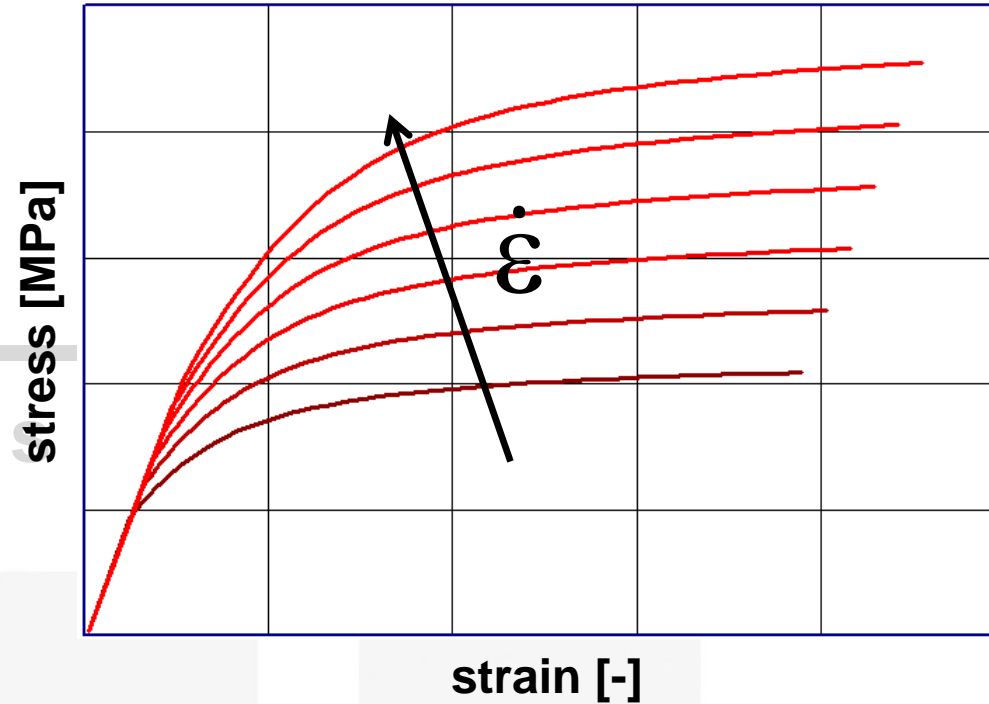
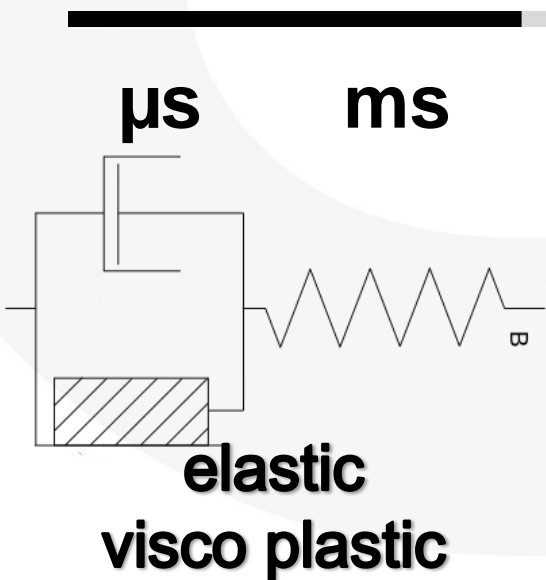
energy  
absorption  
failure



source: [http://www.wikiwand.com/de/Rheologisches\\_Modelle](http://www.wikiwand.com/de/Rheologisches_Modelle)

# Material behavior of plastics

## time dependent behavior



source: [http://www.wikiwand.com/de/Rheologisches\\_Modelle](http://www.wikiwand.com/de/Rheologisches_Modelle)

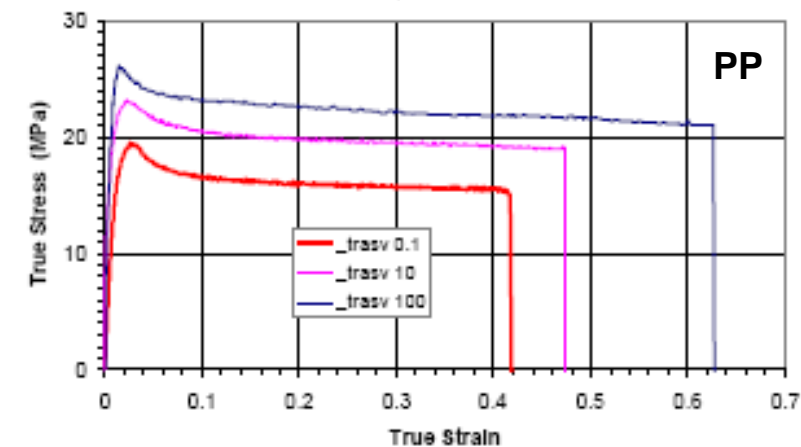
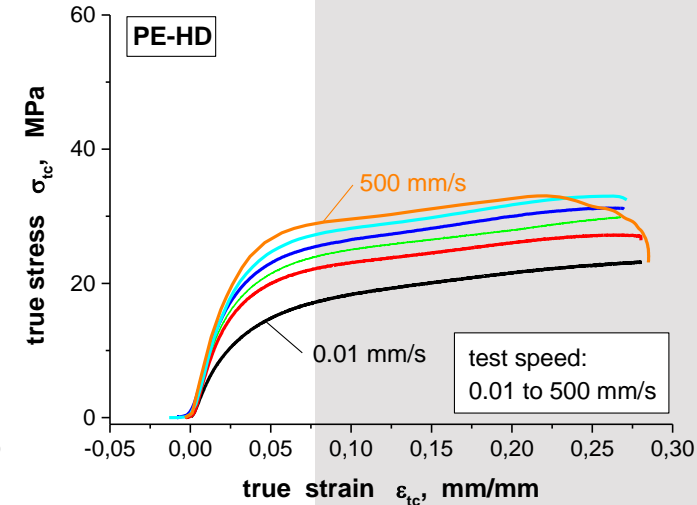
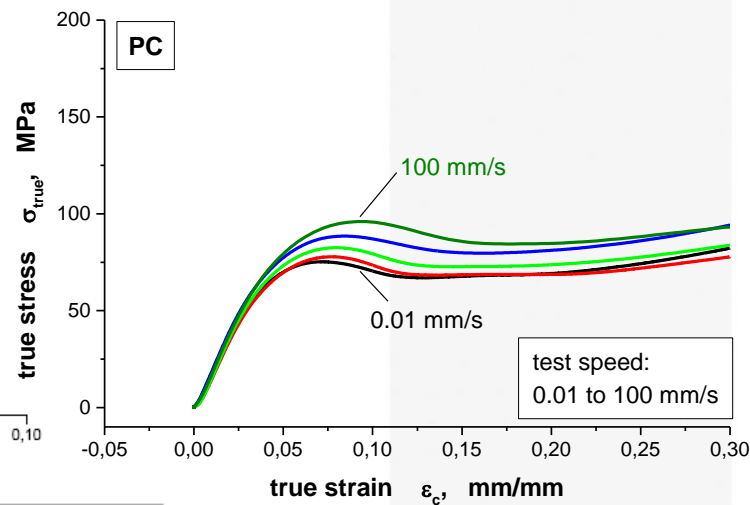
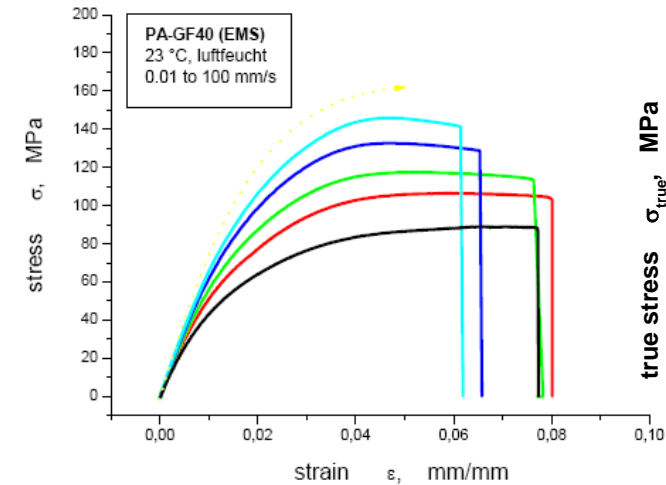


# Material behavior of plastics

## dynamic behavior – classical tensile tests

Dependent on the material the dynamic behavior is more or less distinct.

Examples for various materials:



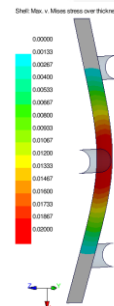
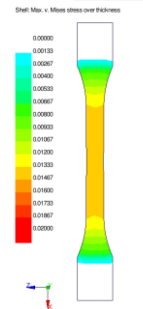
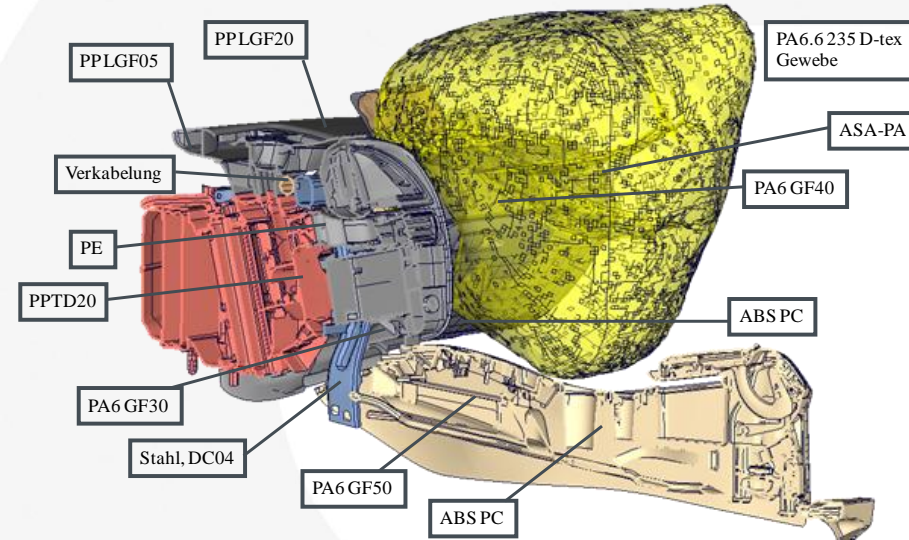
Source:

R. W. Lang, Werkstoffprüfung der Kunststoffe, Vorlesungsbehef IWKP, 2002

Z. Major, M. Reiter, Characterization of Dynamic Behavior of Engineering Polymers, 4a – VDI Technologietag 2008

M. Nutini, Material data for CAE simulation. The approach of Basell Polyolefins, 4a – VDI Technologietag 2008

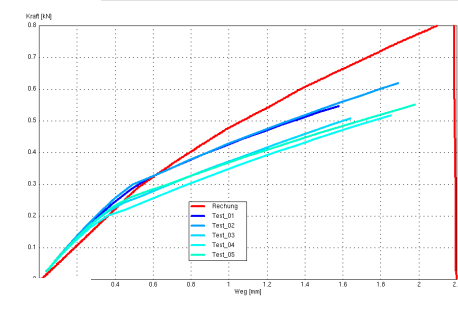
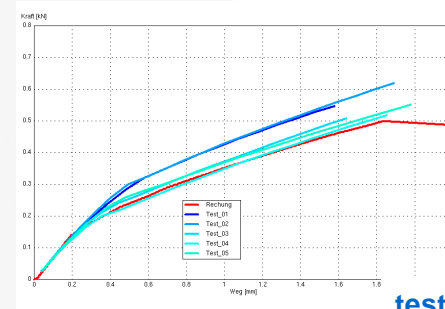
## material variety



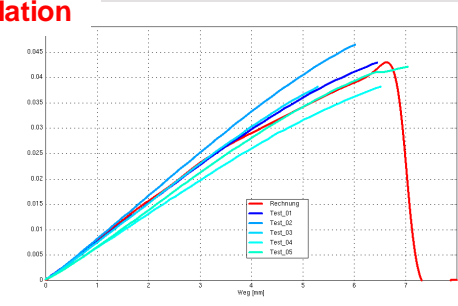
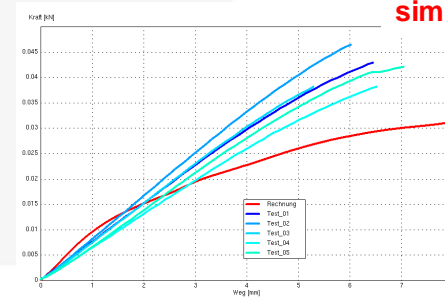
## bending load case

original test curve tension

scaling 1.25

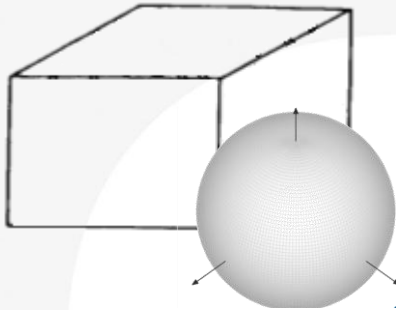


test simulation

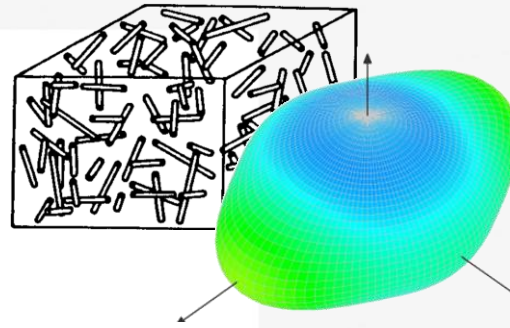


Source: R. Luijckx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG*, 4a Technologietag 2010

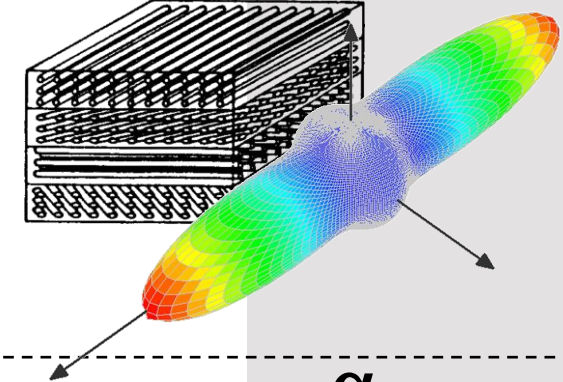
### Plastics



### SFRT / LFRT

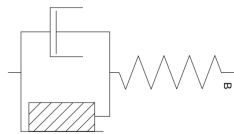


### Composite



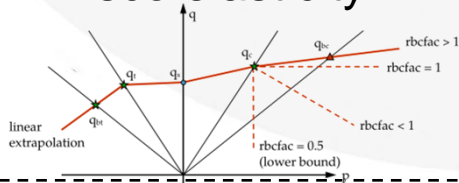
#### \*MAT\_024

- quick & dirty
- Mises plasticity



#### \*MAT\_187 (\*MAT\_124)

- complex yield surface
- visco elasticity



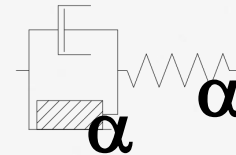
#### \*MAT\_002

- orthotropic elastic



#### \*MAT\_157

- orthotropic
- elastic viscoplastic
- Hill plasticity



#### \*MAT\_215

- micro mechanical model

#### \*MAT\_022/

#### \*MAT\_054/058

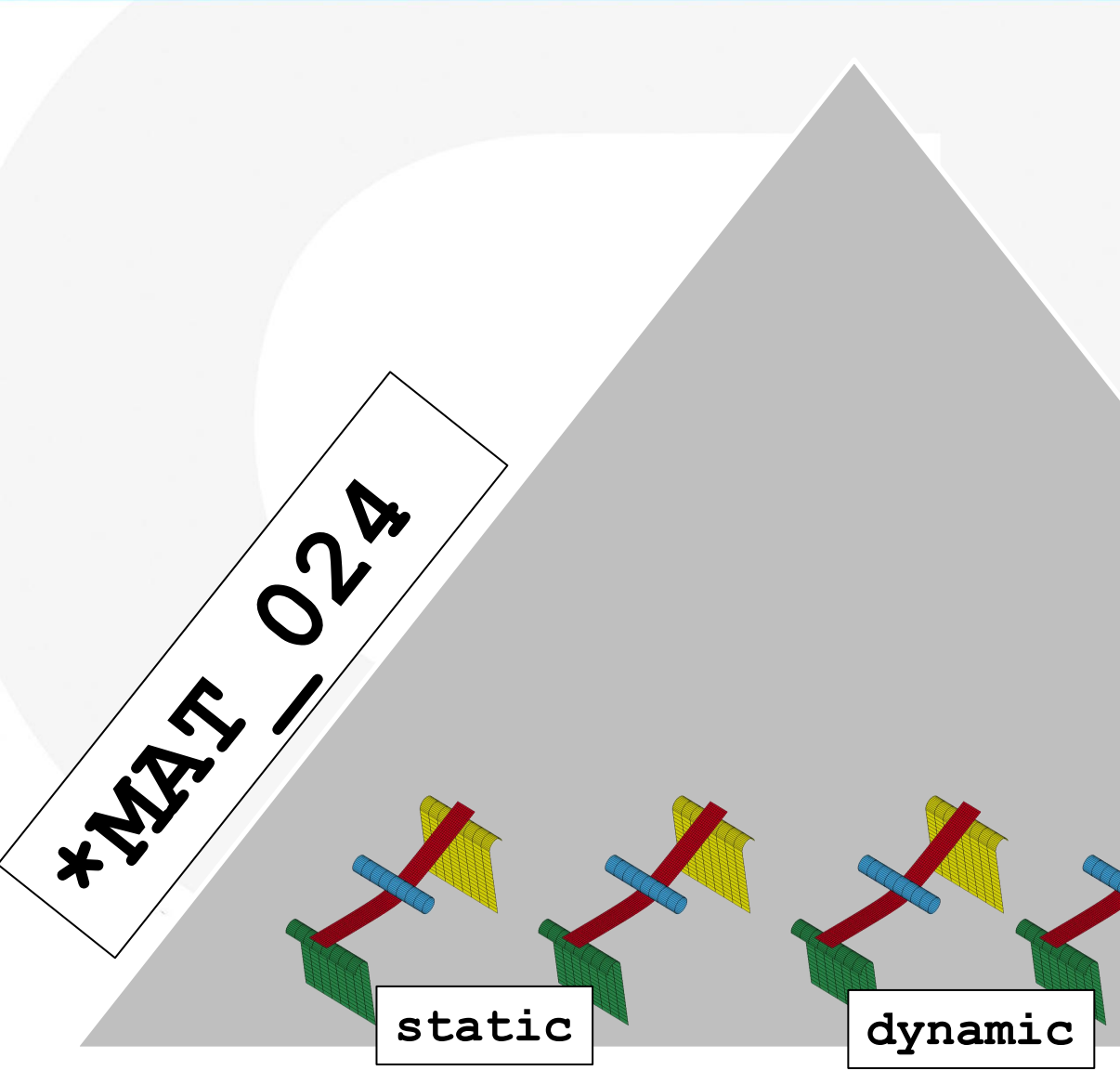
- orthotropic elastic
- Damage



#### \*MAT\_262

- more enhanced
- Puck failure criteria

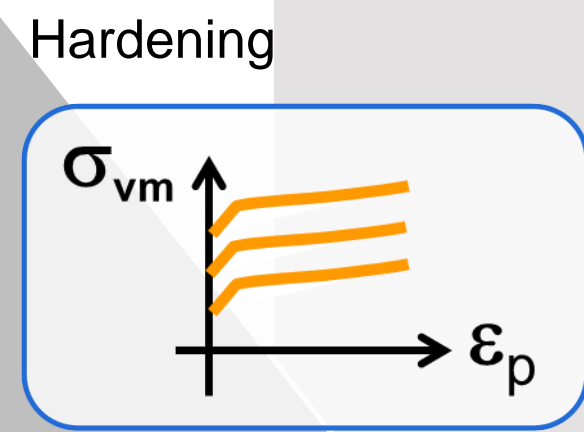
$\alpha$  – orientation dependent



**4a**  
■ **IMPETUS**  
**ADVANCED**  
dynamic testing system  
validated material cards  
intelligent software solution

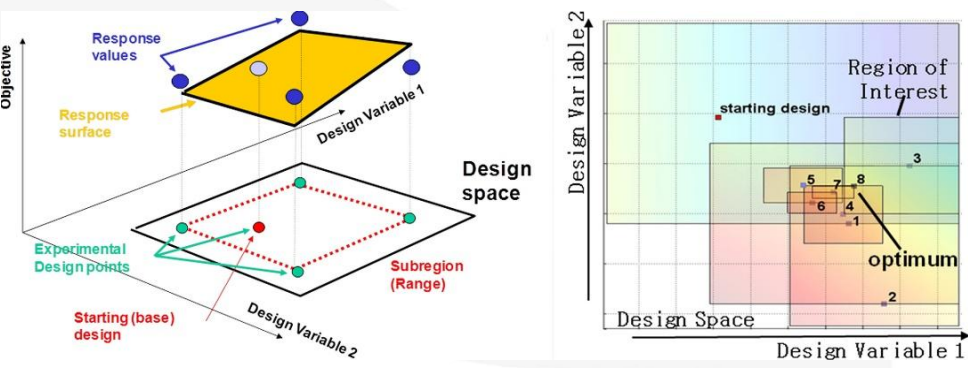
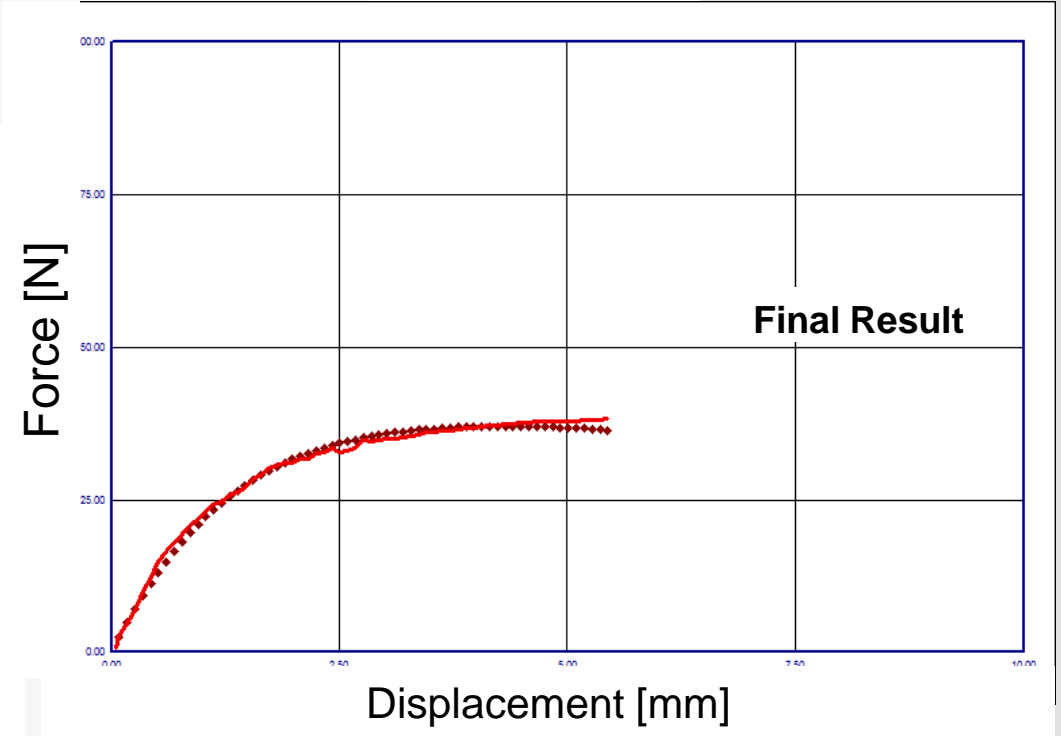
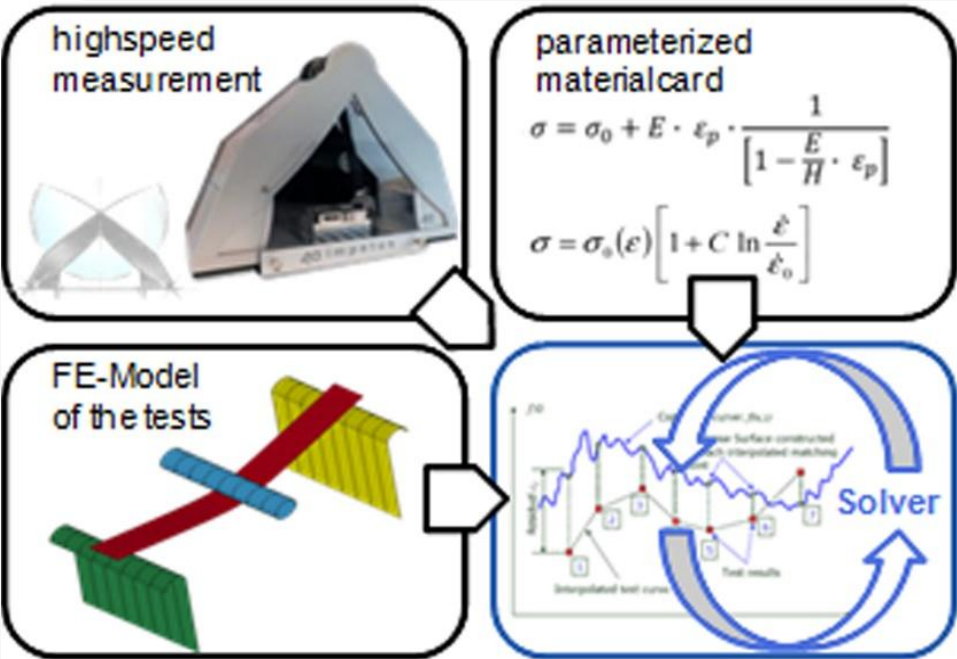
[Watch Video on YouTube<sup>©</sup>](#)

I N P H Y S I C S W E T R U S T



# MPIP - Material Parameter Identification Process

## reverse engineering



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

© 4a engineering GmbH, all rights reserved

# 4a impetus – new software features

## MPIP - Material Parameter Identification Process

Starting parameter

Young's Modulus

Yield

Strainrate

Asymmetry

Component

Automated optimization

ID	Name	Optimization/Validation	Status	VP Autovalue
161124_001	Young's Modulus	Optimization	✓	<input type="checkbox"/>
161124_002	Plastic data	Optimization	✓	<input type="checkbox"/>
161124_003	Strain rate dependency	Optimization	R	<input checked="" type="checkbox"/>
161124_004	Validation	Validation	✓	<input type="checkbox"/>

ID	Name	Optimization/Validation	Status	VP Autovalue
161124_001	Young's Modulus	Optimization	✓	<input type="checkbox"/>
161124_002	Plastic data	Optimization	✓	<input type="checkbox"/>
161124_003	Strain rate dependency	Optimization	R	<input checked="" type="checkbox"/>
161124_004	Validation	Validation	✓	<input type="checkbox"/>

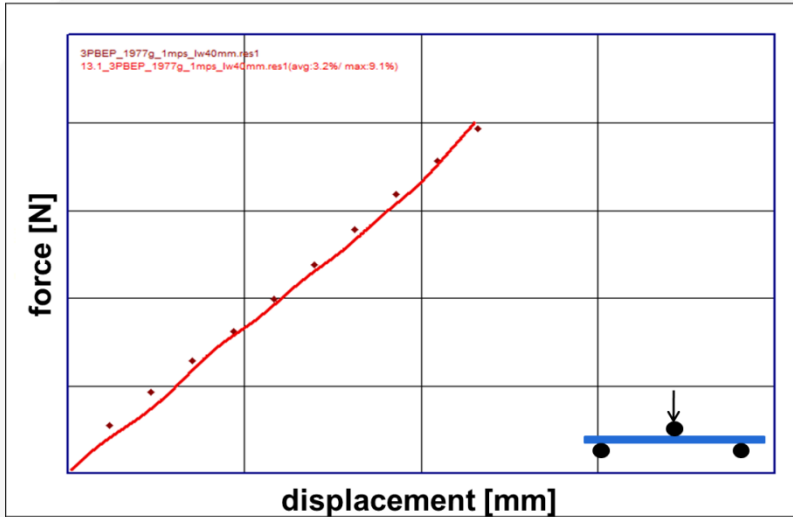
calc max strain: 0.2 [1]  
 calc strainrates: 0.0001 - 100 [1/s]

Init Autofit    Open LS-Opt Viewer

DV	Autovalue	161124_001	161124_002	161124_003	161124_004
e_E	2009.4	2049.762	2049.762	PRUN(c)	PRUN(c)
e_nue	n.a.	0.3	0.3	PRUN(c)	PRUN(c)
y_0	15.344	n.a.	12.2752	PRUN(c)	PRUN(c)
h_y	n.a.	n.a.	12.2752	=y_0	=y_0
h_ET	-1.4782	n.a.	1024.881	PRUN(c)	PRUN(c)
h_h	15.344	n.a.	7.672	PRUN(c)	PRUN(c)
v_p	9.5407	n.a.	9.5407	AUTO	PRUN
v_epspt	0.0001	n.a.	0.0001	AUTO(c)	PRUN(c)

Run    Stop    Exit

# MPIP - Material Parameter Identification Process from bending → \*MAT\_024



$v_0$   
[m/s]  
**1**

.... averaged test curves  
— result of simulation

Starting  
parameter

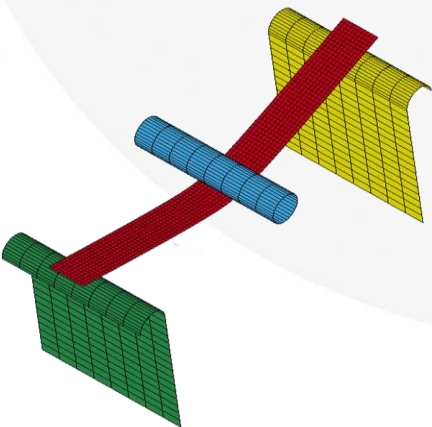
**Young's  
Modulus**

Yield

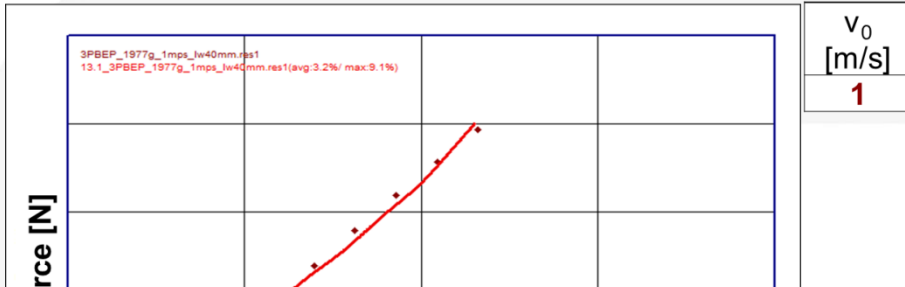
Strainrate

Asymmetry

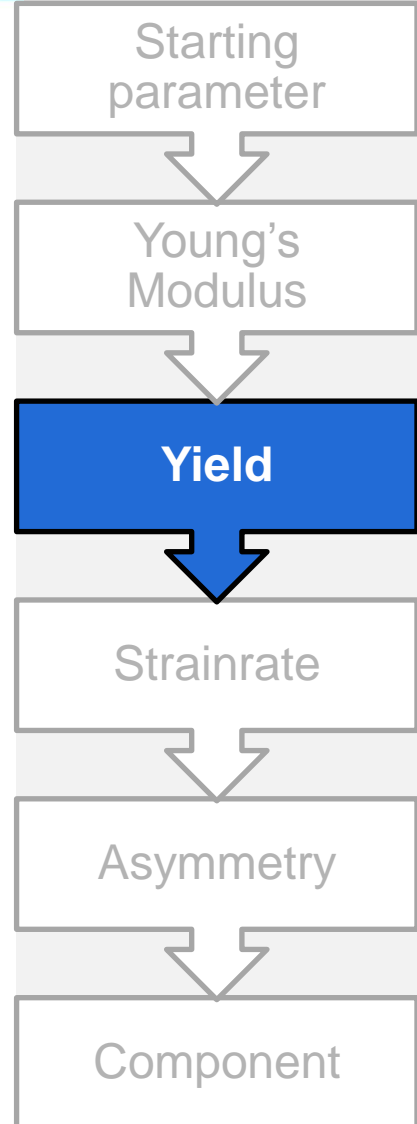
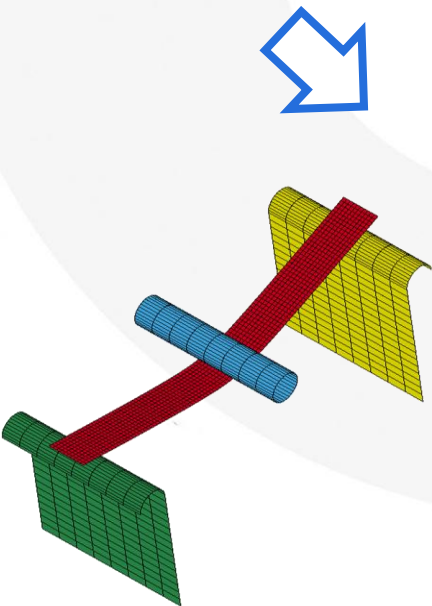
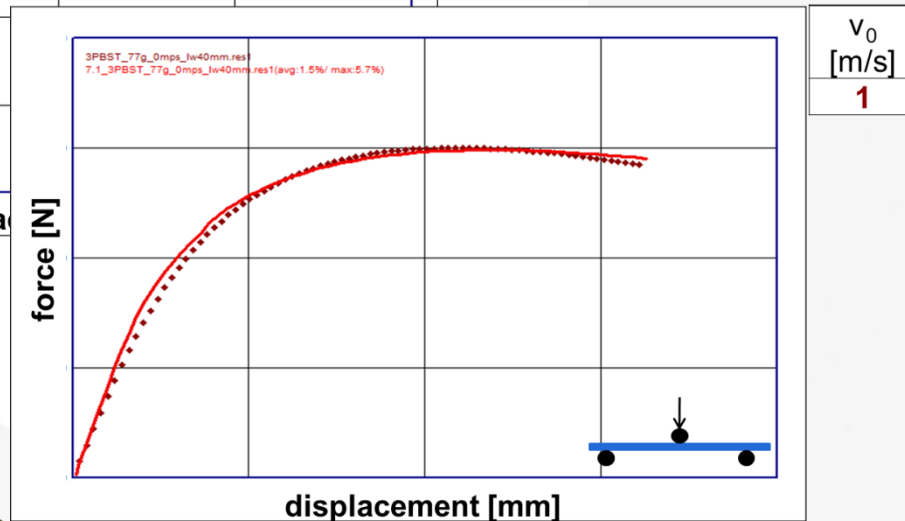
Component



# MPIP - Material Parameter Identification Process from bending → \*MAT\_024

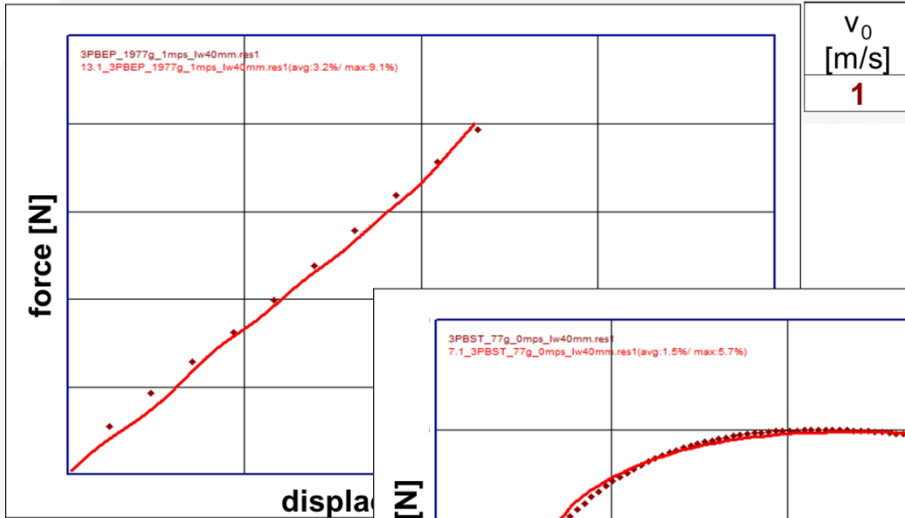


.... averaged test curves  
— result of simulation

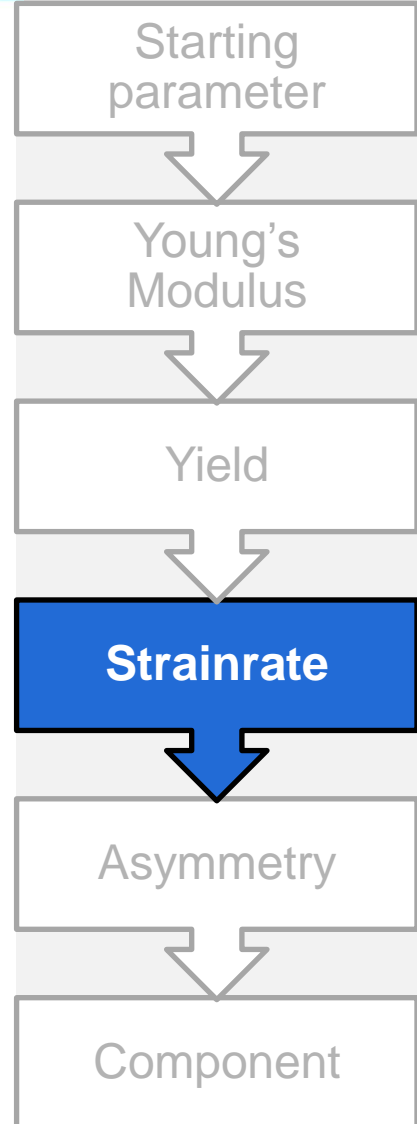
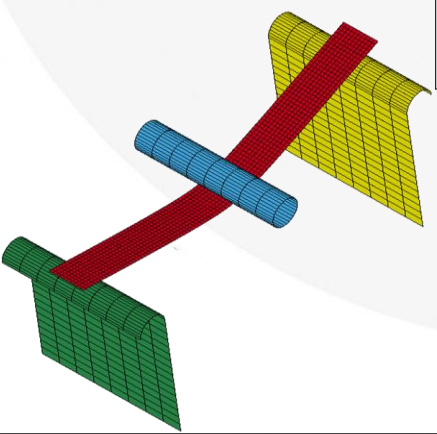
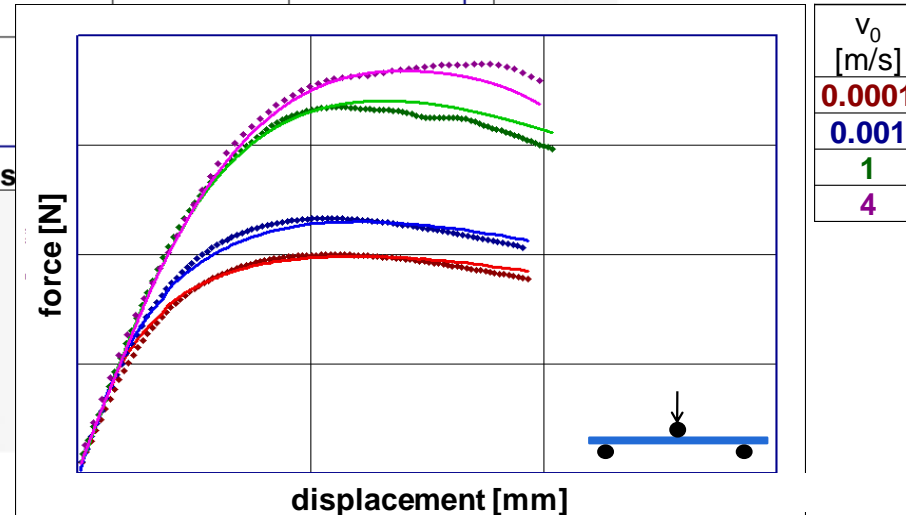
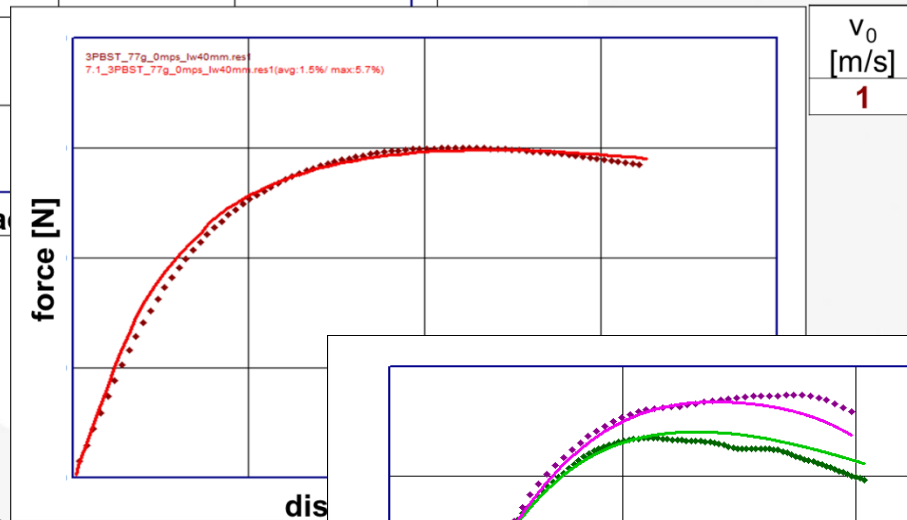




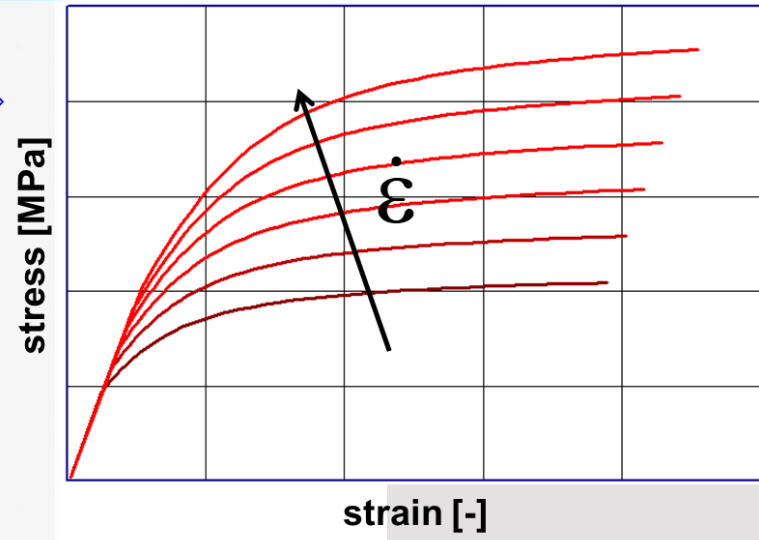
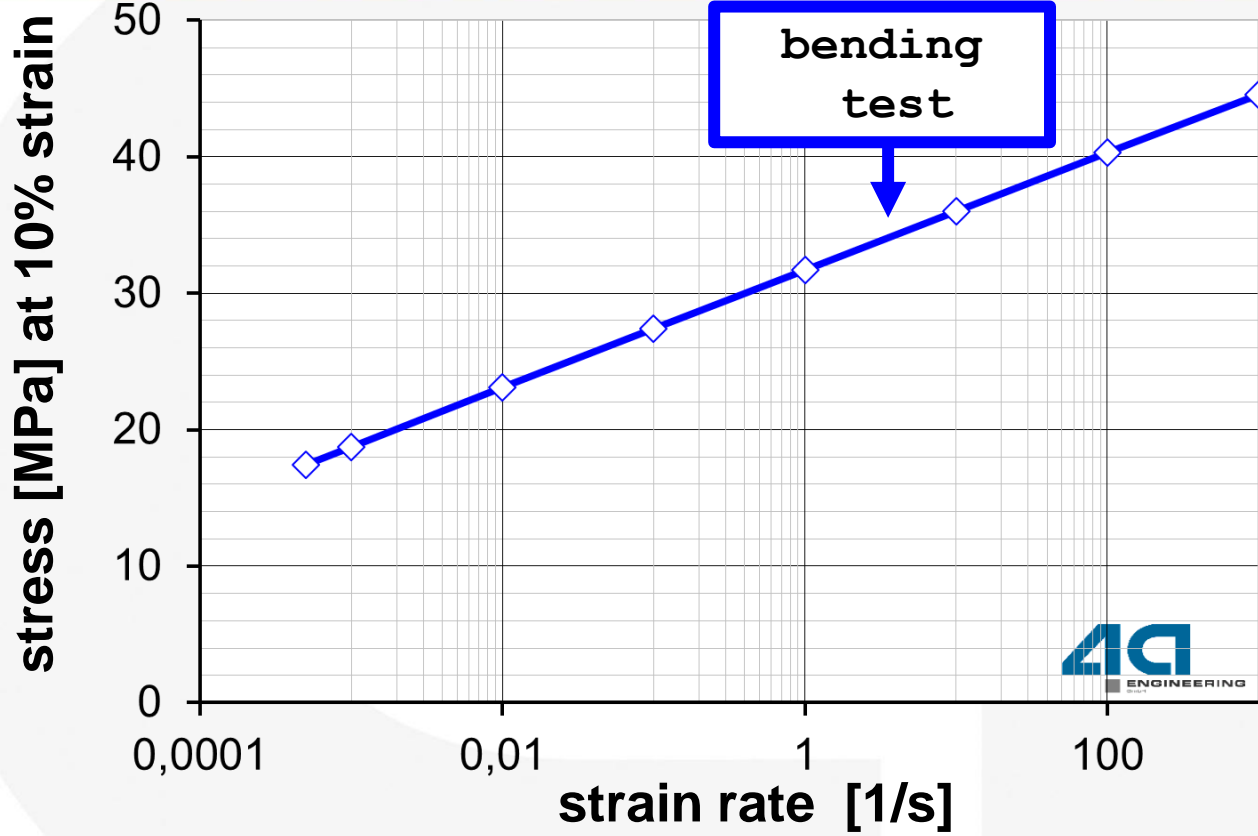
# MPIP - Material Parameter Identification Process from bending → \*MAT\_024



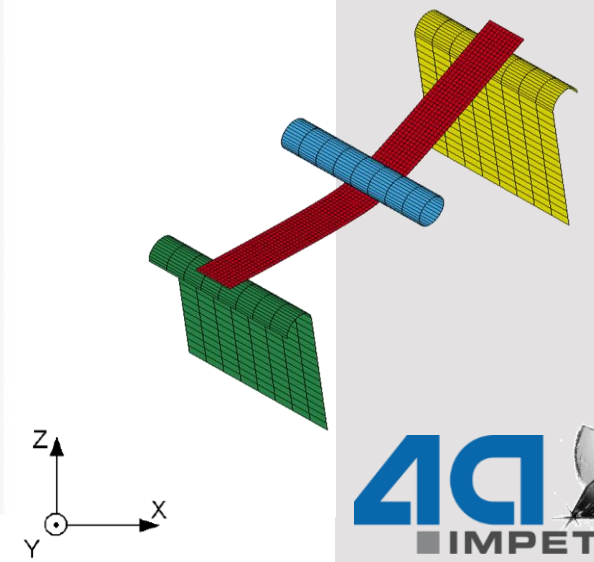
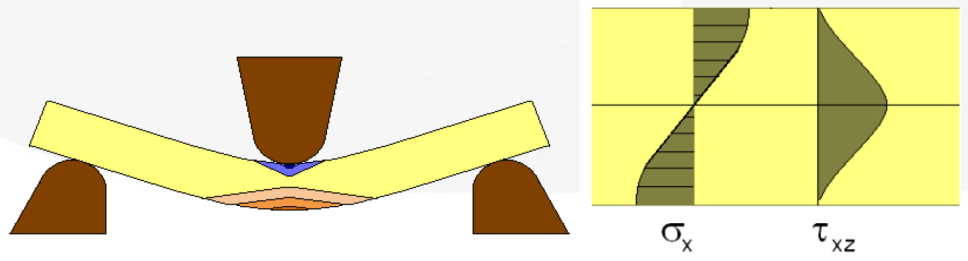
.... averaged test curves  
— result of simulation



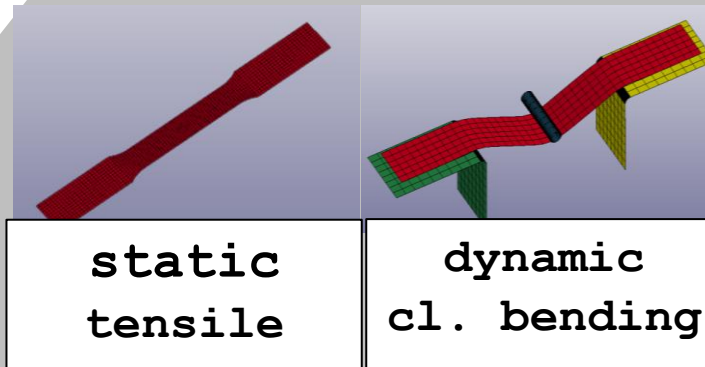
# MPIP - Material Parameter Identification Process from bending $\rightarrow$ \*MAT\_024



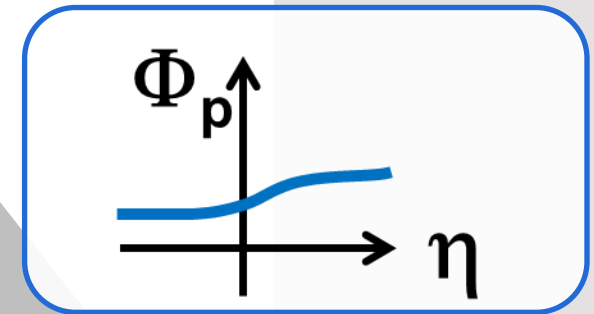
v [m/s]	span [mm]
0.0001	40
0.001	40
1	40
4	40



**\*MAT\_124/187**

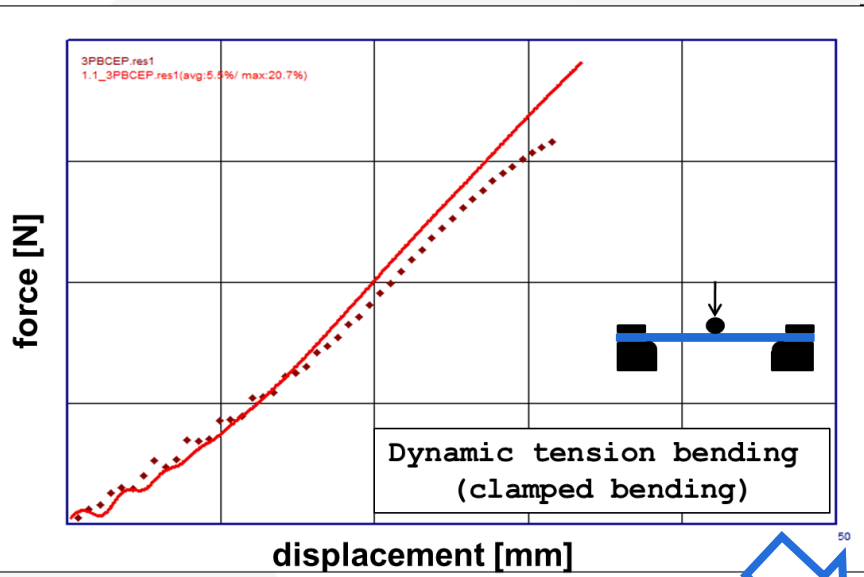


Triaxiality  
complex yield surface



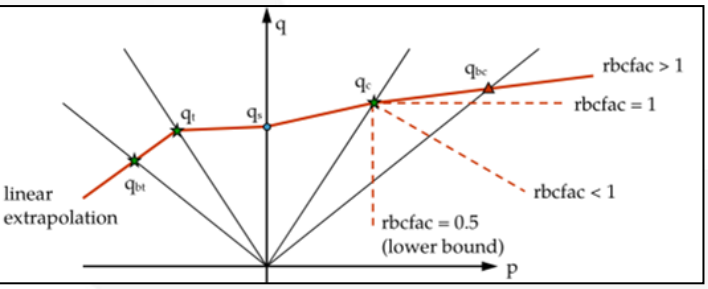
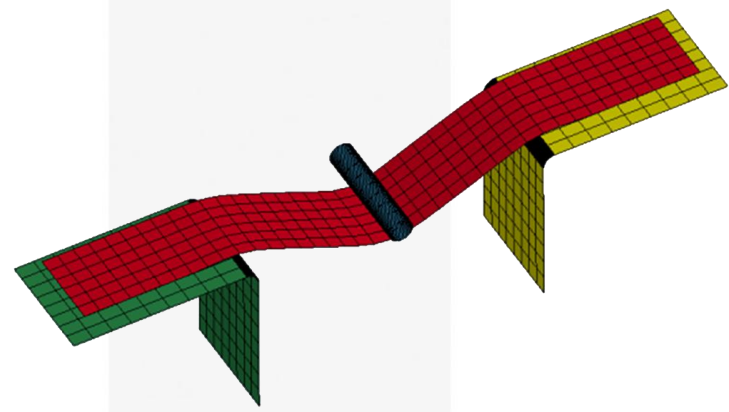
# MPIP - Material Parameter Identification Process

## from tension/bending → \*MAT\_124/187

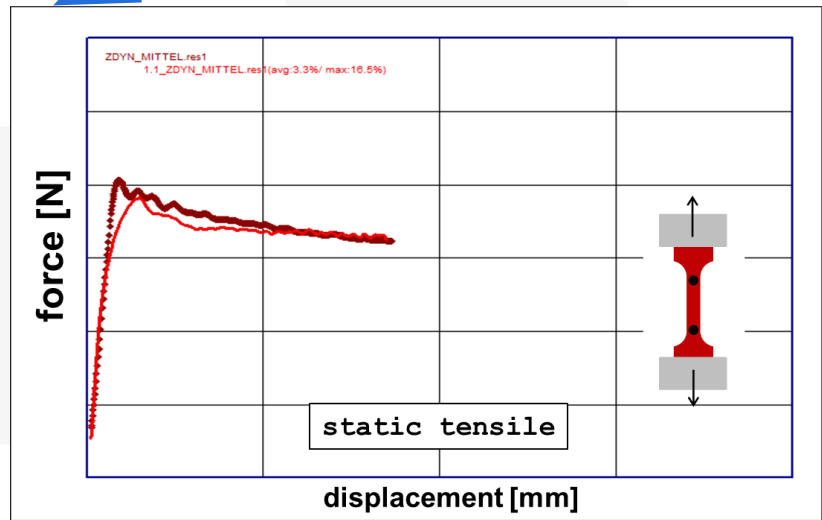


$v_0$   
[m/s]  
**4**

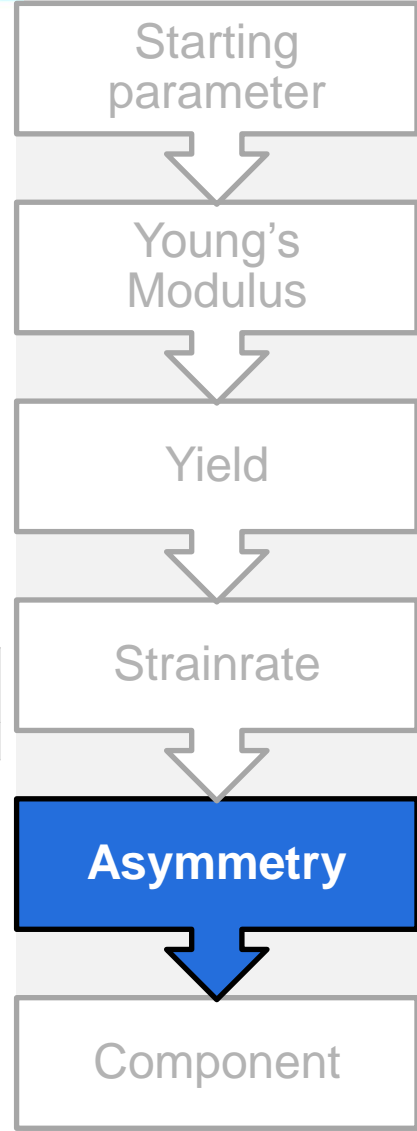
.... averaged test curves  
— result of simulation



[LSDYNA MANUAL]



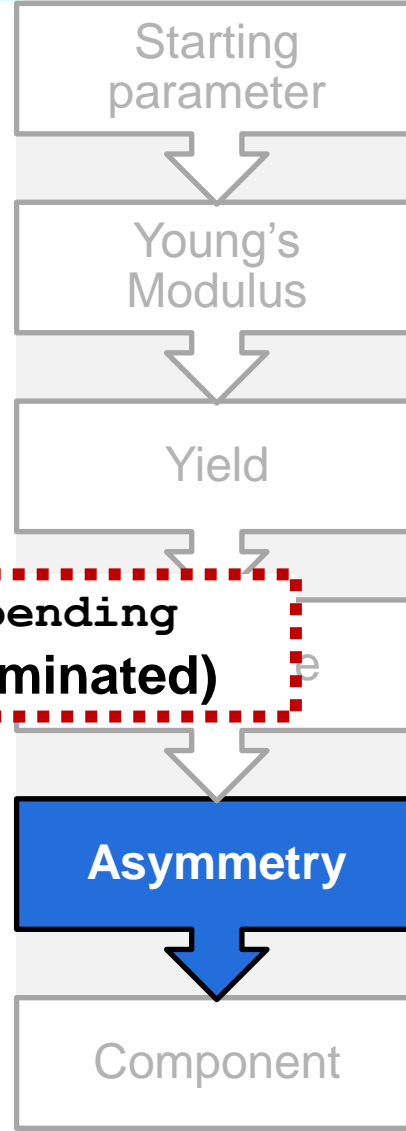
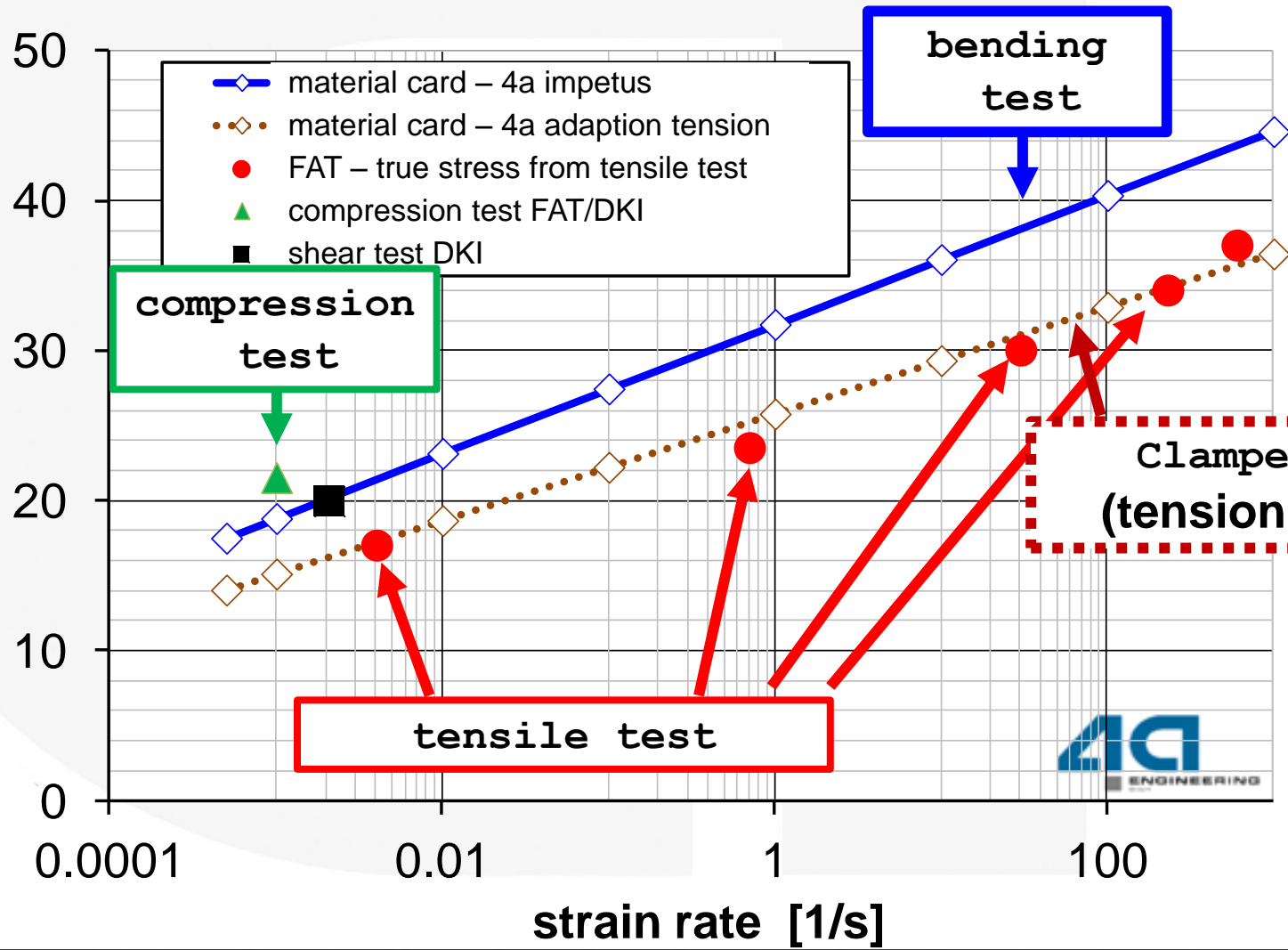
$v_0$   
[m/s]  
**0.001**



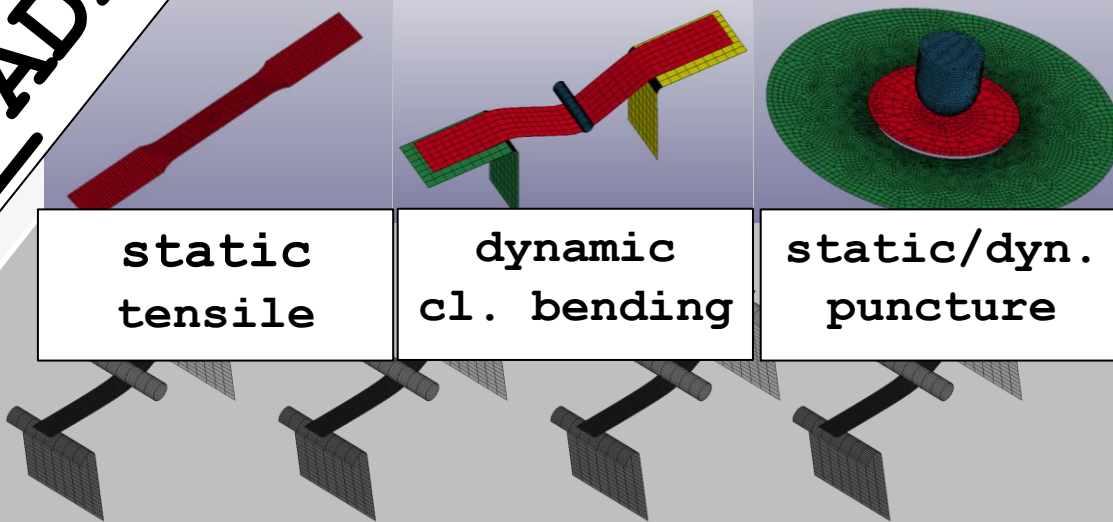
# MPIP - Material Parameter Identification Process

## comparison of test results

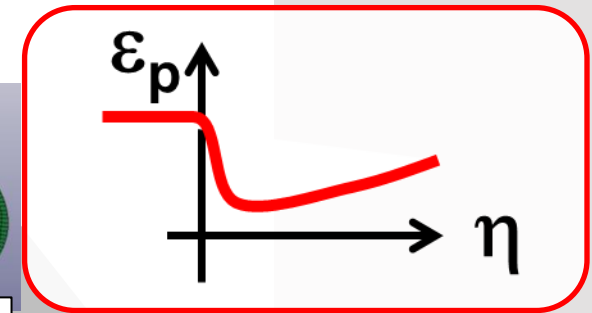
stress [MPa] at 10% strain



**\*MAT - ADD - EROSION**

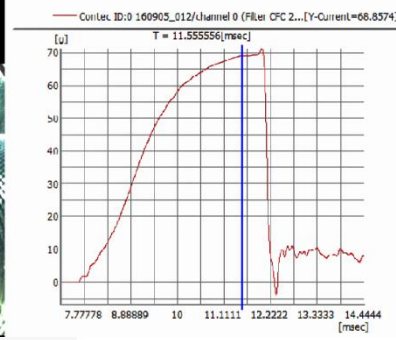
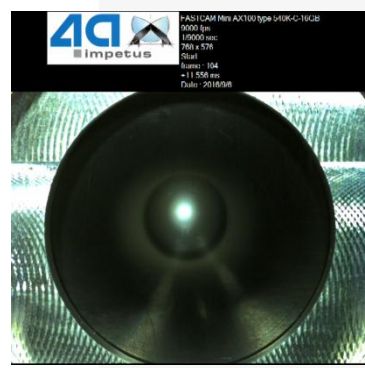
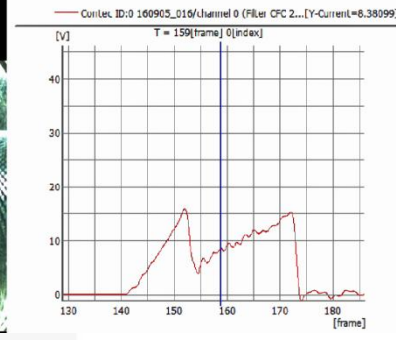
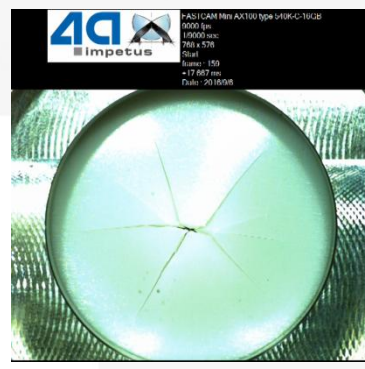
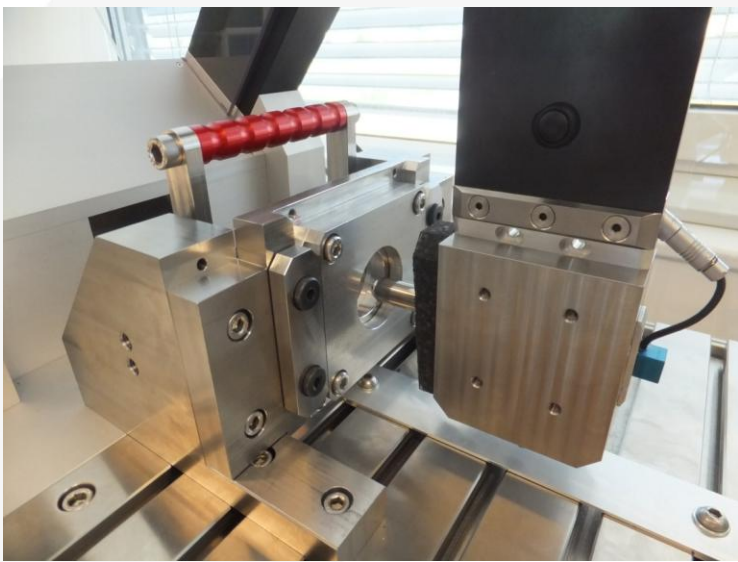


Damage/Failure



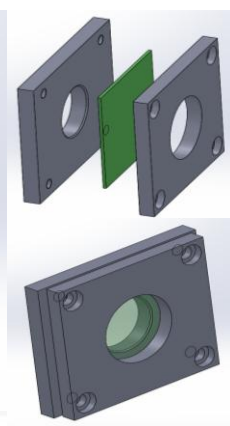
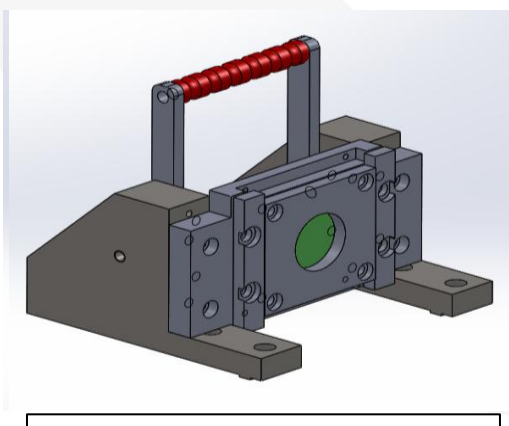
# MPIP - Material Parameter Identification Process from puncture → \*MAT\_ADD\_EROSION

## Test results:



brittle  
e.g. POM

ductile  
e.g. PCPET



**Biaxial failure**

# MPIP - Material Parameter Identification Process

## fracture models → \*MAT\_ADD\_EROSION

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

lower triax value

upper triax value

step size triax

Shear Damage Settings

FLC Damage Settings

Strainrate Settings

Postfracture

Loadcases

Results

Parameter model\* Model database

170503\_024 Material Designvariables Layers

Density	-1
Plasticity	vonMISES
Function (Hardening, Elastic curve form)	
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	0.33	Johnson Cook
upper triax value	None	mod Xue-Wierzbicki
step size triax	None	Xue-Wierzbicki
Fracture Energy (TRAX)		Mohr-Coulomb

Materialcard MMEC

Image Comment

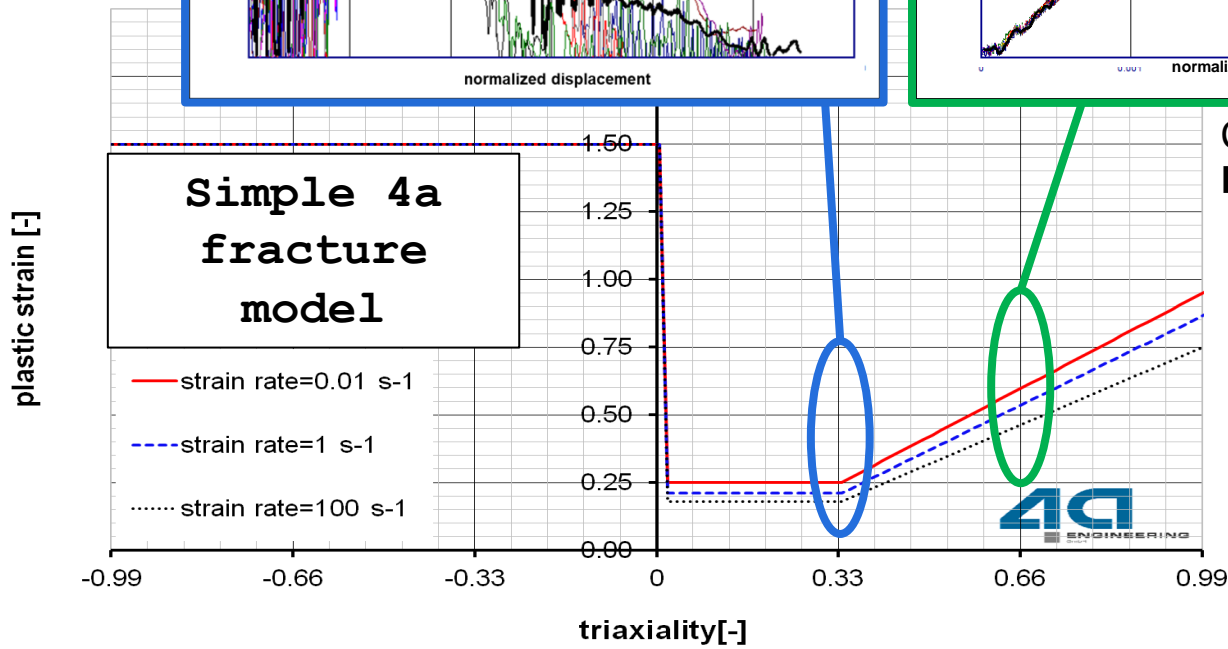
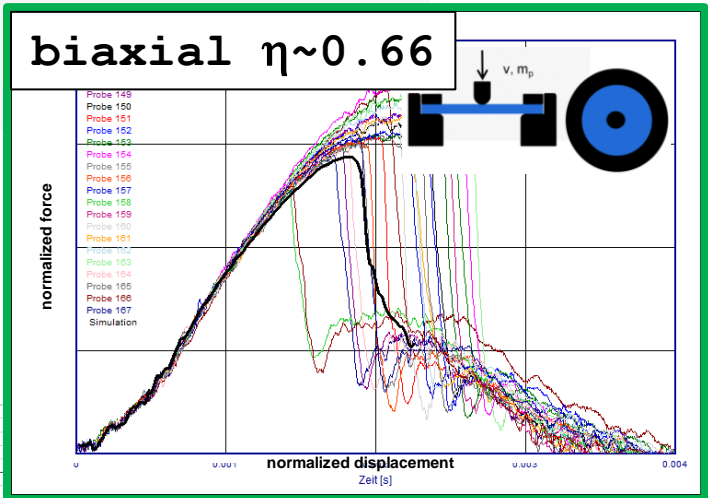
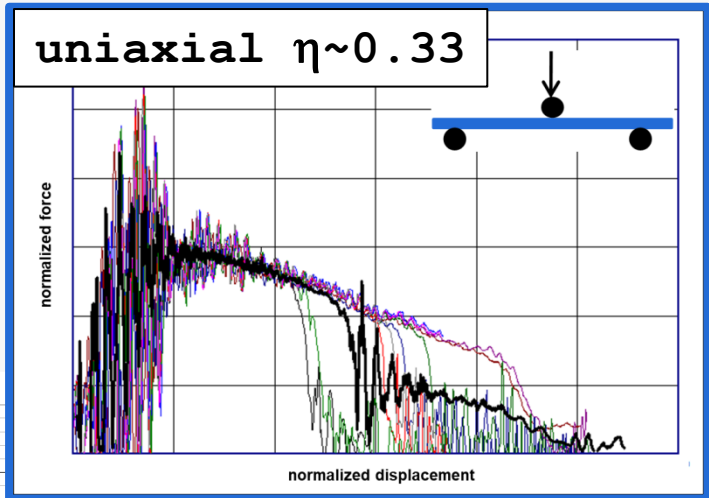
$$f_{d_{JCD1}} + f_{d_{JCD2}} \cdot e^{-f_{d_{JCD3}} \cdot \eta}$$

available in 4a impetus GUI

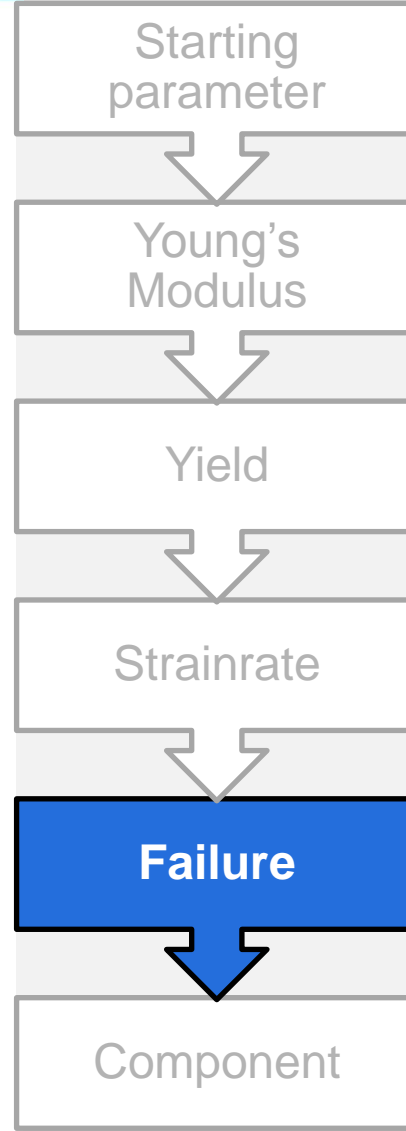


# MPIP - Material Parameter Identification Process

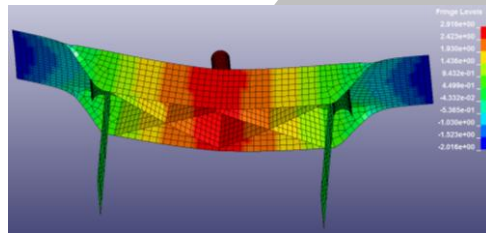
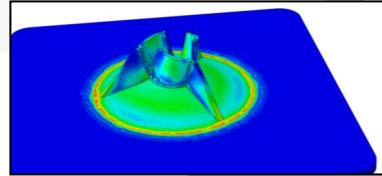
## fracture models → \*MAT\_ADD\_EROSION



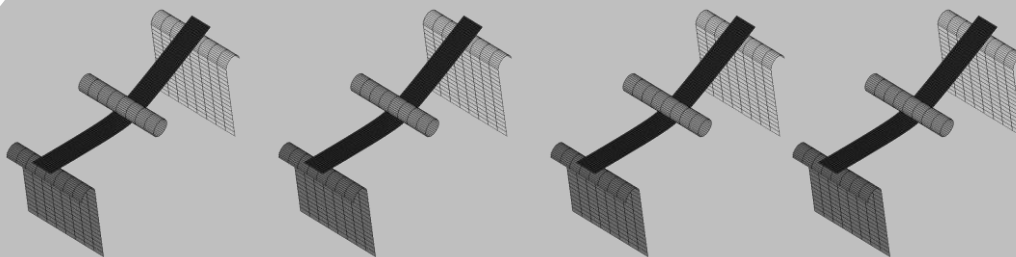
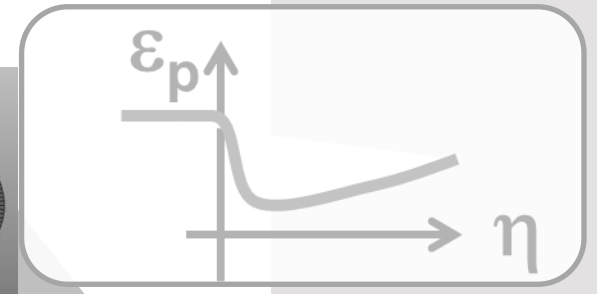
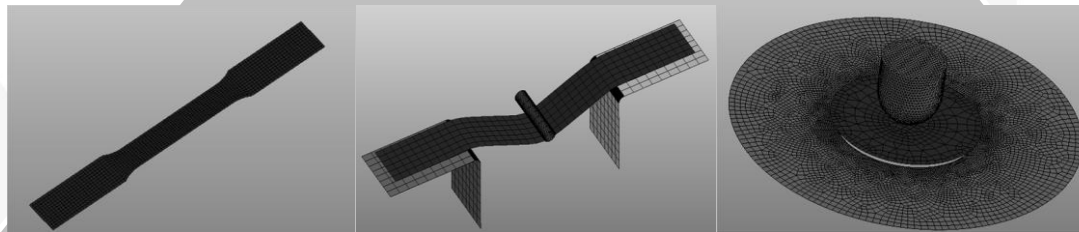
Colored: Test curves  
Black: Simulation



See more: A. Fertschej, P. Reithofer - *Failure models for plastics - material characterization for \*MAT\_ADD\_EROSION (DIEM)*; 11th European LS-DYNA Conference, Salzburg

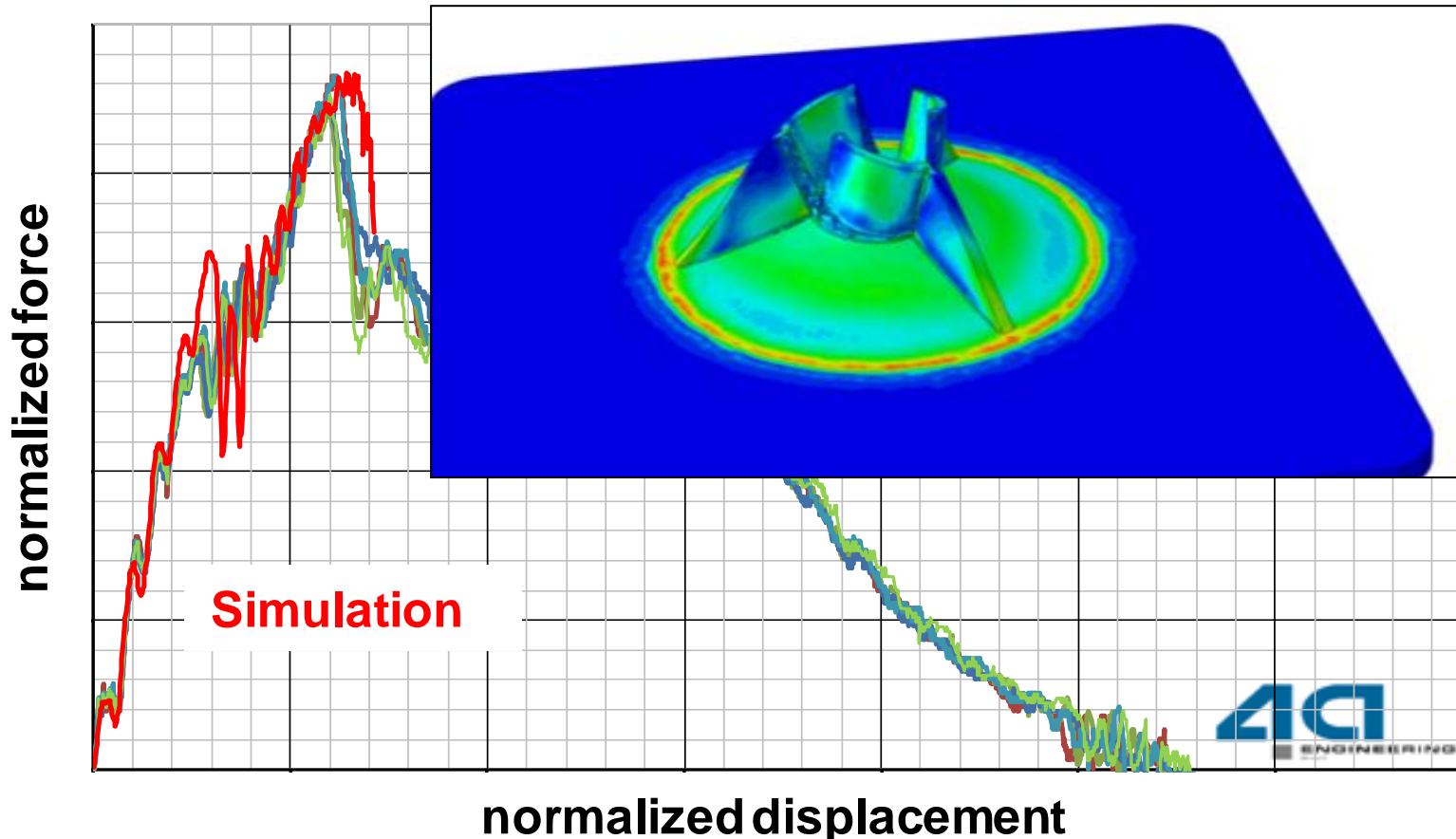


Validation



# MPIP - Material Parameter Identification Process

## Validation on component



See more: A. Fertschej, P. Reithofer, M. Rollant - Failure of thermoplastics - PART 2, Material modeling and simulation, LS-DYNA Konferenz 2015, Würzburg

Starting  
parameter

Young's  
Modulus

Yield

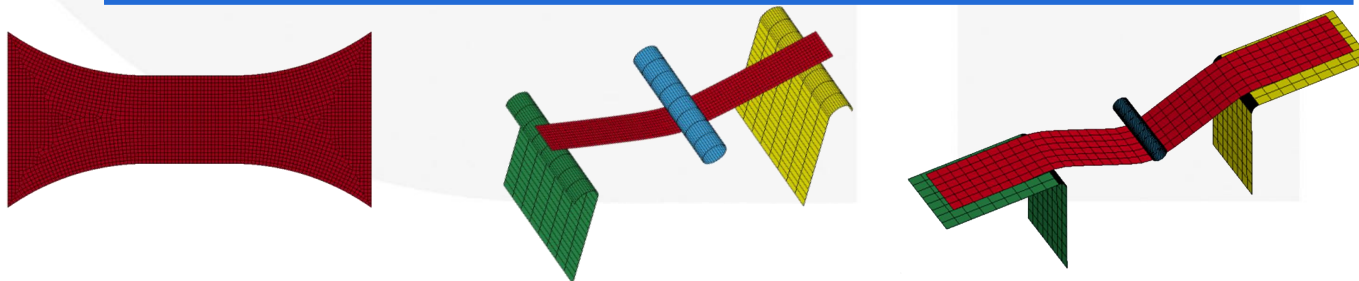
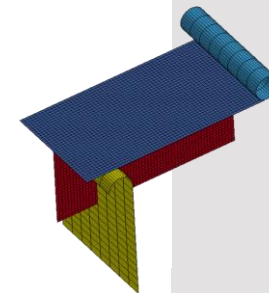
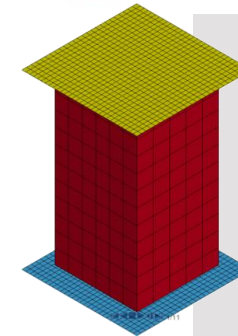
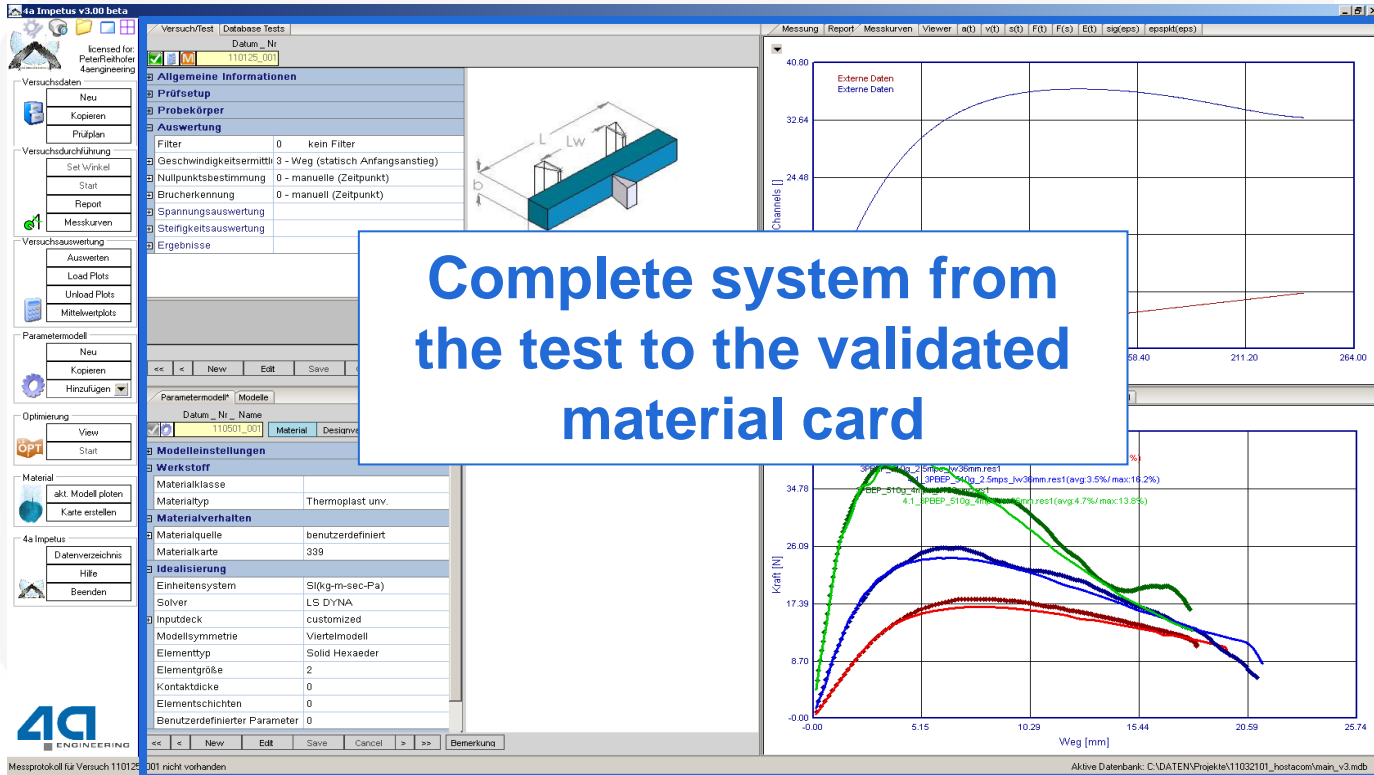
Strainrate

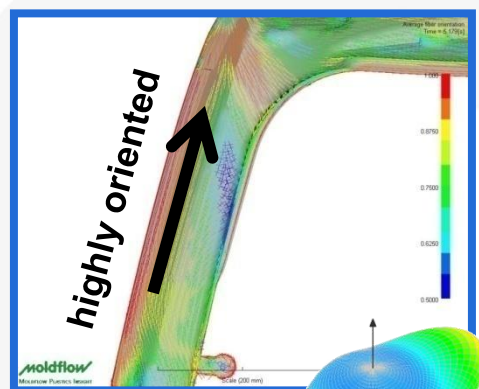
Asymmetry  
Failure

**Component**

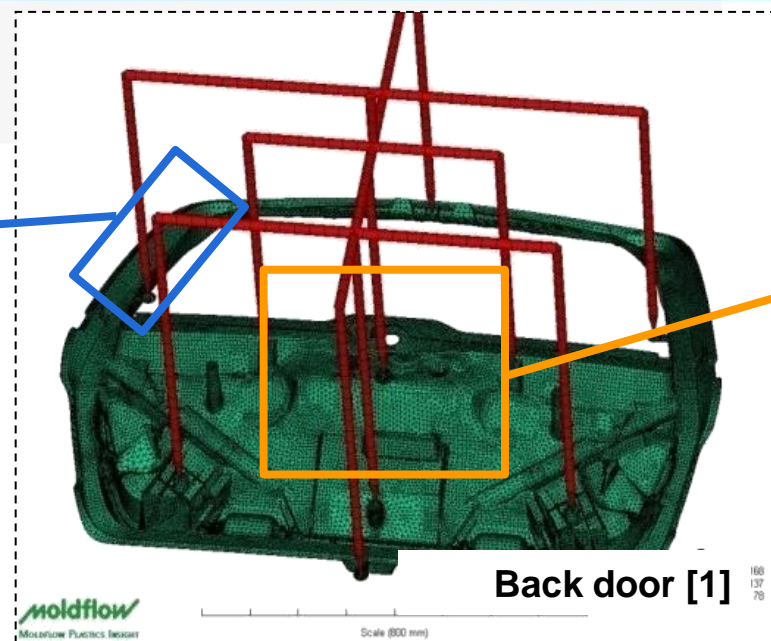
# MPIP - Material Parameter Identification Process

## 4a impetus - intelligent testing systems

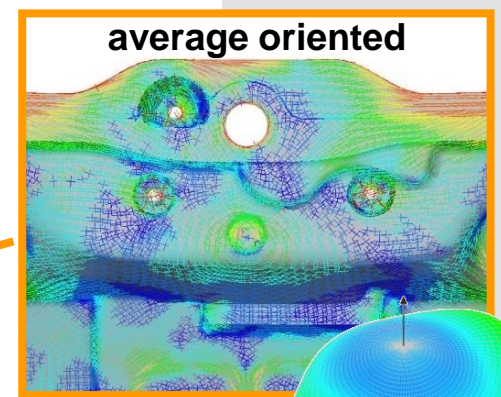




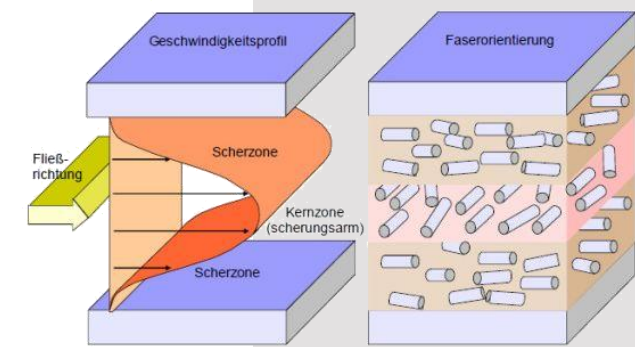
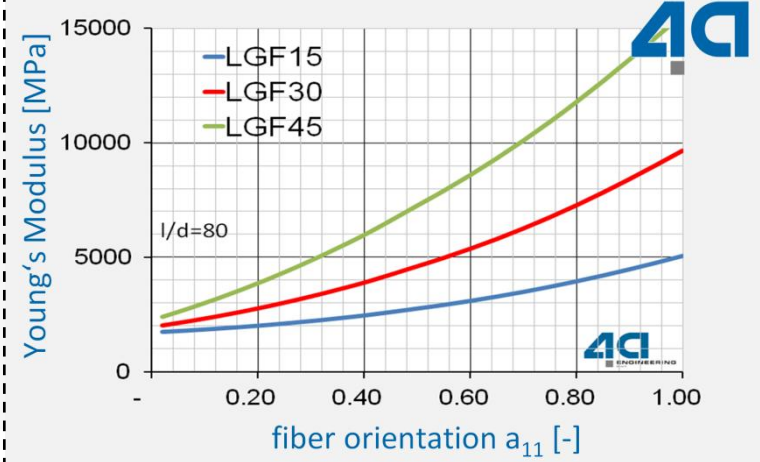
$$a_{ij} = \begin{bmatrix} 0,87 & 0 & 0 \\ 0 & 0,11 & 0 \\ 0 & 0 & 0,02 \end{bmatrix}$$



Back door [1]



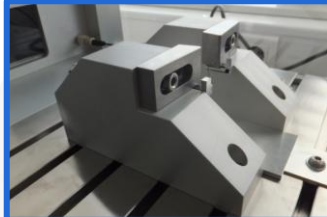
$$a_{ij} = \begin{bmatrix} 0,66 & 0 & 0 \\ 0 & 0,32 & 0 \\ 0 & 0 & 0,02 \end{bmatrix}$$



Source: wiki.polymerservice-merseburg.de

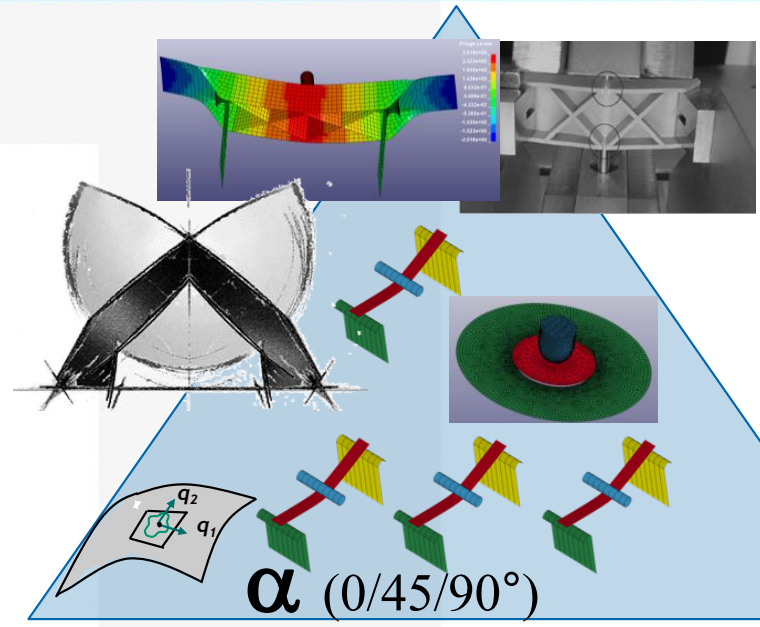
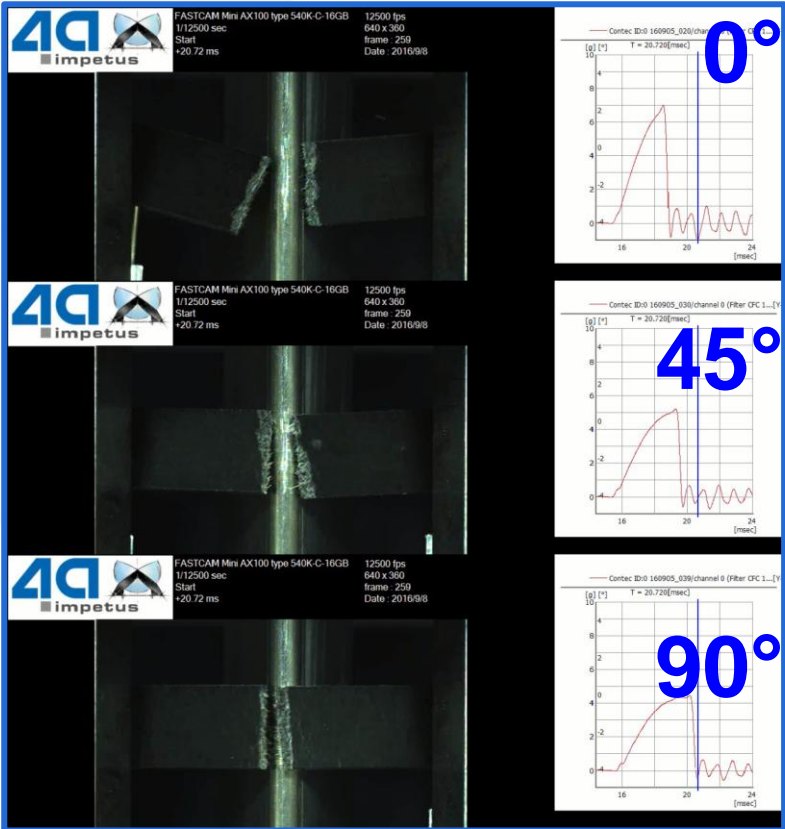
# SFRT / LFRT \*MAT\_157/\*MAT\_215 (4A\_MICROMECH)

## material characterization pyramid

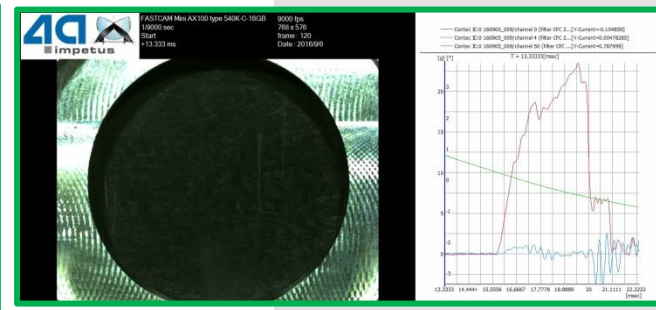
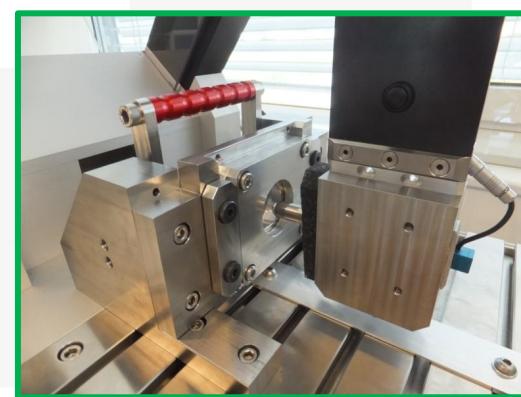
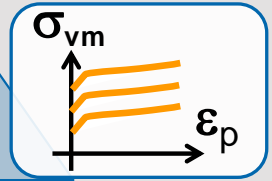
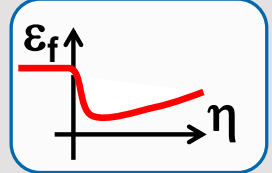


Bending

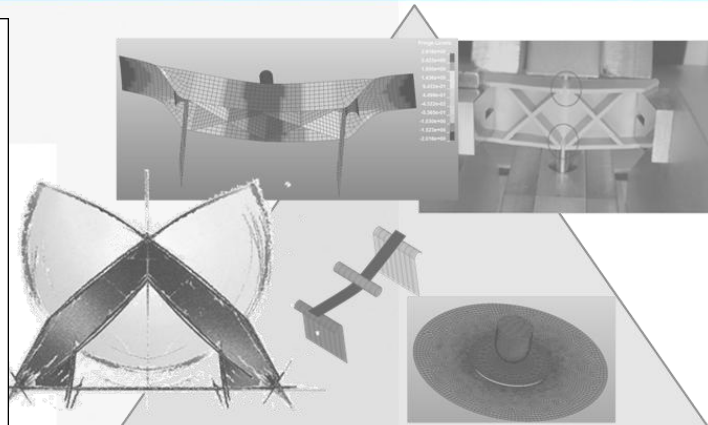
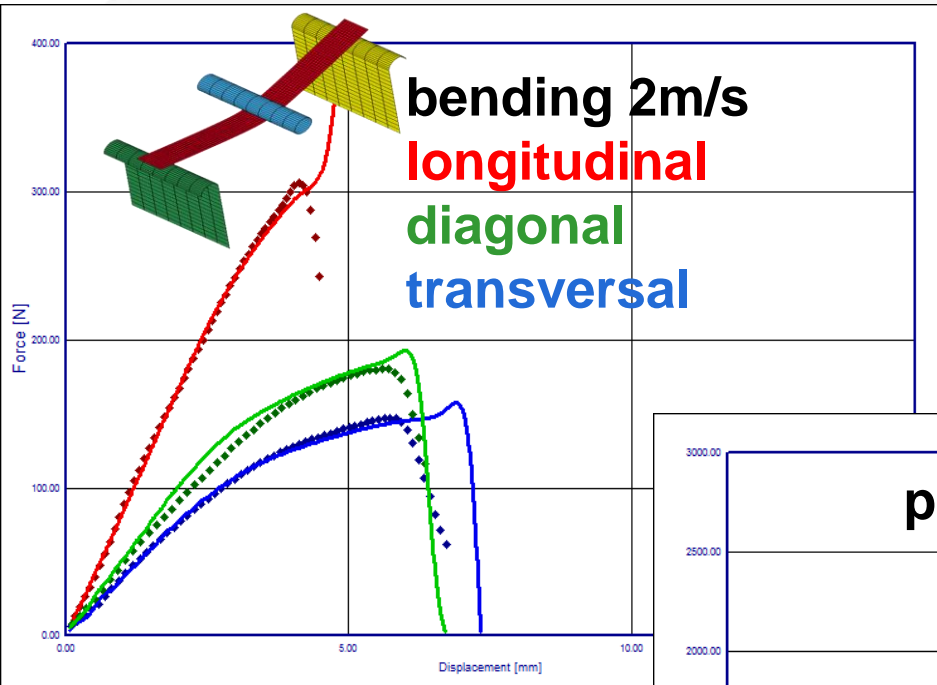
# Orientation



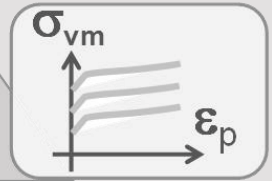
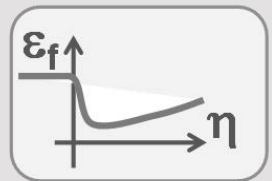
component validation



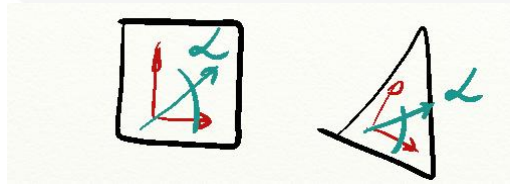
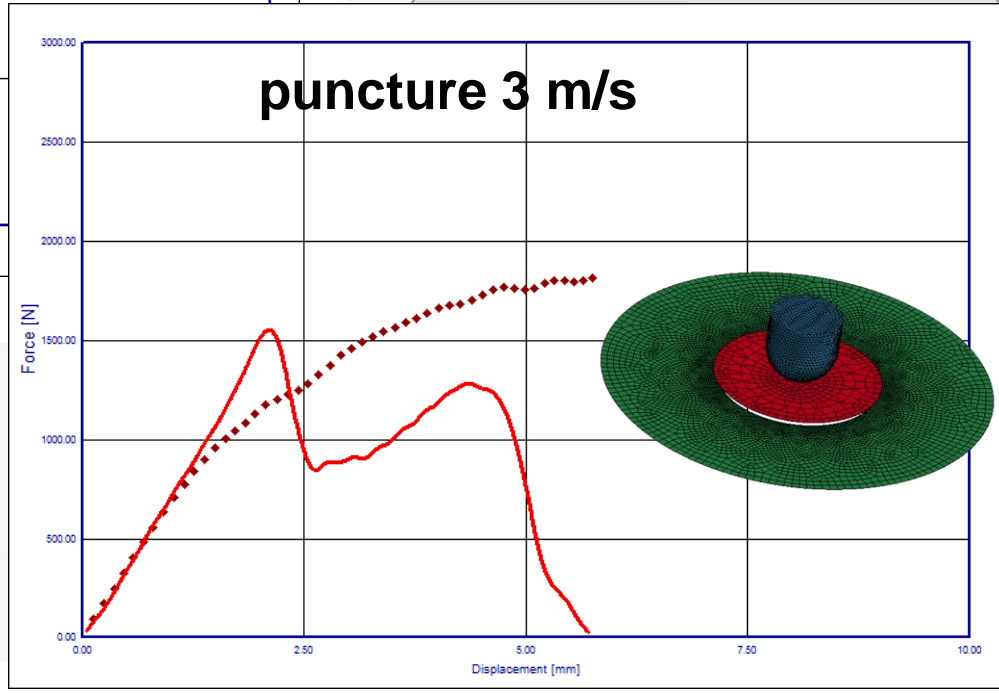
Puncture



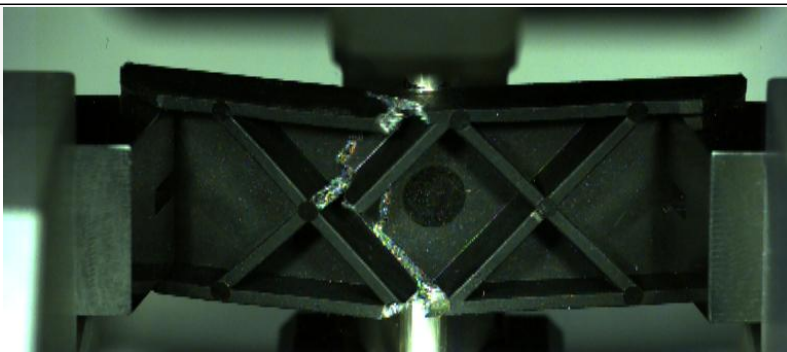
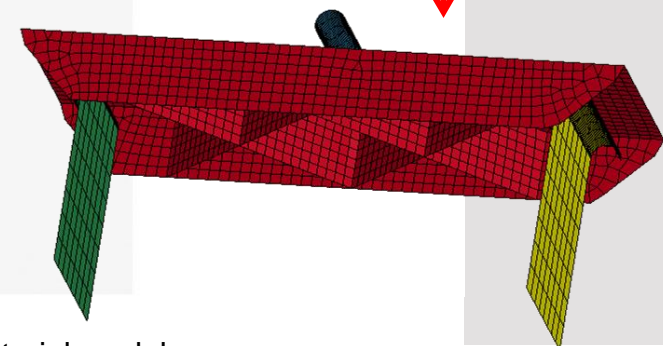
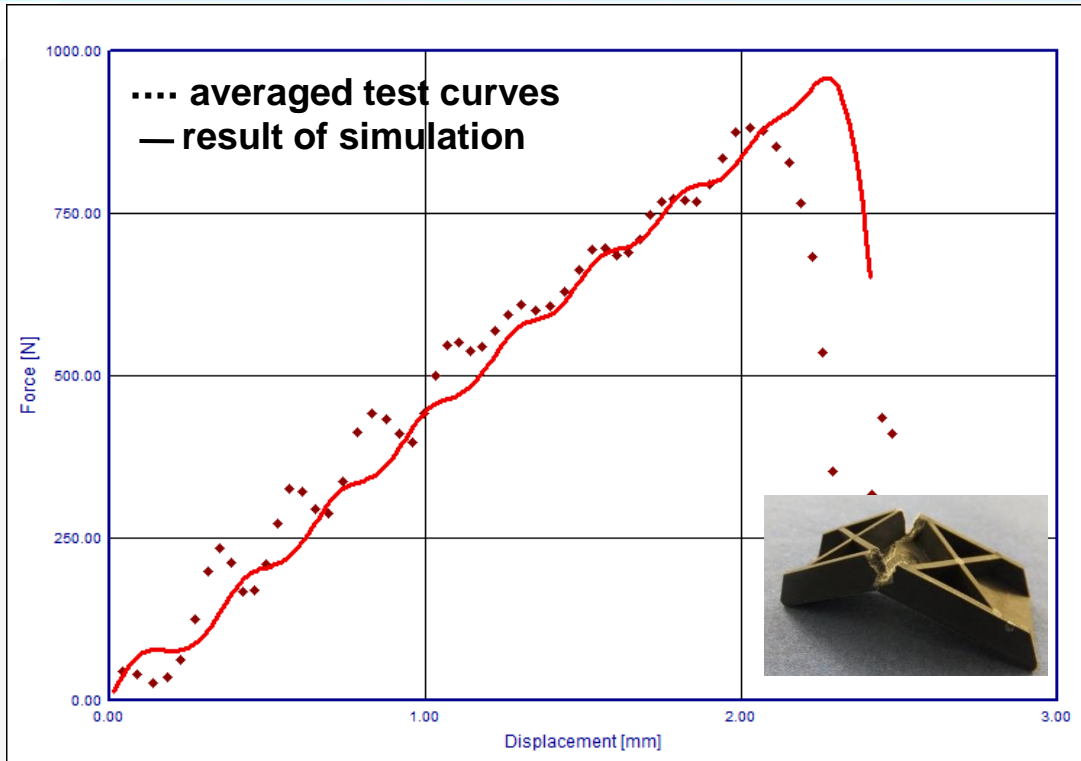
component validation



.... averaged test curves  
 — result of simulation



## Validation



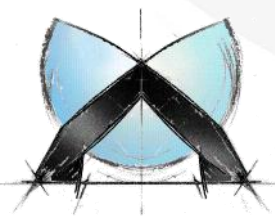
Source: LS DYNA Forum 2016 - \*MAT\_4A\_MICROMECC – micro mechanic based material model

© 4a engineering GmbH, all rights reserved



# SFRT / LFRT

## *Case Study Drop Test*



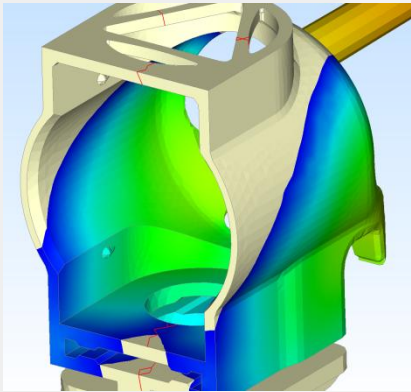
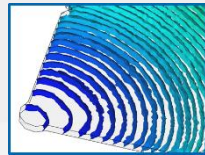
**4a impetus - intelligent testing systems  
powered by 4a engineering GmbH**



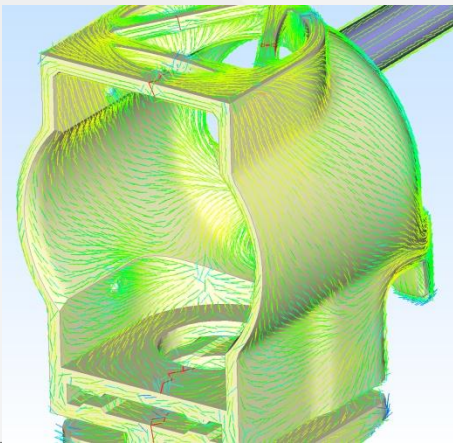
© 4a engineering GmbH, all rights reserved

## Process simulation

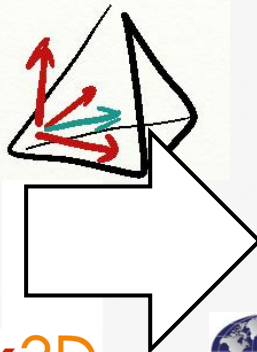
### Filling



### Fiber orientation

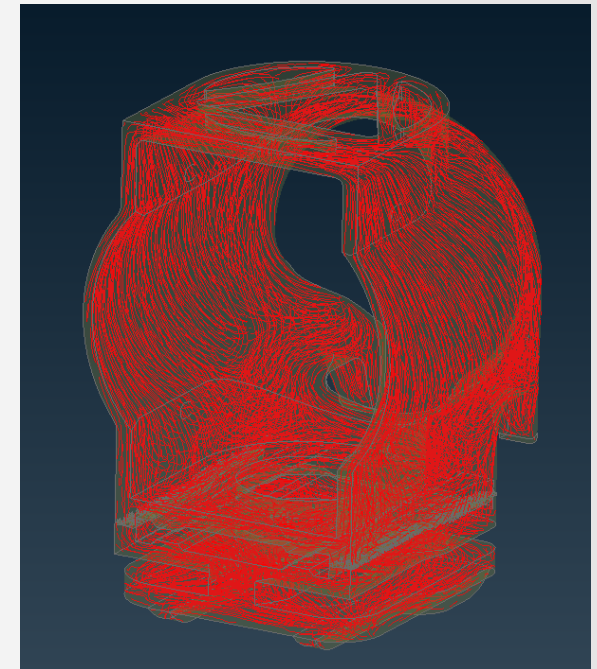
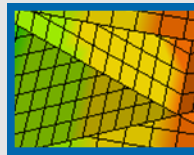


mapping



## Structural simulation

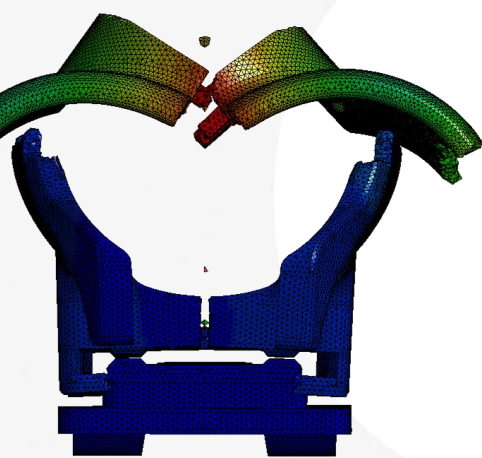
### Drop test



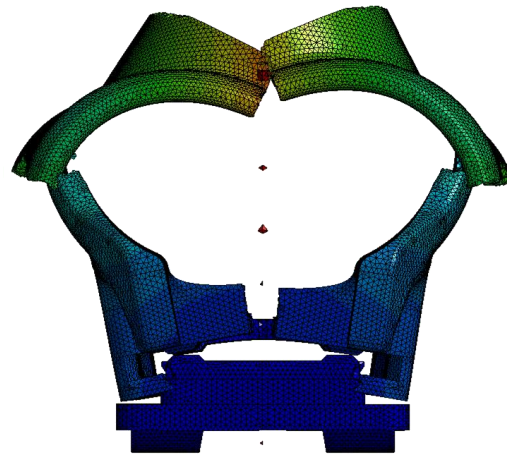
### Fiber orientation

\*ELEMENT\_SOLID\_ORTHO

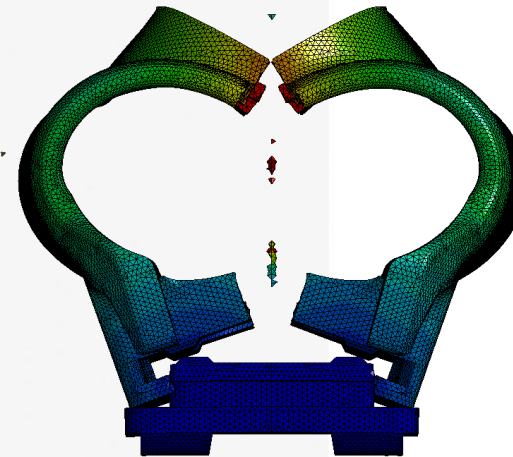
more: R. Steinberger, et.al. Hirtenberger Automotive Group – *Considering the Local Anisotropy of Short Fiber Reinforced Plastics*, European Dynaforum 2017 © 4a engineering GmbH, all rights reserved



**\*MAT\_24**  
transversal



**\*MAT\_24**  
longitudinal



**\*MAT\_157/215**  
local anisotropy

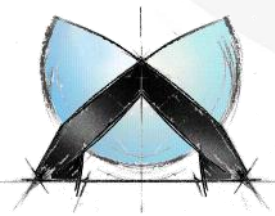


test



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

# *Summary & Outlook*

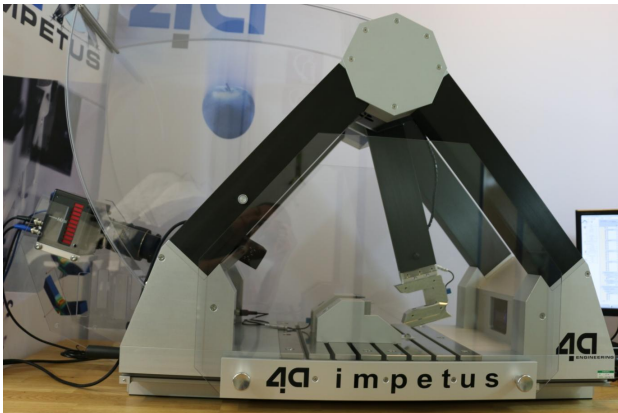


**4a impetus - intelligent testing systems  
powered by 4a engineering GmbH**



© 4a engineering GmbH, all rights reserved

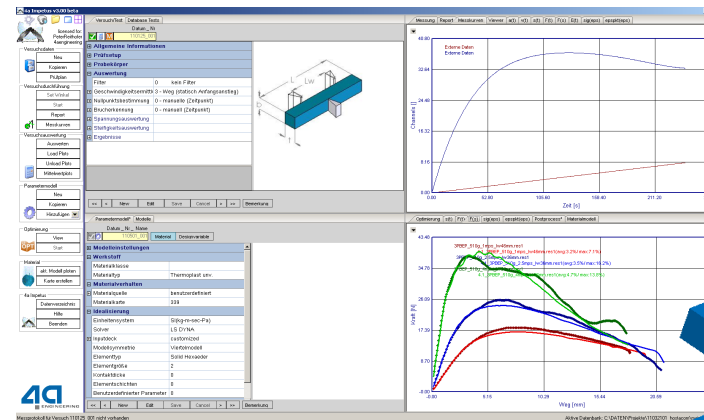
### 4a impetus Hardware



- 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

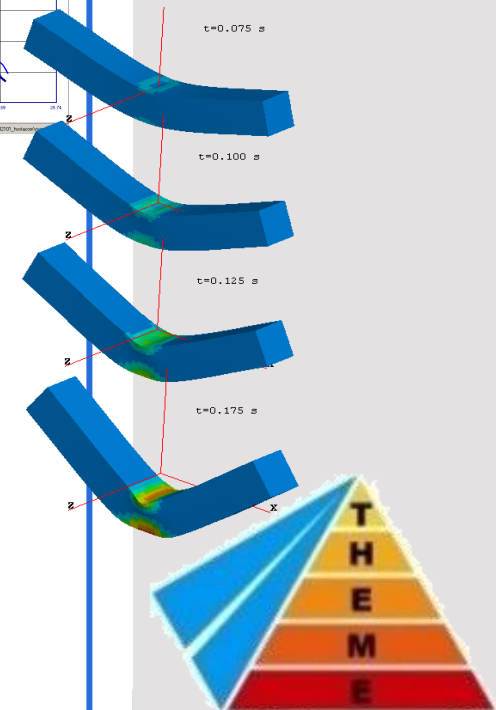
**plastic and composites**

### 4a impetus Software



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

**for all material types**





**테마엔지니어링(주)**

**Local Korean Partner**

**Thank you for your attention!**



**„in physics we trust”**

