IMPETUS

VALIMAT

WORKSHOP
From Test to Material Card

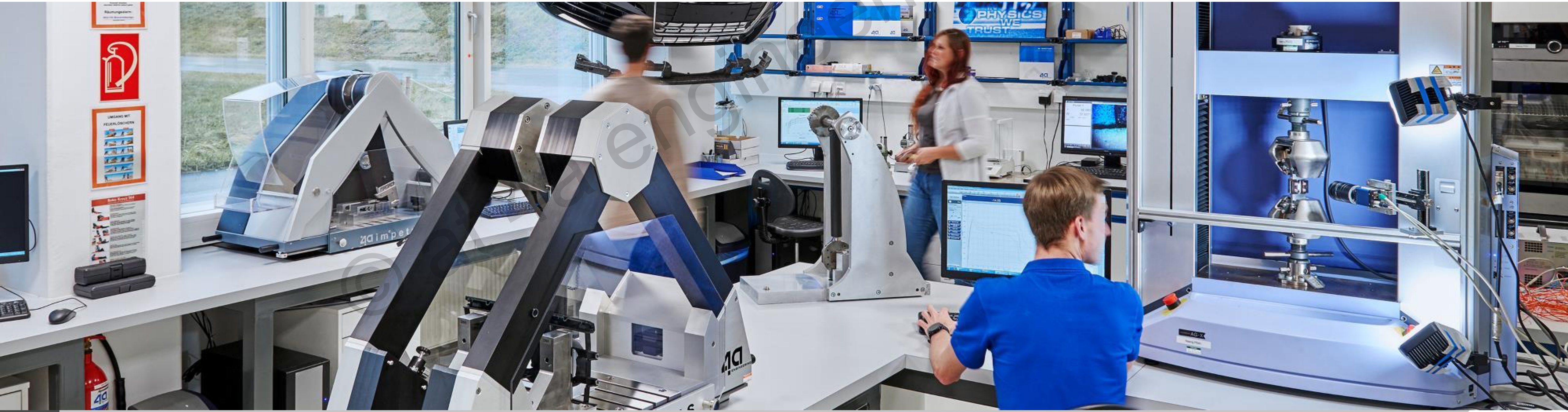
P. Reithofer, St. Riemelmoser

Nagoya, **23.01.2020**

In cooperation with

JSOL CORPORATION

AR BROWN
Think Quality & Create Value



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VALIMAT

SEMINAR AGENDA

10:00 - 10:45 INTRODUCTION

Material behavior for plastics

Introduction to VALIMAT™ - workflow for generating material cards

10:45 - 12:15 IMPETUS™ HANDS ON

Hardware introduction and hands on testing

13:15 - 14:45 VALIMAT™ HANDS ON

Evaluation of test data and organizing databases

AUTOFIT: *MAT_024 parameter identification using the new feature

14:45 - 15:30 ADVANCED TOPICS

Parameter identification:

- for yield surface and flow rule i.e. *MAT_187
- for damage and failure i.e. *MAT_ADD_EROSION

Outlook on upcoming material models

15:30 - 16:30 Q&A

4a ENGINEERING

In cooperation with

JSOL CORPORATION AR BROWN Think Quality & Create Value

P. Reithofer, St. Riemelmoser pres_20012301_pr_eng_JSOL-workshop

excellence in

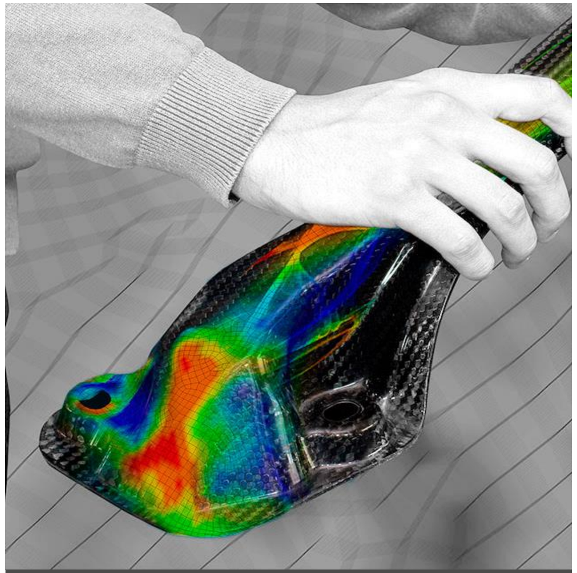
plastics&simulation

testing equipment

lightweight products

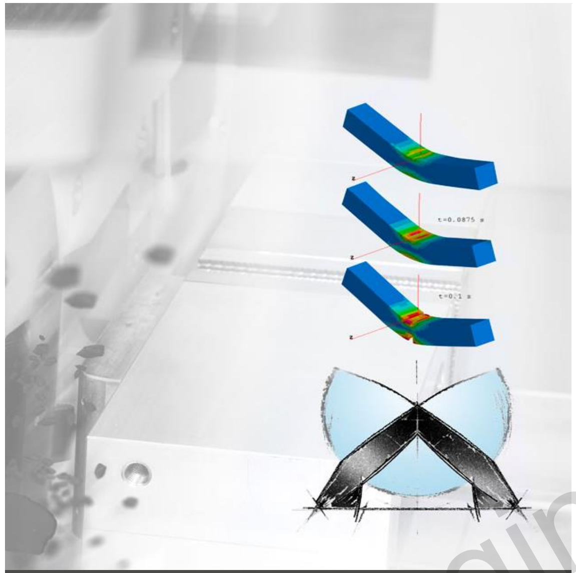
© Google Maps

4a business units



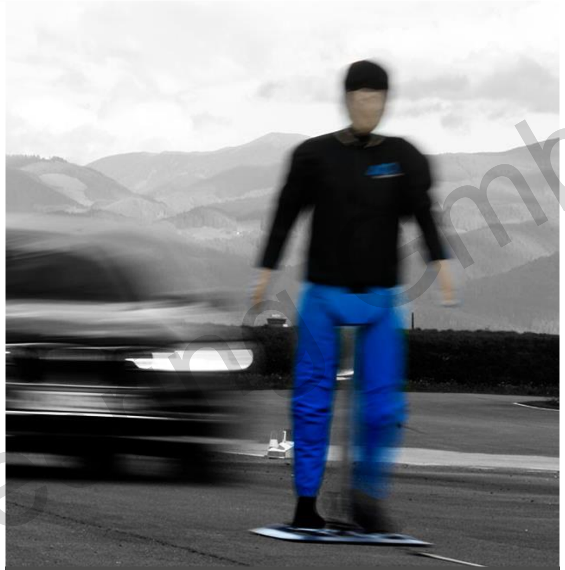
4a engineering

Engineering and simulation for plastic products and composites



Impetus

Testing equipment generating material data for the dynamic simulation of plastics



4activeSystems

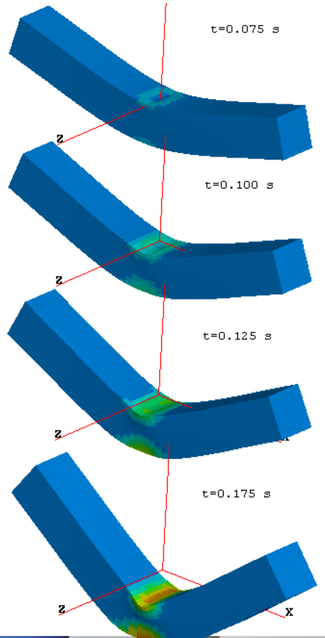
Dummies and testing facilities for active vehicle safety

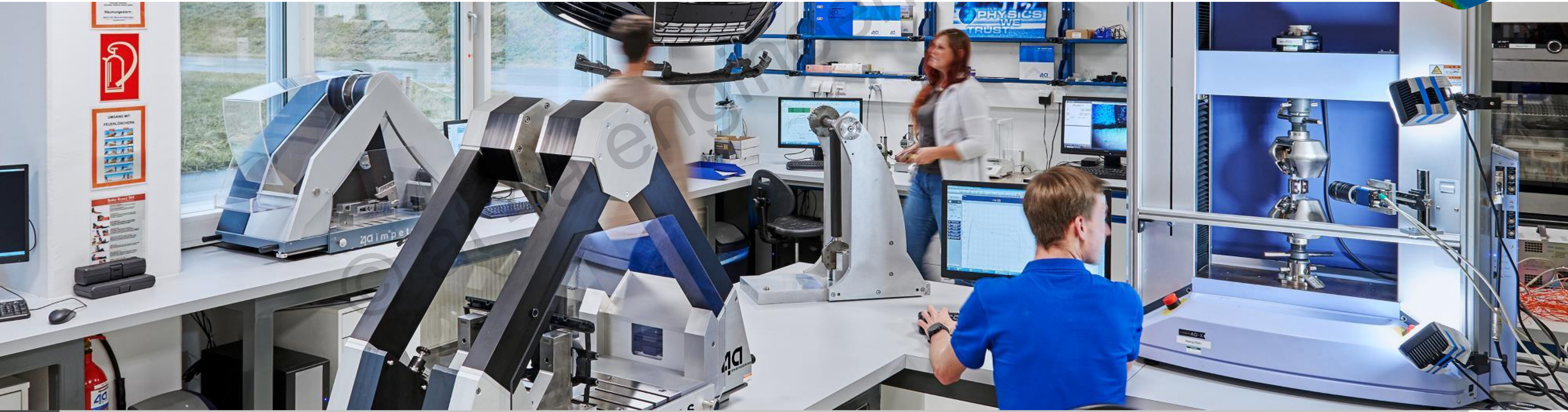
4a manufacturing

Specialized thin foams and multi layer materials

Material characterization - services

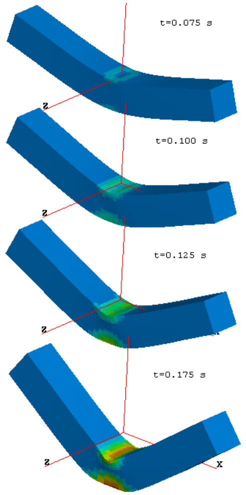
- efficient high-dynamic testing
- dynamic material behaviour
- plastics, foams, composites, …
- **validated material cards ready to use for your crash-simulation**



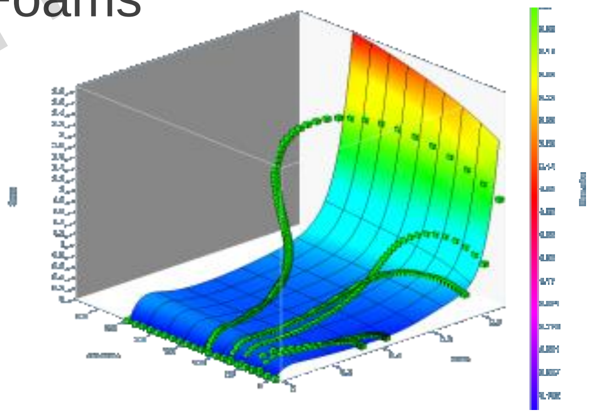


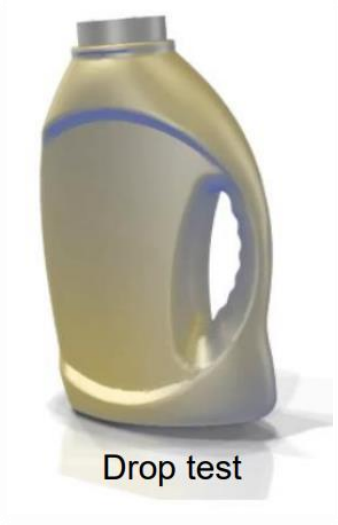
Case study – drop test

- Drop test of plastic bottle
- Easy to use material card
- **good prediction with new material card from 4a**

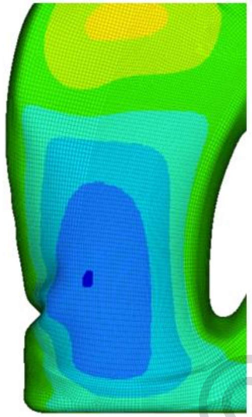


- Droptest of Beamer
- Packaging EPS/EPP Foams
- Energy absorption

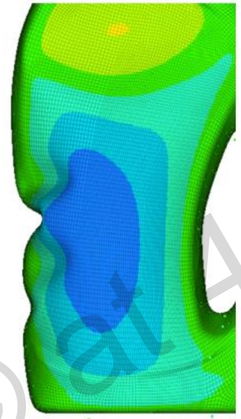




Drop test

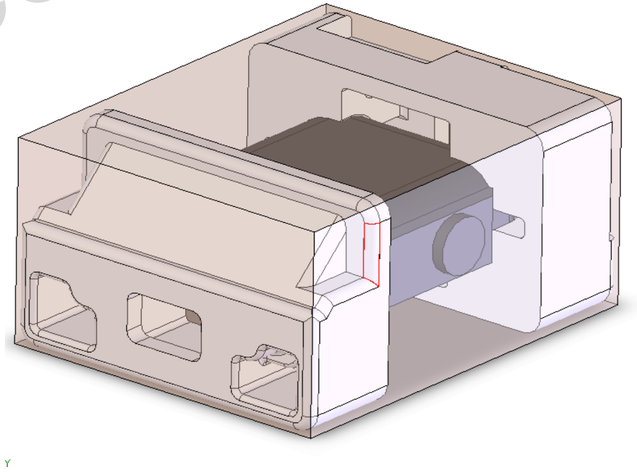


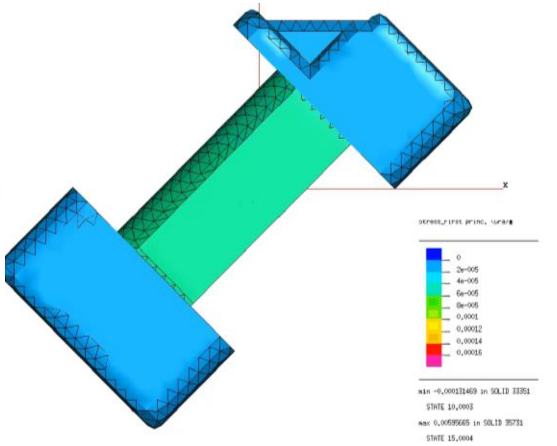
No
rate dependency
(old)



With
rate dependency
(new)

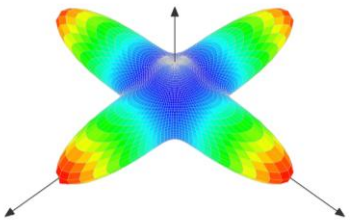
Experiment: Drop test



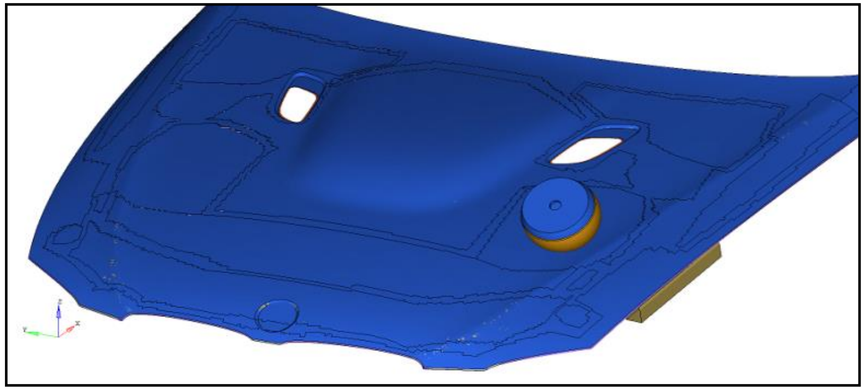


SOURCE: LINK to PAPER

Case study - composite



- 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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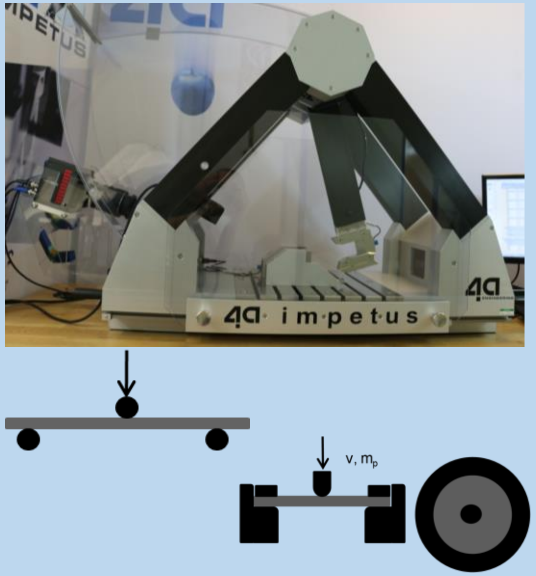
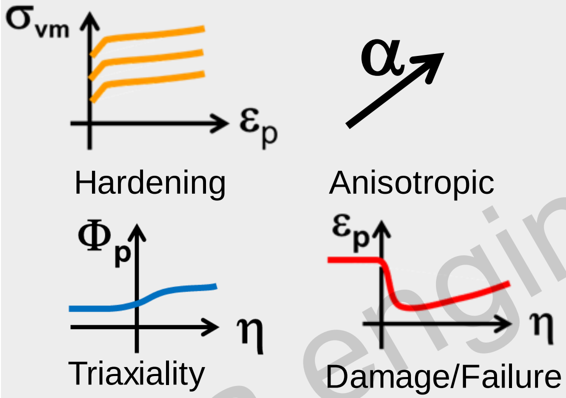


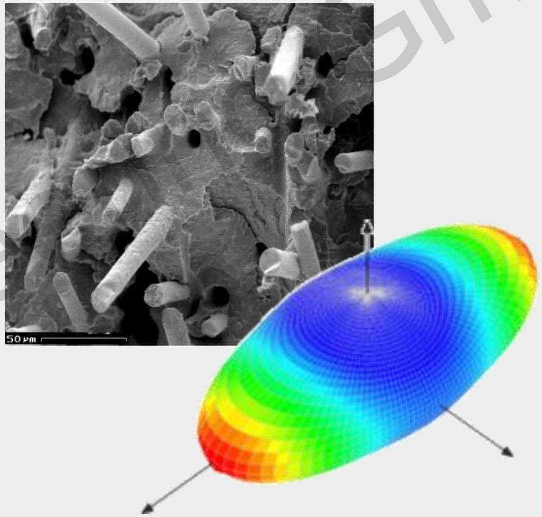
efficient
dynamic testing

VALIMAT



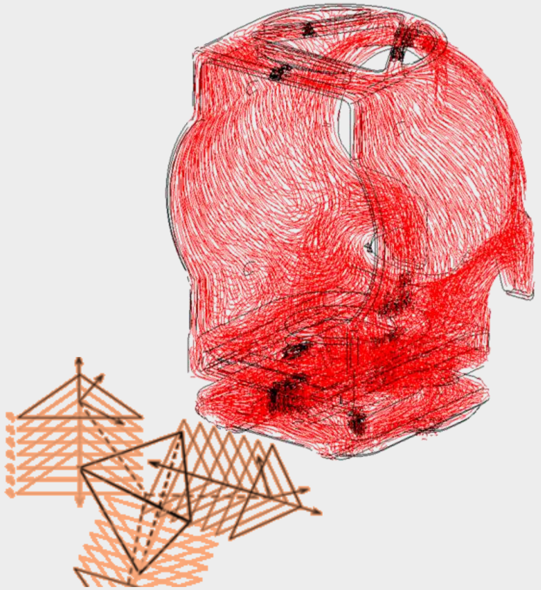
from test to validated
material cards

MICROMEC



3D anisotropic
material cards

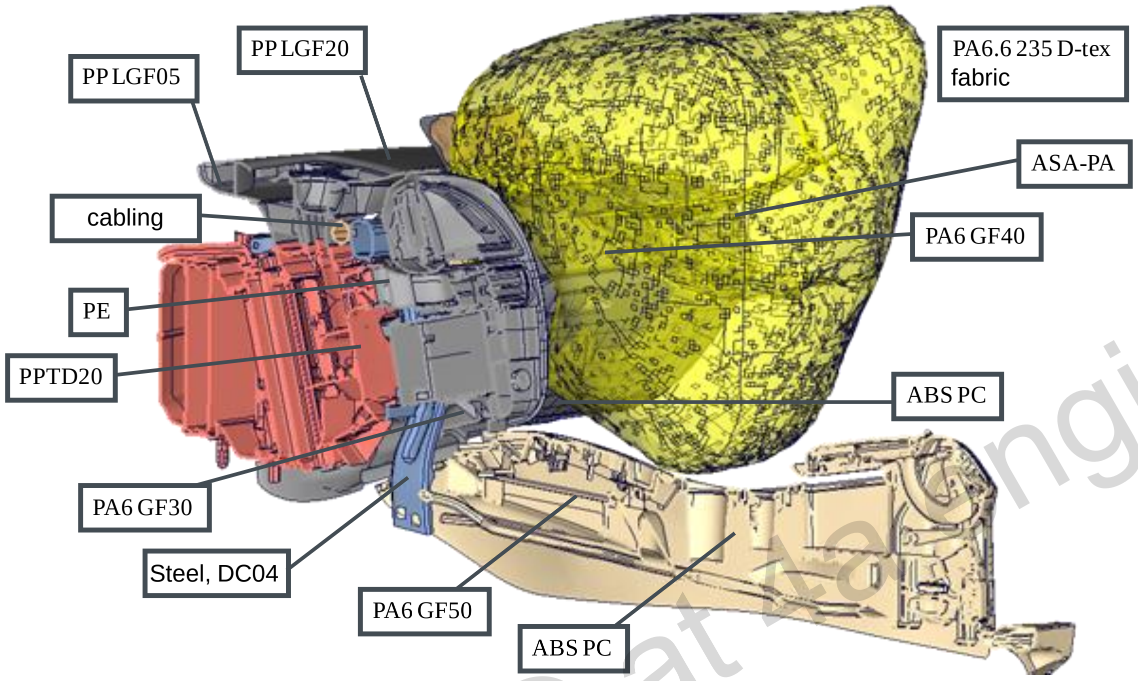
FIBERMAP



individual mapping
process information

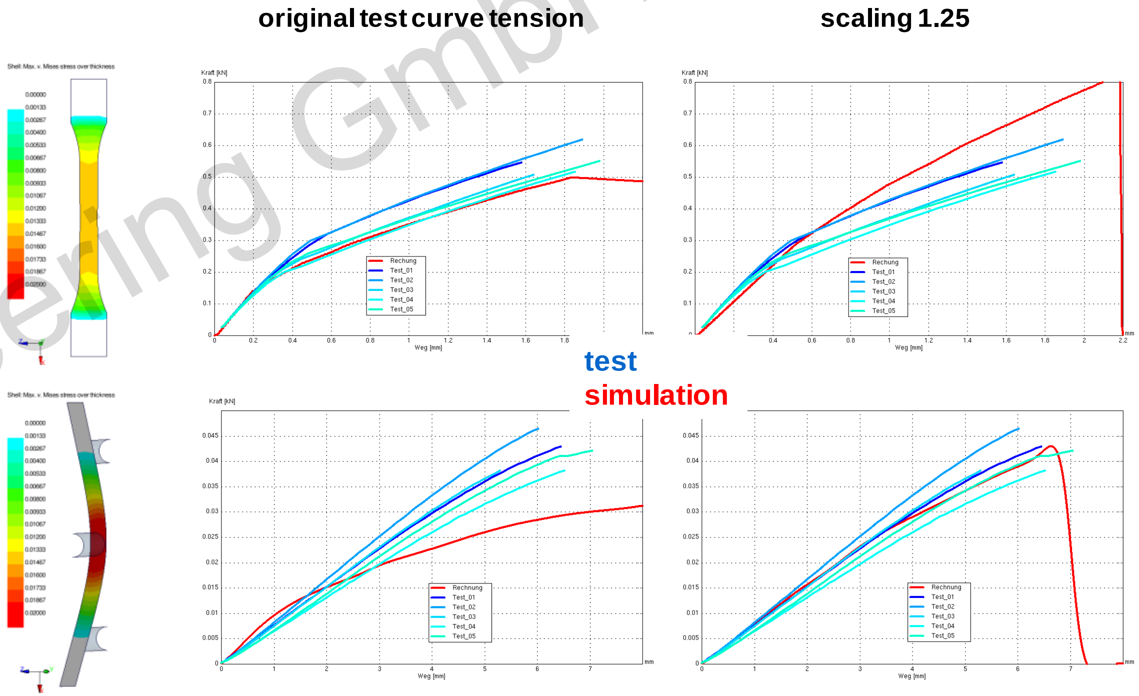
Plastics in the industry

material variety



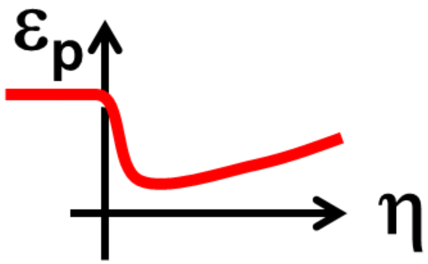
Source: R. Luijkx - *Kunststoffmaterialien in der Interieur Funktionsauslegung bei Audi AG,* 4a Technologietag 2010

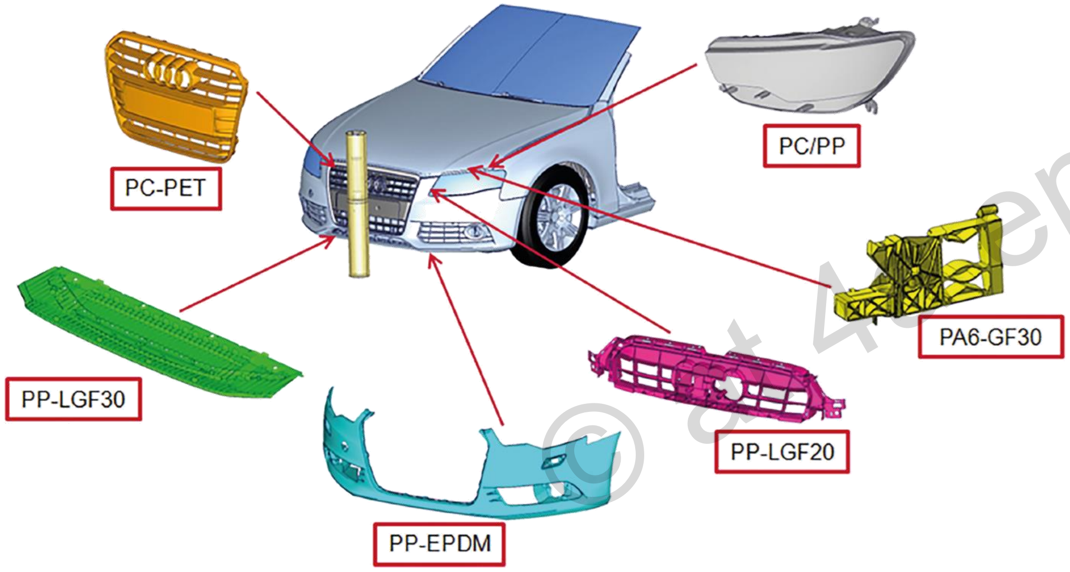
bending load case

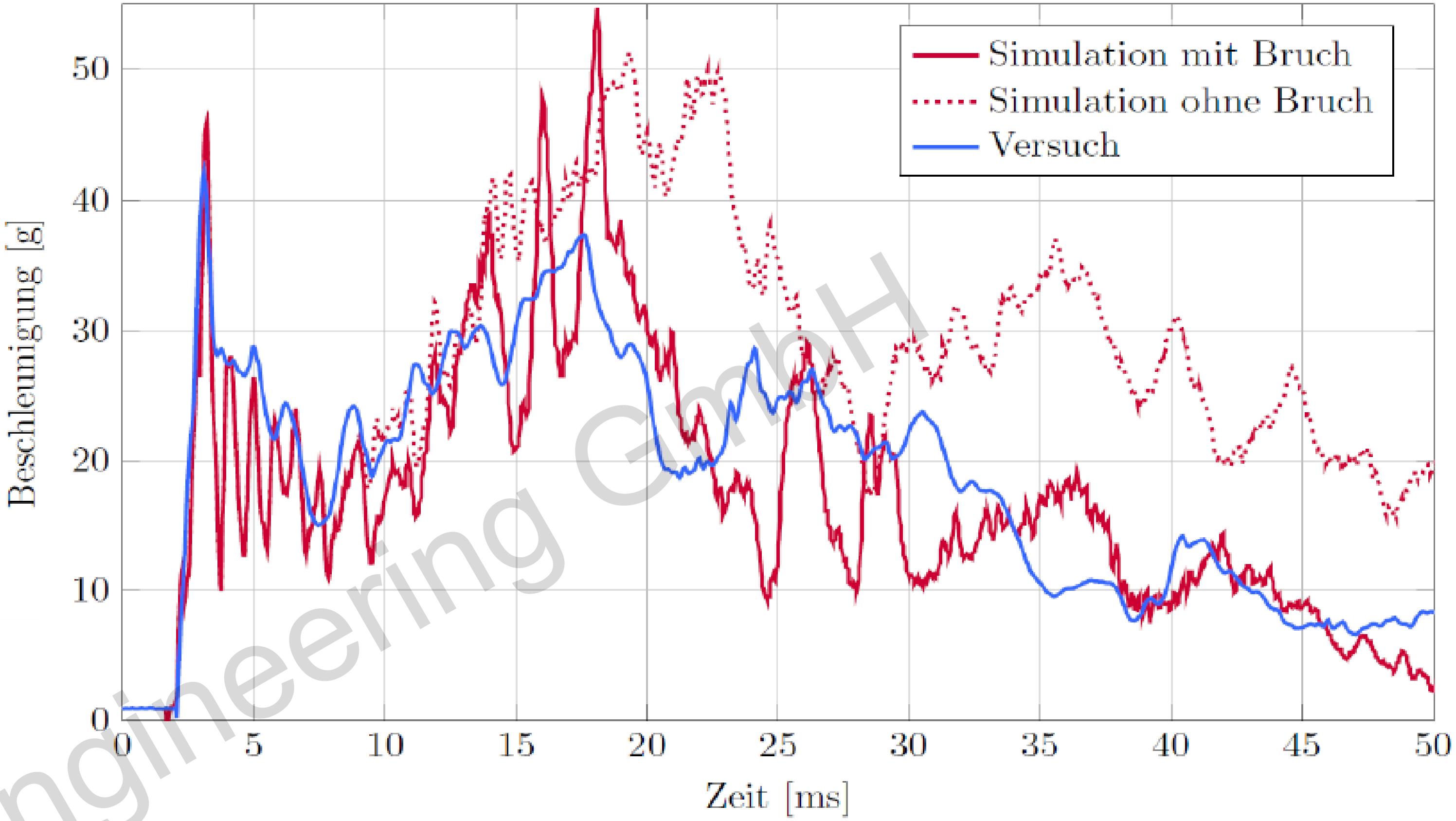


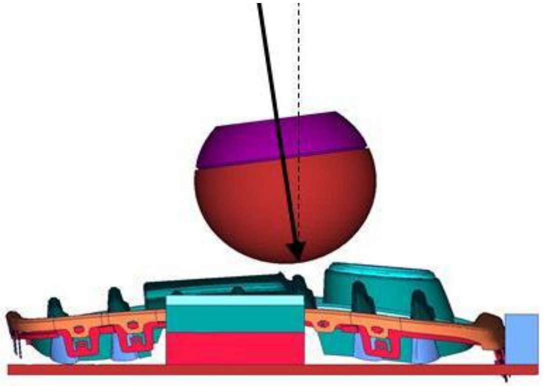
Plastics in the industry

Damage/Failure









Audi

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

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

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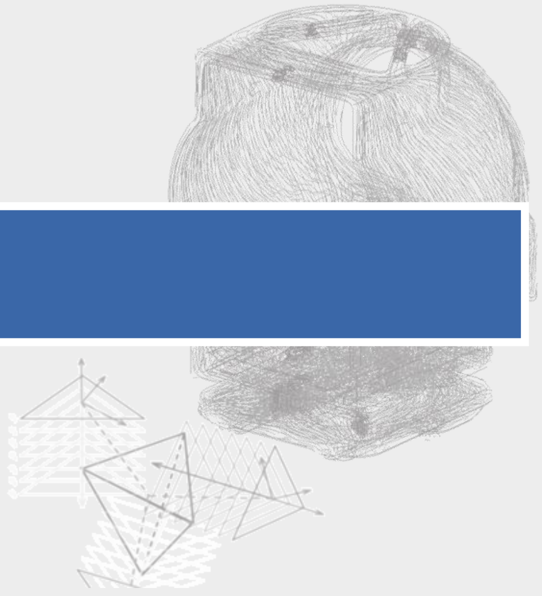
VALIMAT

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, ...

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

From test to material card

VALIMAT

plastics

engineering

production

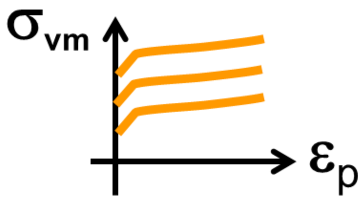
excellence in validation

concepts

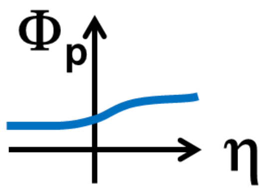
simulation

lightweight

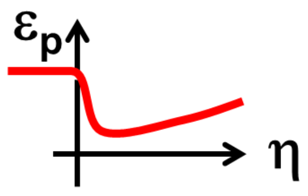
prototypes



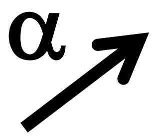
Hardening



Triaxiality



Damage/Failure



Anisotropic

Material data generation for simulation

Current Situation

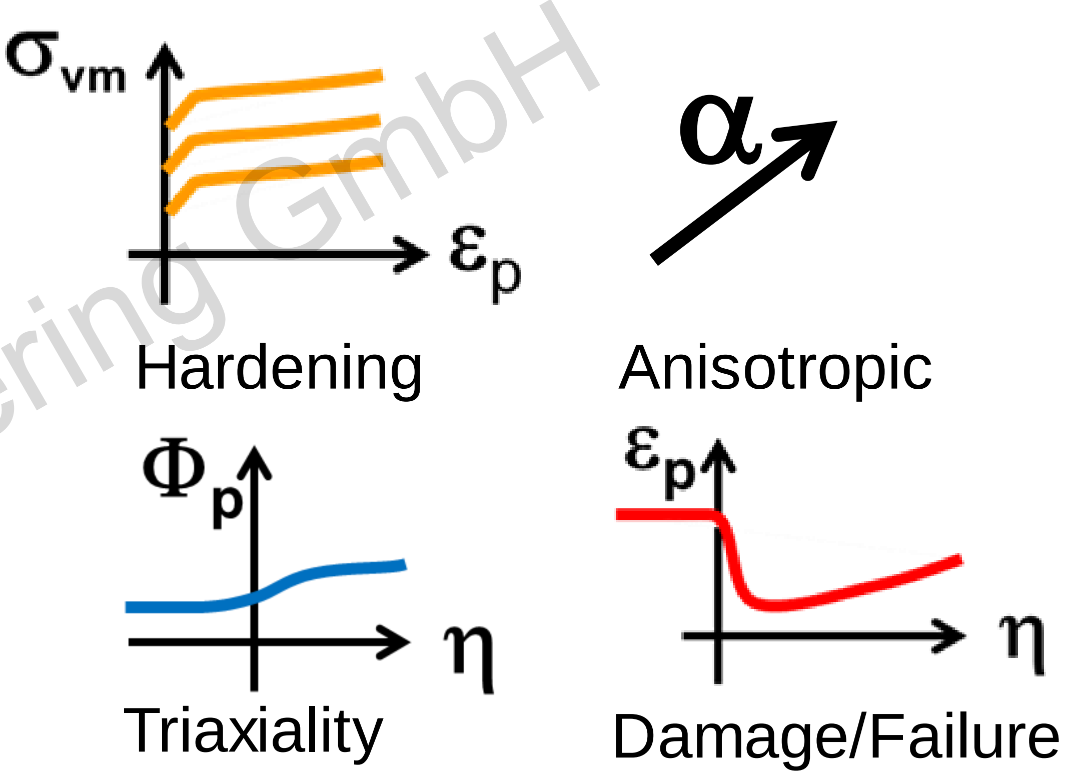
- more and more data
- Not only tension
  - Different loadcases (compression, shear, ….)
- More complex simulation models
  Investigations on failure

NEEDED

→ Smart USER INTERFACE

→ Optimization

→ DATABASE handling data

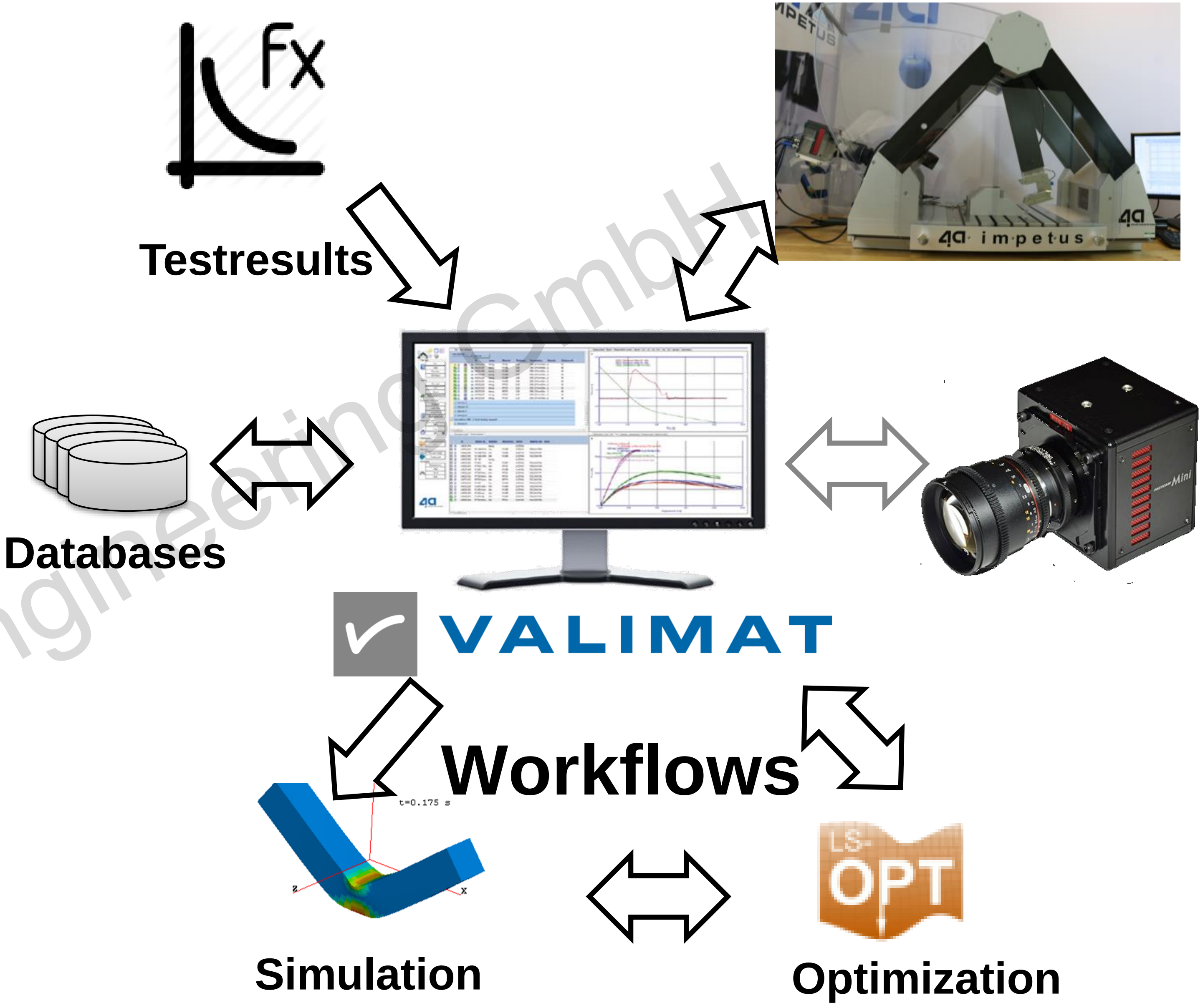


from test to material card

VALIMAT™

Advantage

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



Testresults

Databases

VALIMAT

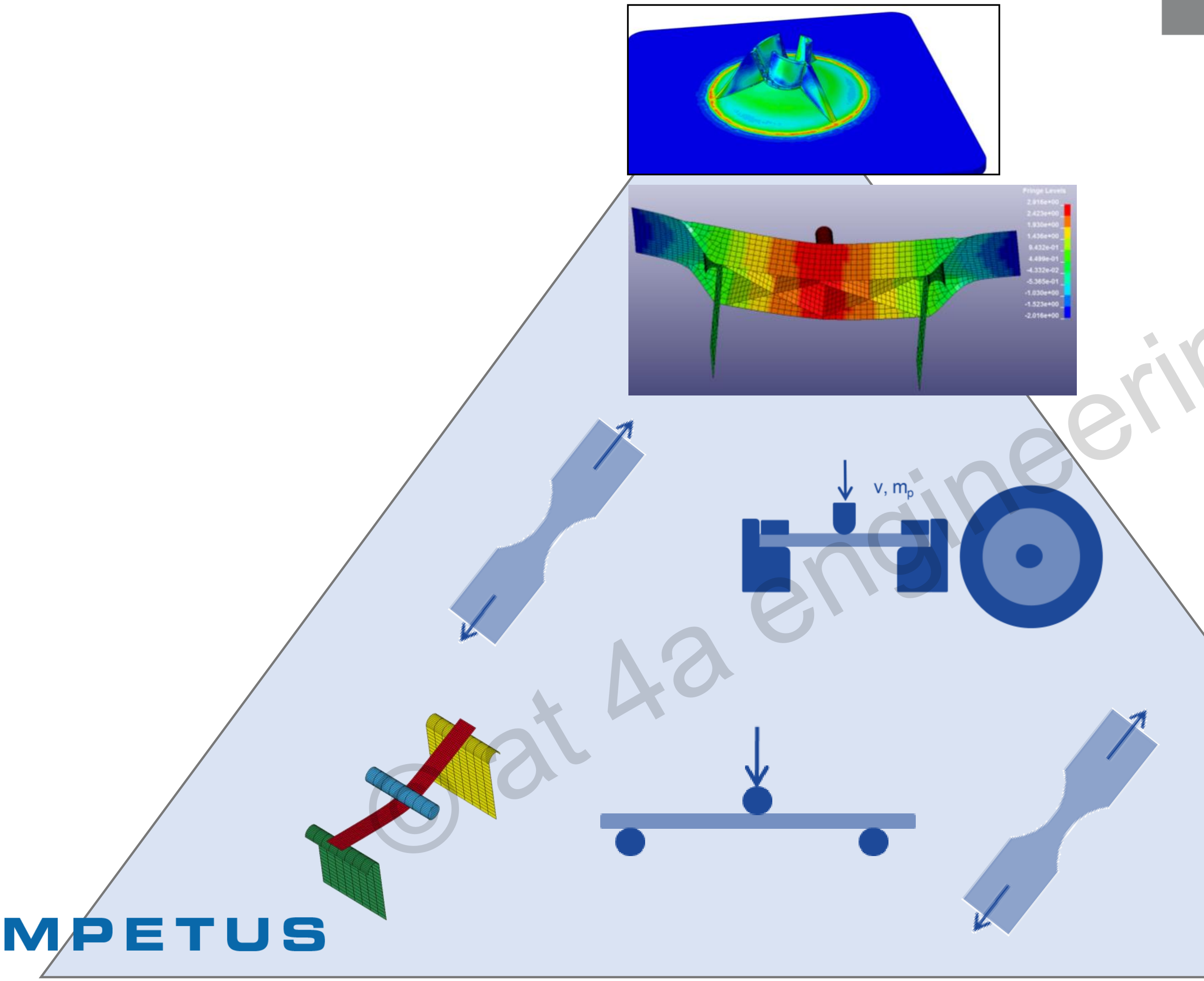
Workflows

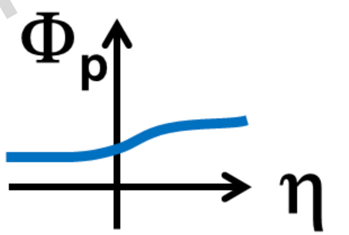
Simulation

Optimization

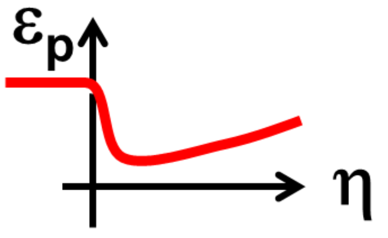
From test to material card

Deformation → Failure
Creep → Static → Crash
ISOTROPIC → ANISOTROPIC

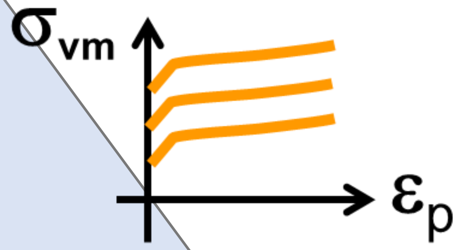




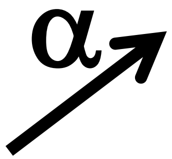
Triaxiality



Damage/Failure

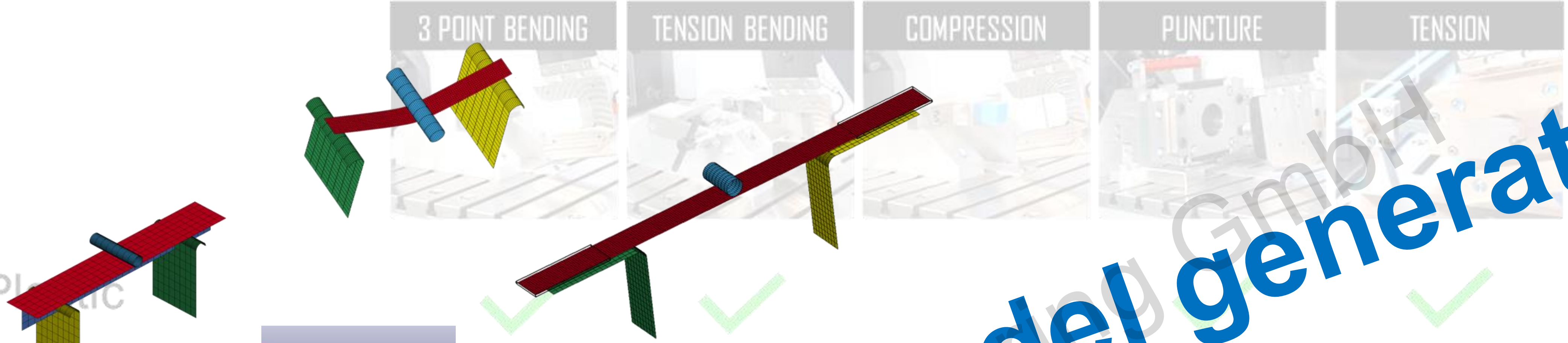


Hardening



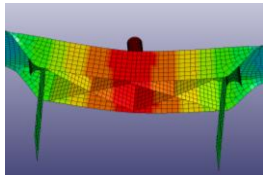
Anisotropic

Efficient dynamic testing

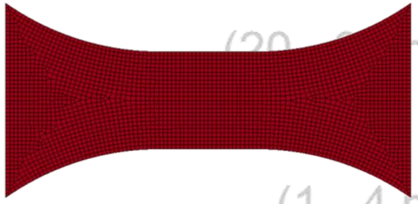


ypical
thickness

Pl ic (1 - 4 mm)



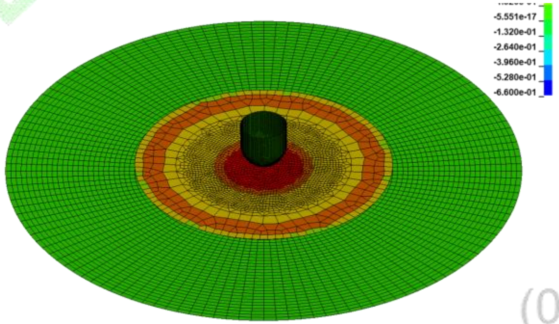
Foam (20 mm)

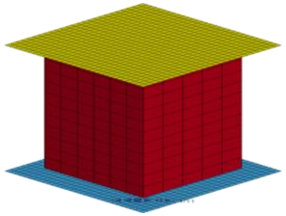


Composite (1 - 4 mm)

automated FE-model generation

VALIMAT



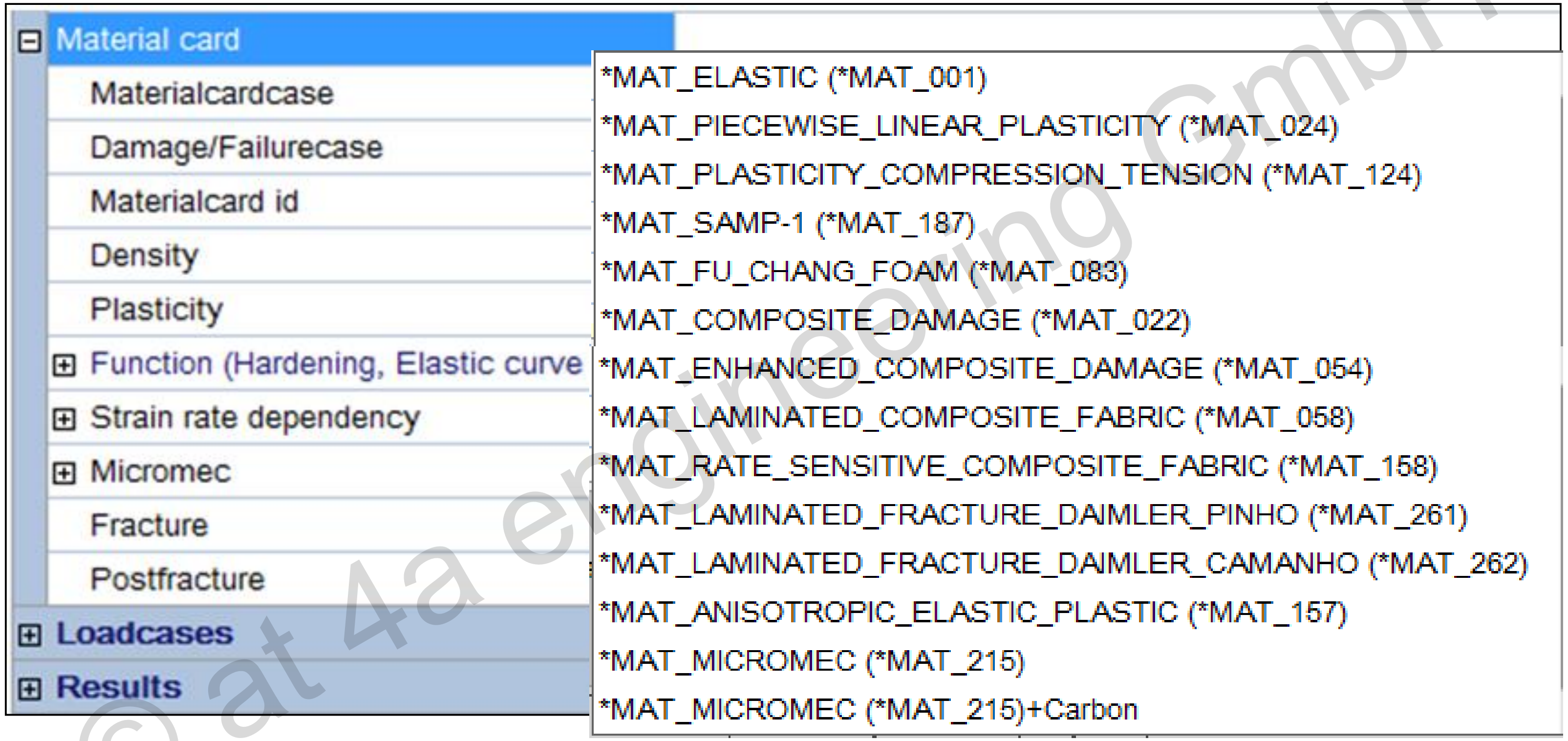


Alumin (1 – 2.5 mm)

Metals (0.5 – 1.5 mm)

Material models

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

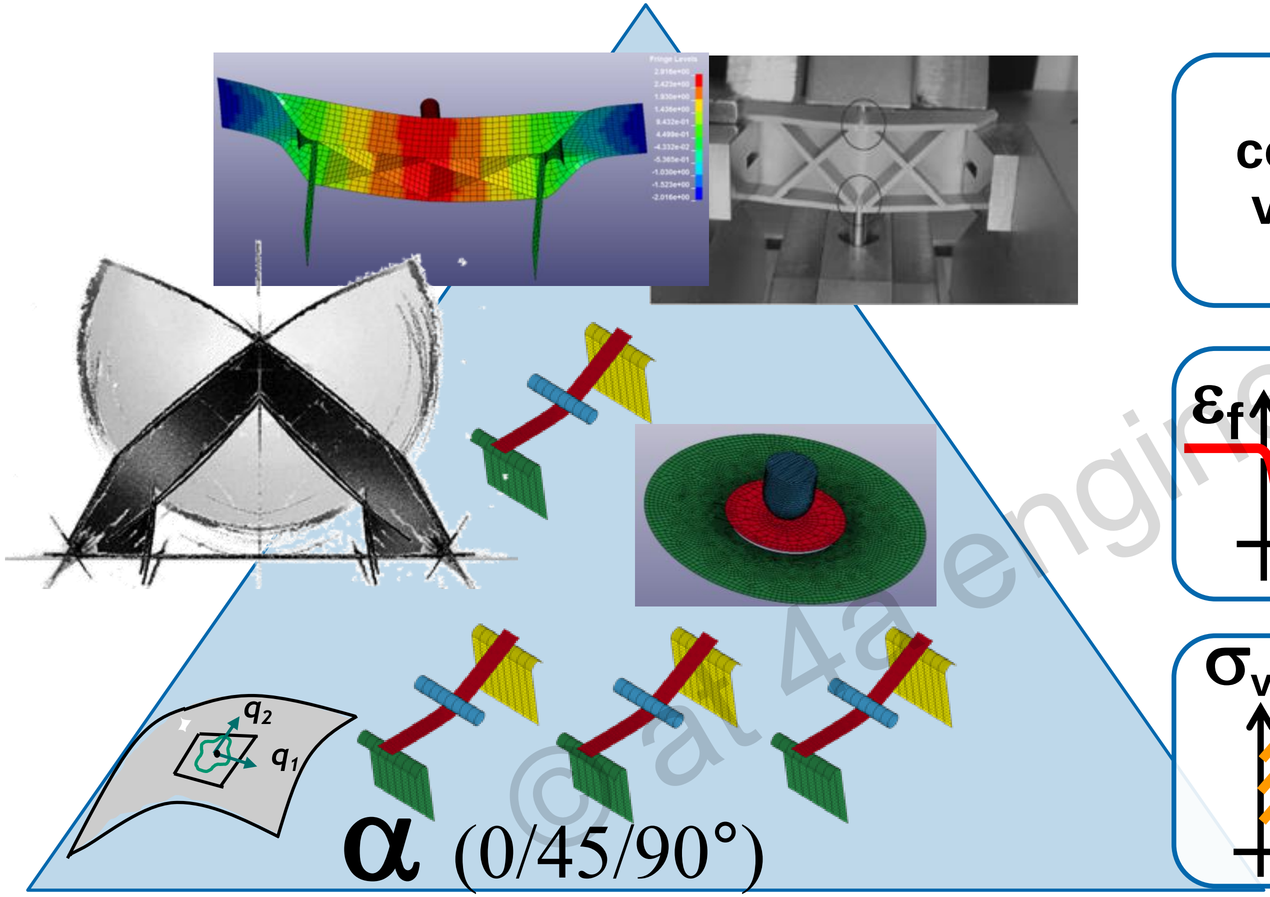


Material card
Materialcardcase
Damage/Failurecase
Materialcard id
Density
Plasticity
Function (Hardening, Elastic curve
Strain rate dependency
Micromec
Fracture
Postfracture
Loadcases
Results

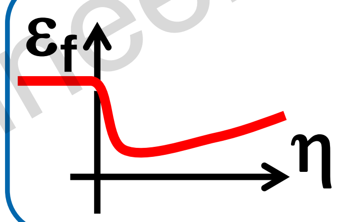
*MAT_ELASTIC (*MAT_001)
*MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_024)
*MAT_PLASTICITY_COMPRESSION_TENSION (*MAT_124)
*MAT_SAMP-1 (*MAT_187)
*MAT_FU_CHANG_FOAM (*MAT_083)
*MAT_COMPOSITE_DAMAGE (*MAT_022)
*MAT_ENHANCED_COMPOSITE_DAMAGE (*MAT_054)
*MAT_LAMINATED_COMPOSITE_FABRIC (*MAT_058)
*MAT_RATE_SENSITIVE_COMPOSITE_FABRIC (*MAT_158)
*MAT_LAMINATED_FRACTURE_DAIMLER_PINHO (*MAT_261)
*MAT_LAMINATED_FRACTURE_DAIMLER_CAMANHO (*MAT_262)
*MAT_ANISOTROPIC_ELASTIC_PLASTIC (*MAT_157)
*MAT_MICROMEC (*MAT_215)
*MAT_MICROMEC (*MAT_215)+Carbon

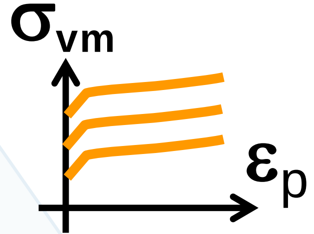
- ***Whole number*** of LS-Dyna material models is available through ***userdefined material cards***

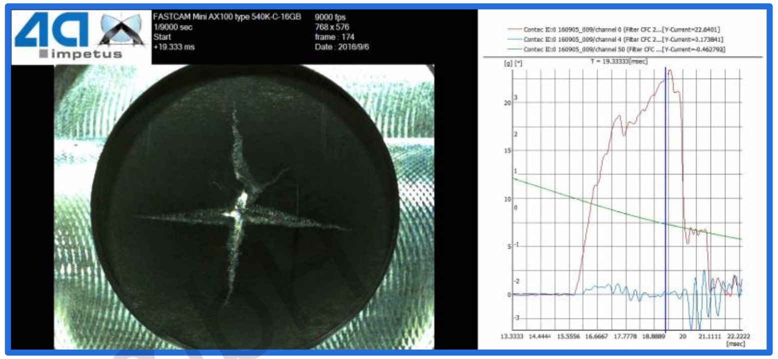
From test to material card

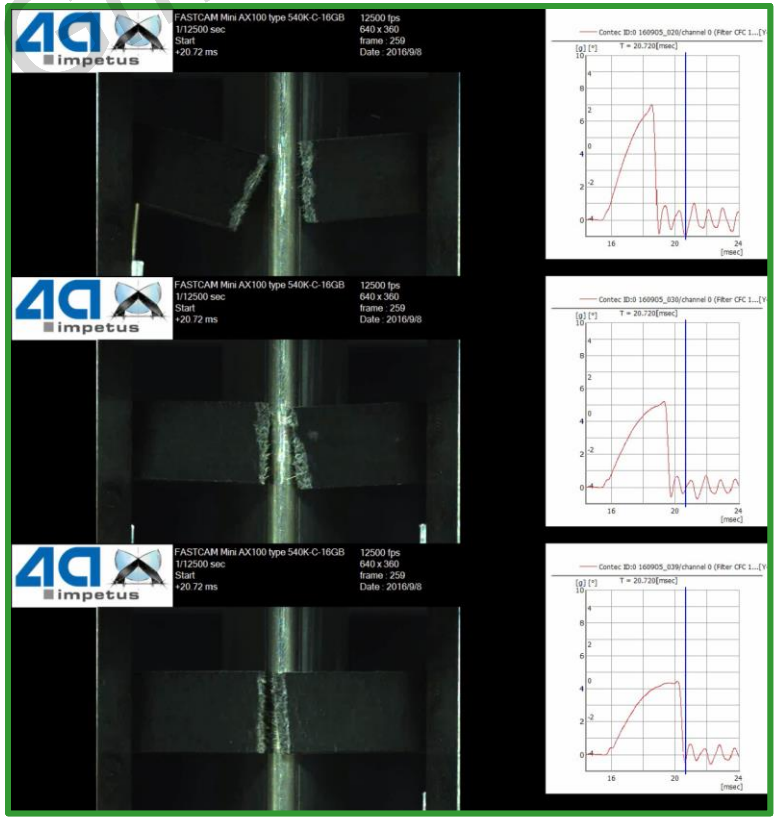


component validation



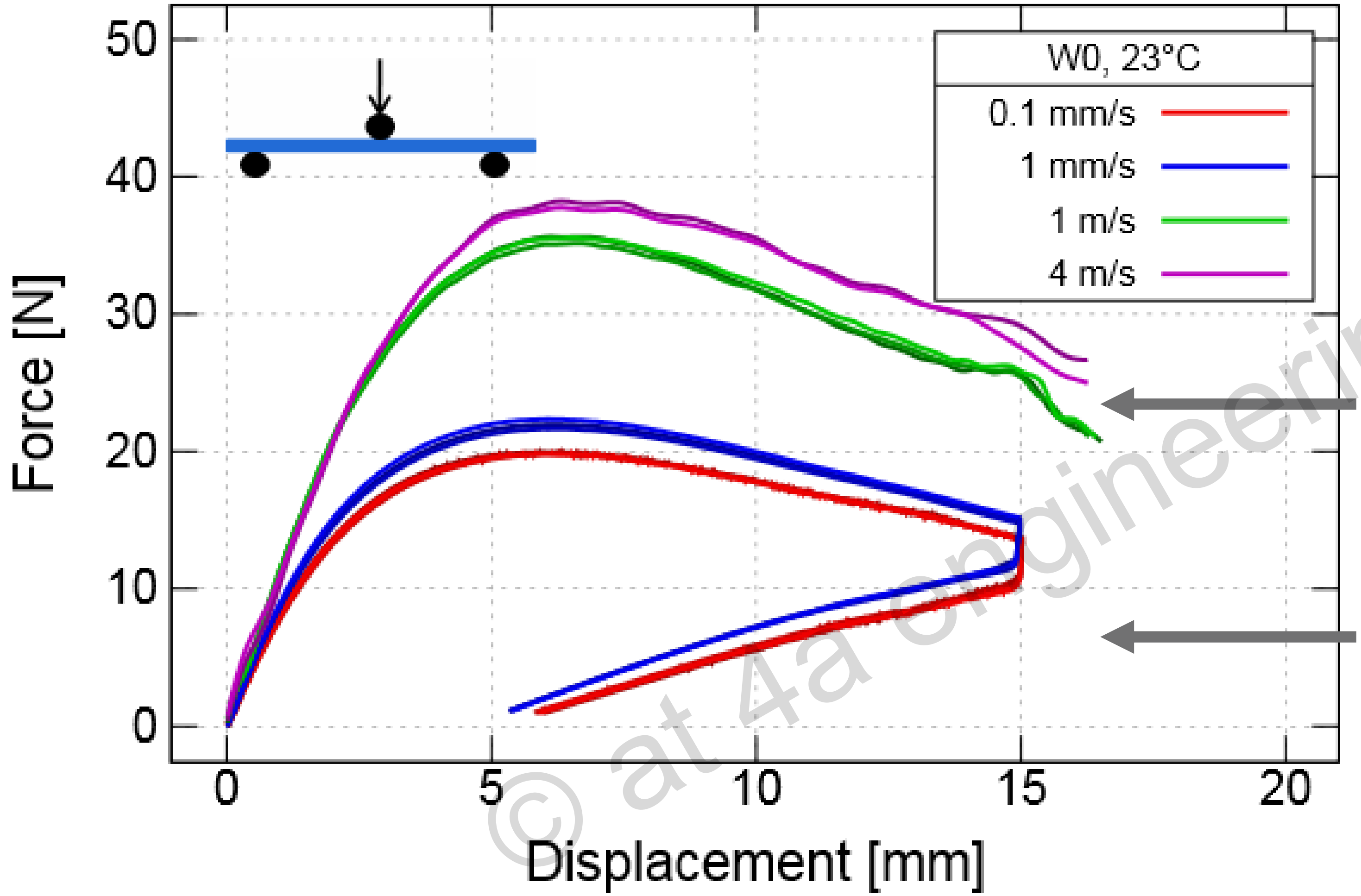






See more: P Reithofer, et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

Efficient dynamic testing



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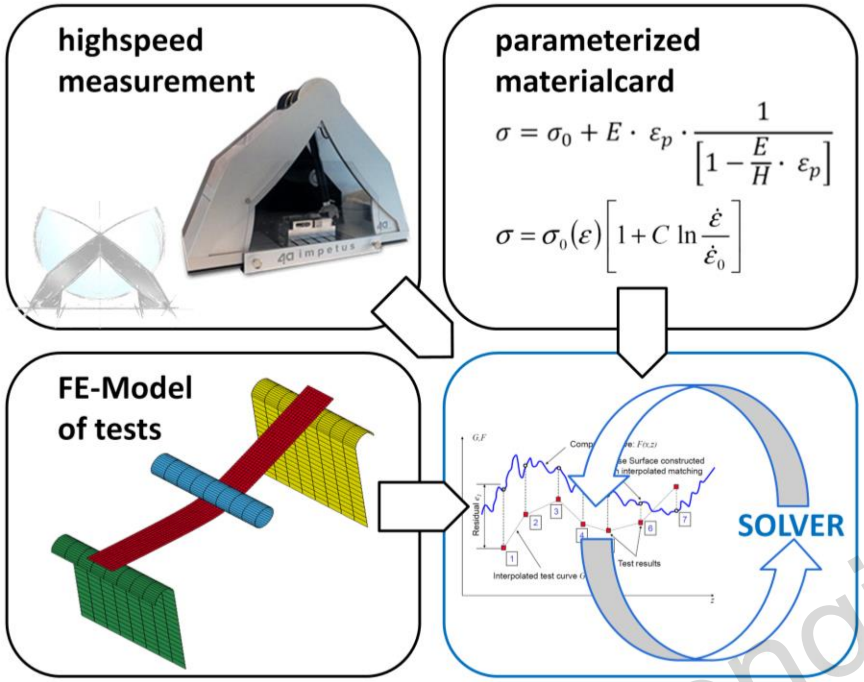
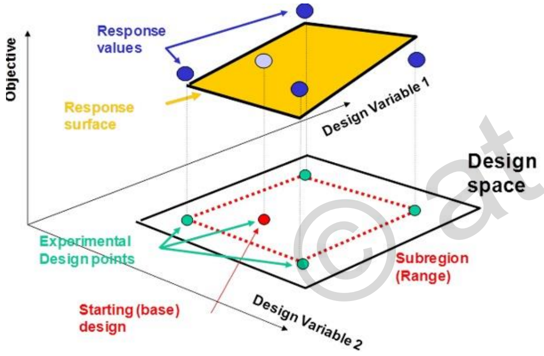
Universal static testing

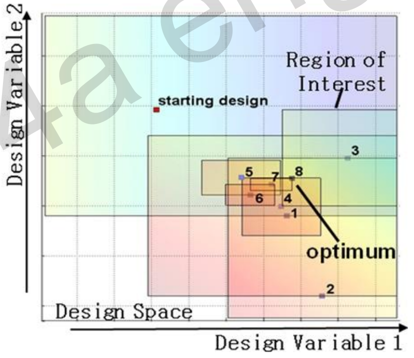
Reverse engineering

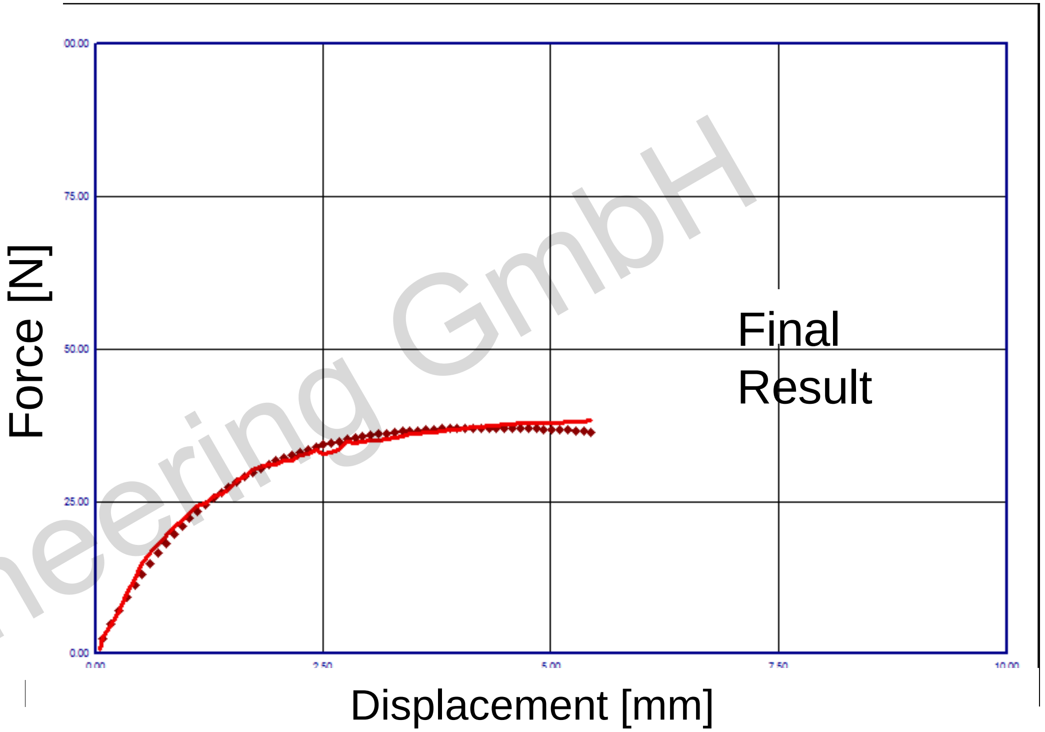


$$\sigma = \sigma_0 + E \cdot \varepsilon_p \cdot \frac{1}{\left[1 - \frac{E}{H} \cdot \varepsilon_p\right]}$$

$$\sigma = \sigma_0(\varepsilon)\left[1 + C \ln\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right]$$

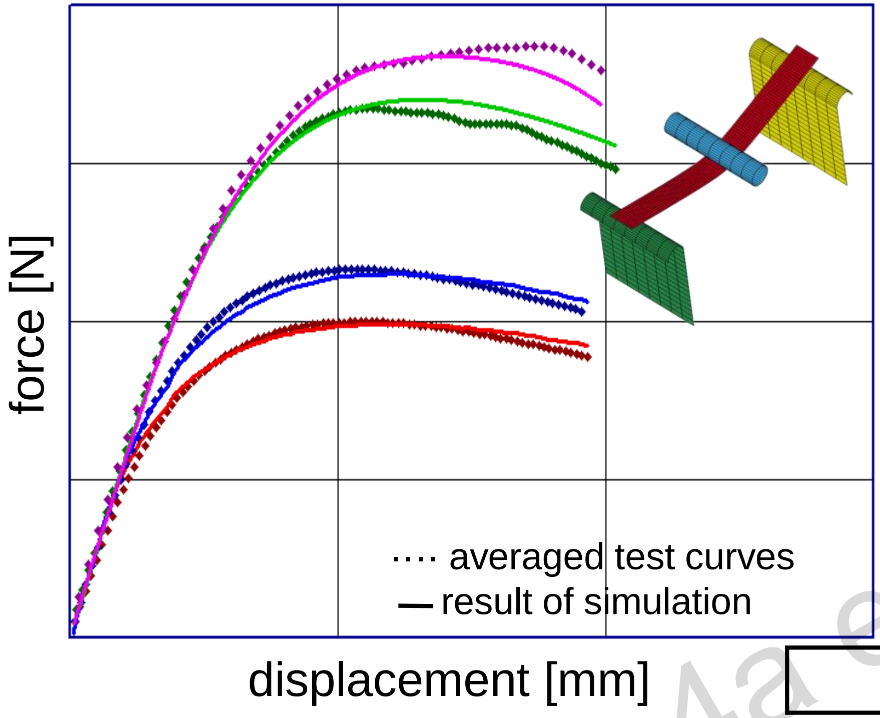




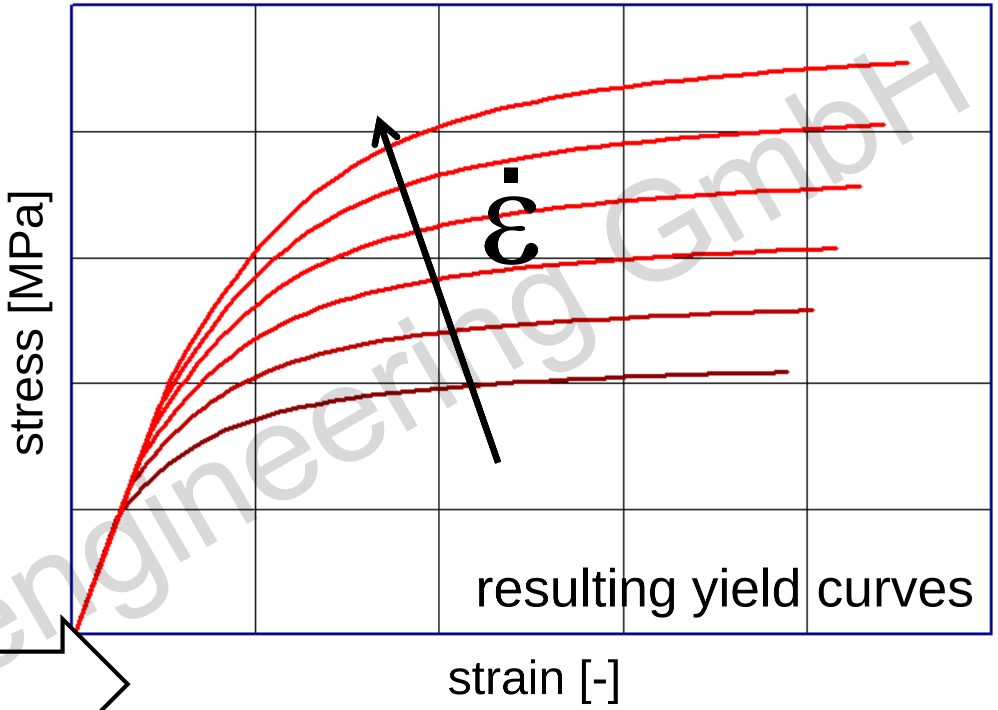


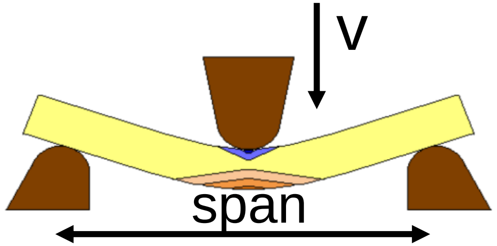
Source: Dynamic Material Characterization Using 4a impetus – PPS Conference 2015, Graz

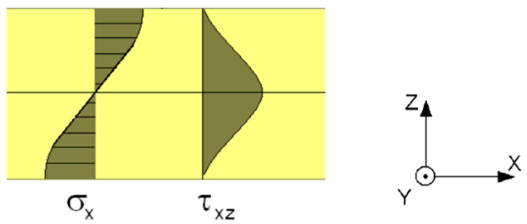
From bending → `*MAT_024`

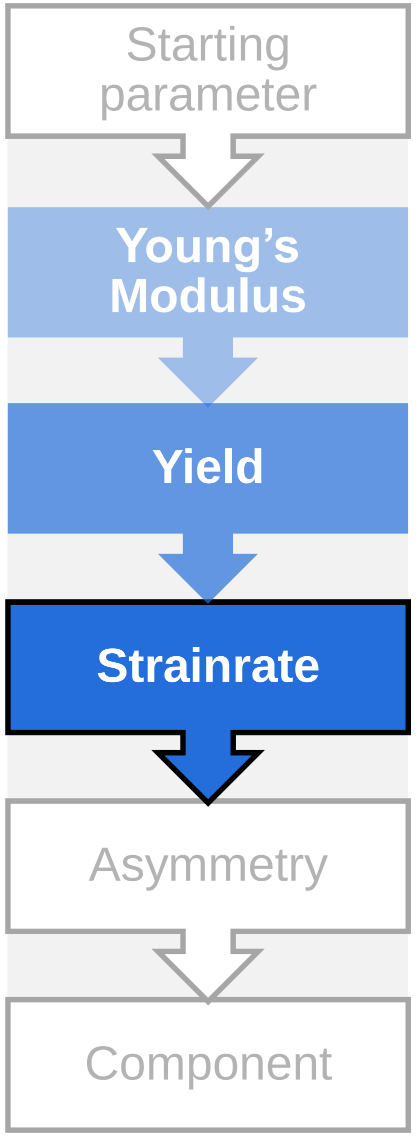


v [m/s]	span [mm]
0.0001	**40**
0.001	**40**
1	**40**
4	**40**









Starting parameter

Young’s Modulus

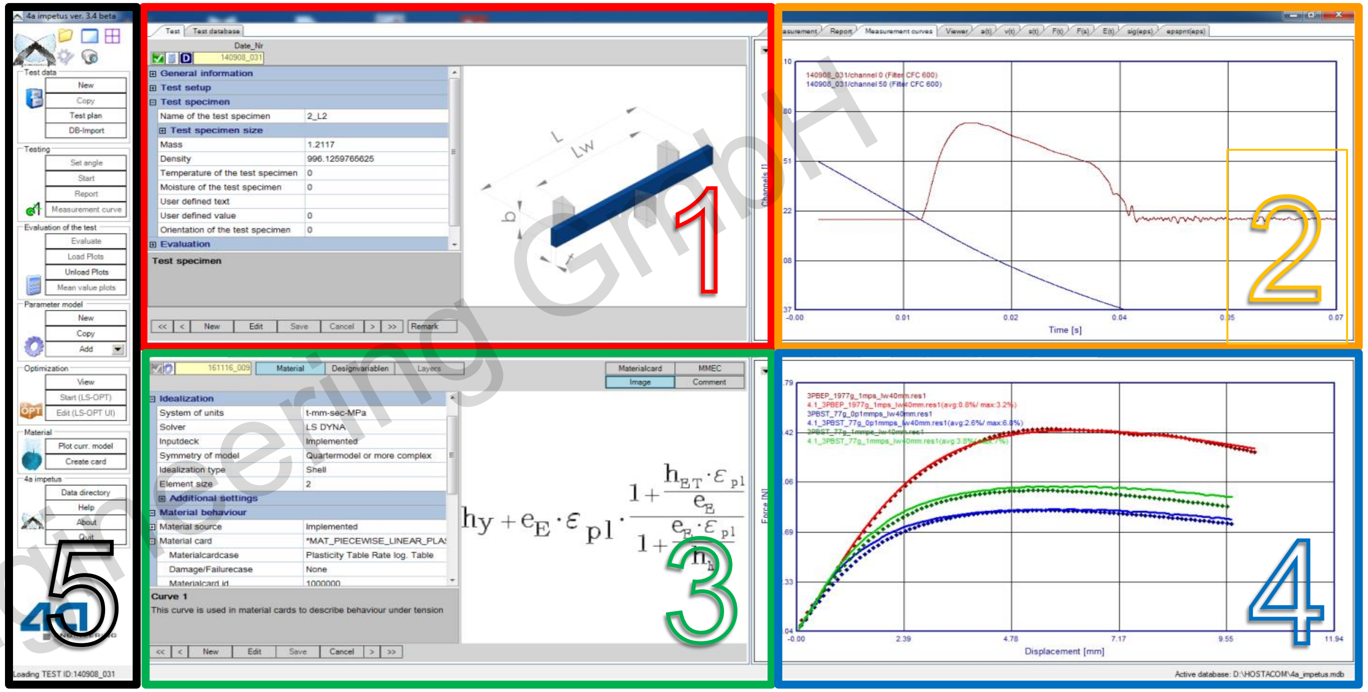
Yield

Strainrate

Asymmetry

Component

GUI - the graphic user interface is divided into five parts



Date_Nr: 140908_031

General information
Test setup
Test specimen

Name of the test specimen	2_L2
Test specimen size	
Mass	1.2117
Density	996.1259765625
Temperature of the test specimen	0
Moisture of the test specimen	0
User defined text	
User defined value	0
Orientation of the test specimen	0

Evaluation

Test specimen

161116_009 — Material | Designvariablen | Layers

Idealization

System of units	t-mm-sec-MPa
Solver	LS DYNA
Inputdeck	Implemented
Symmetry of model	Quartermodel or more complex
Idealization type	Shell
Element size	2
Additional settings	
Material behaviour	
Material source	Implemented
Material card	*MAT_PIECEWISE_LINEAR_PLA
Materialcardcase	Plasticity Table Rate log. Table
Damage/Failurecase	None
Materialcard id	1000000

Curve 1

This curve is used in material cards to describe behaviour under tension

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.

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VALIMAT

SEMINAR AGENDA

10:00 - 10:45 INTRODUCTION

Material behavior for plastics

Introduction to VALIMAT™ - workflow for generating material cards

10:45 - 12:15 IMPETUS™ HANDS ON

Hardware introduction and hands on testing

13:15 - 14:45 VALIMAT™ HANDS ON

Evaluation of test data and organizing databases

AUTOFIT: *MAT_024 parameter identification using the new feature

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Parameter identification:

- for yield surface and flow rule i.e. *MAT_187
- for damage and failure i.e. *MAT_ADD_EROSION

Outlook on upcoming material models

15:30 - 16:30 Q&A

4a ENGINEERING

In cooperation with

JSOL CORPORATION AR BROWN Think Quality & Create Value

Efficient dynamic testing

IMPETUS

plastics

engineering

production

excellence in

HANDS ON

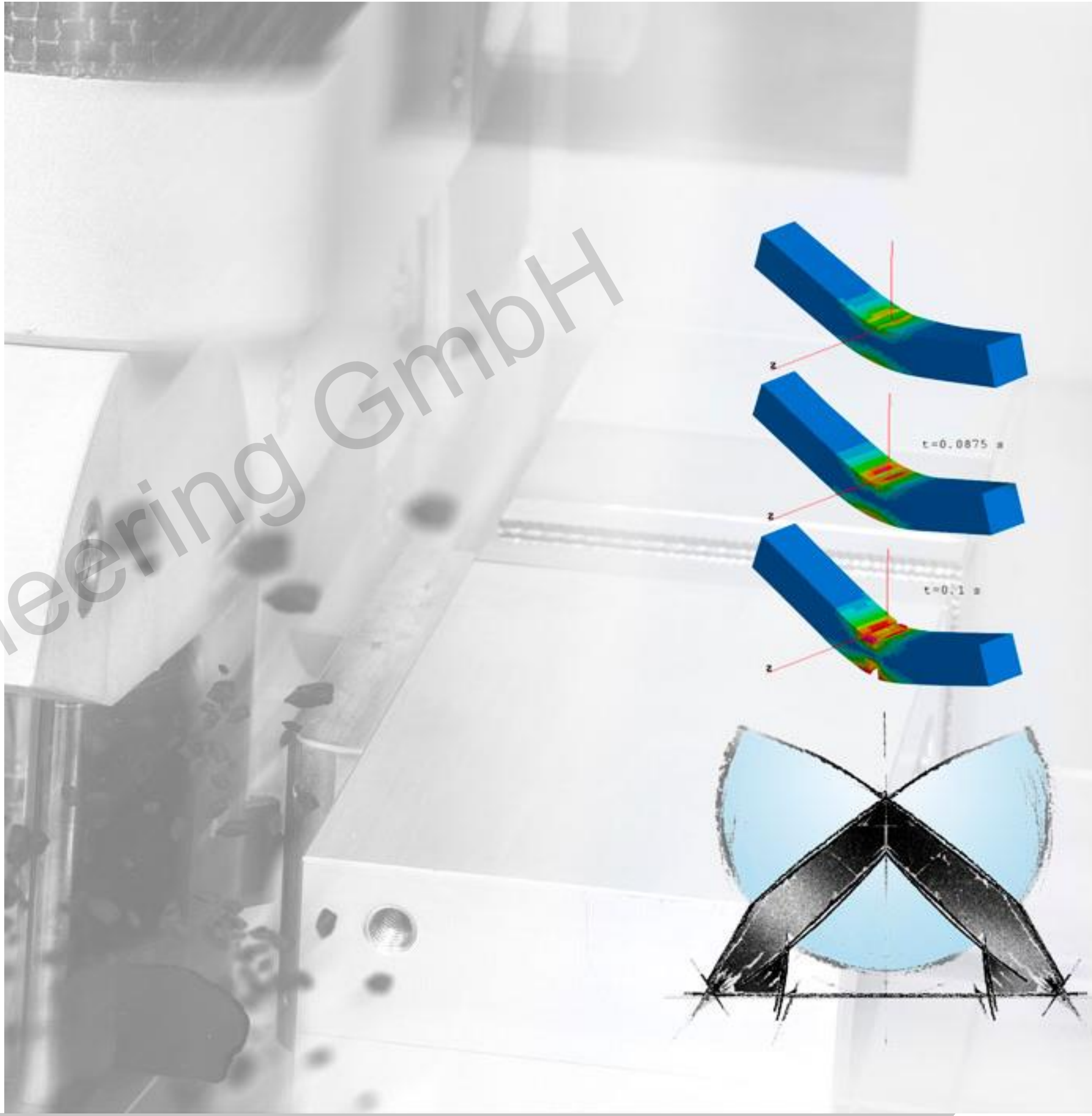
testing

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

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■ ■ ■

IMPETUS™ data specification

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

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

Photron High Speed Camera data specification

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

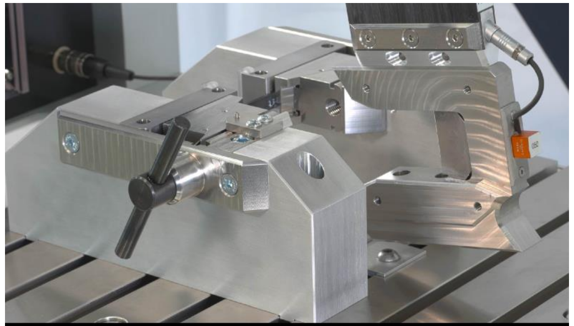
Vision Devices lighting data specification

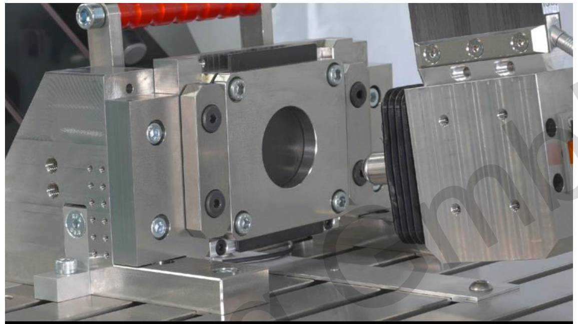
LED VD7000

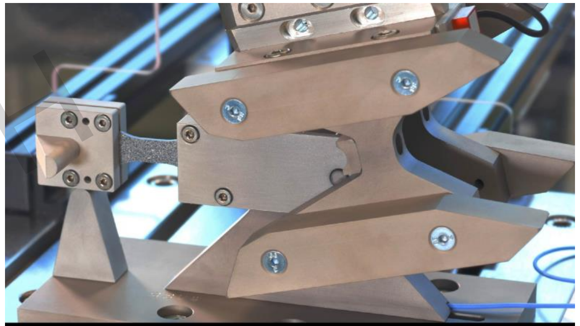
operating voltage	24 - 36	V
rated power	17 - 72	W
Luminous flux	2100	lm
Luminous flux boost	7280	lm
color temperature	6000	K
L x W x H	100 x 46 x 46	mm

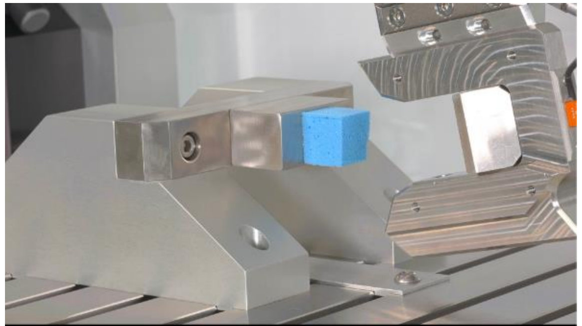
IMPETUS™ - configurations


3 POINT BENDING

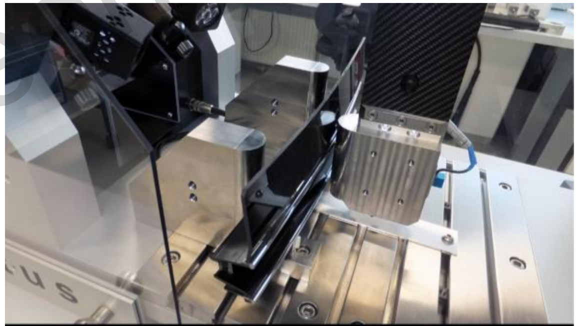

TENSION BENDING


PUNCTURE TEST


TENSION TEST


COMPRESSION TEST


SAMPLE MAGAZIN

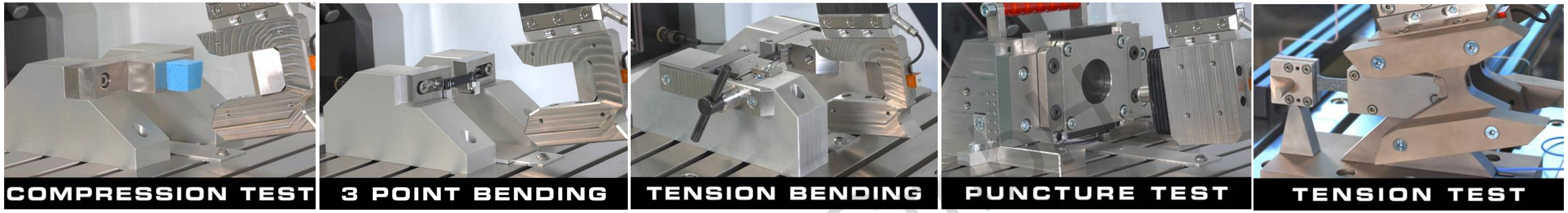

COMPONENT TEST

BASIC

STANDARD

PROFESSIONAL

Efficient dynamic testing



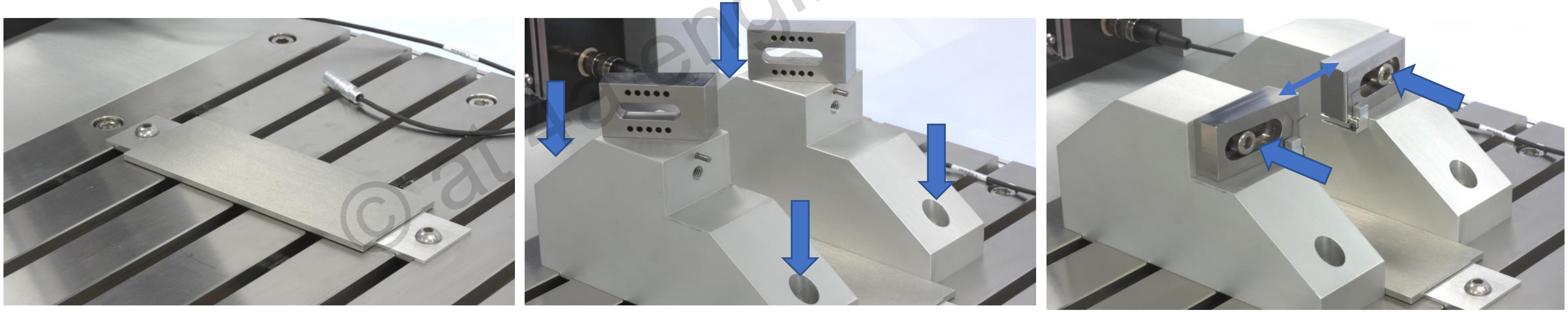
Material *(Typical thickness)*	COMPRESSION TEST	3 POINT BENDING	TENSION BENDING	PUNCTURE TEST	TENSION TEST
Plastic *(1 - 4 mm)*		✓	✓	✓	✓
Foam *(20 - 30 mm)*	✓	~			
Composite *(1 - 4 mm)*		✓		✓	
Aluminum *(1 – 2.5 mm)*		✓	✓		✓
Metals *(0.5 – 1.5 mm)*		✓			

More details on delivery of test setups

C_3PB – 3-point bending

YouTube setup video; highspeed video testing

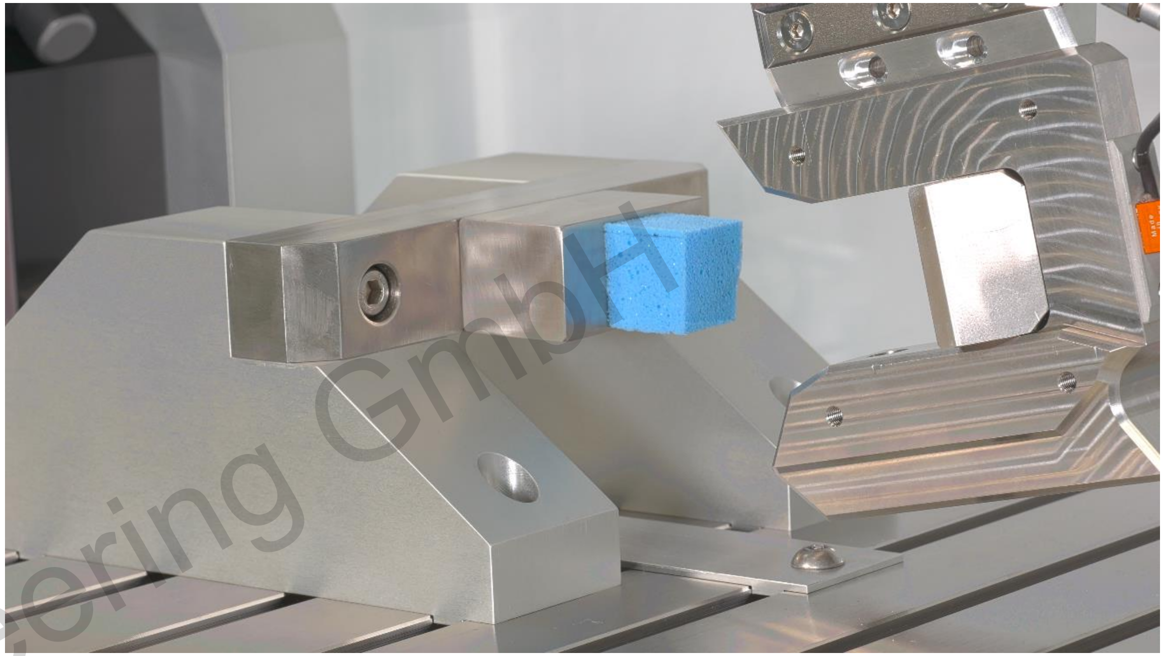
- Put the distance plate in the testing room
- Place the two counter bearings on the T-nut field and fix it with 4 screws
- Set the desired support distance and fix it with two screws at the front



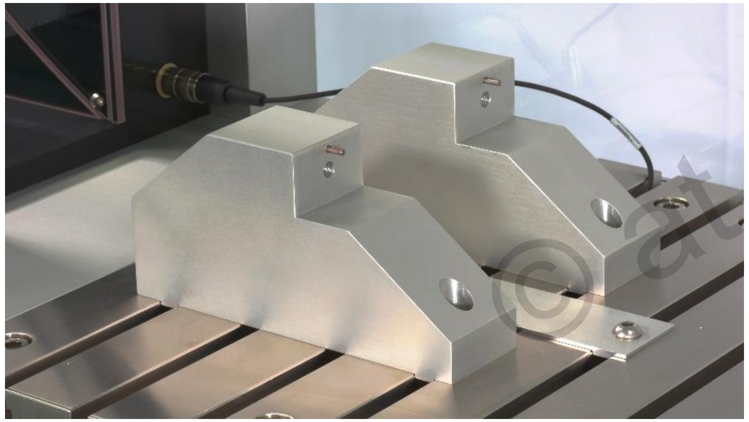
C_3PB - standard setup 3 point bending

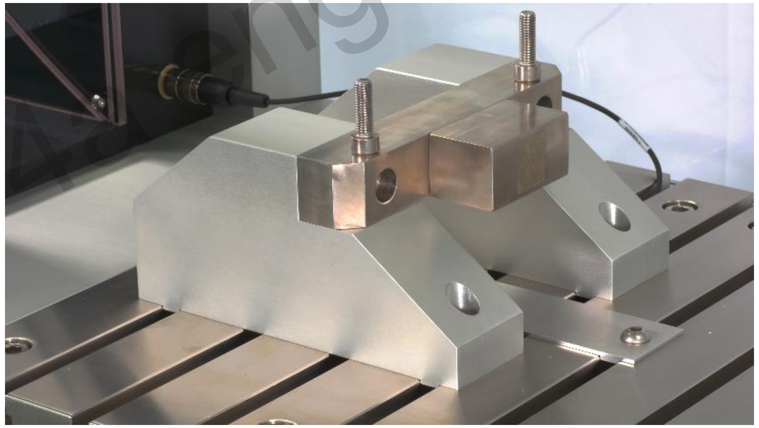
C_CT - compression test

YouTube setup video; highspeed video testing



- Use the counter bearings from the 3-Piont-Bending
- Fix the compression beam with 2 crews on the counter bearings
- Fix one steel block in the middle of the compression beam to adjust the specimen high
- Fix the test piece with a double-sided adhesive tape on the counter bearing



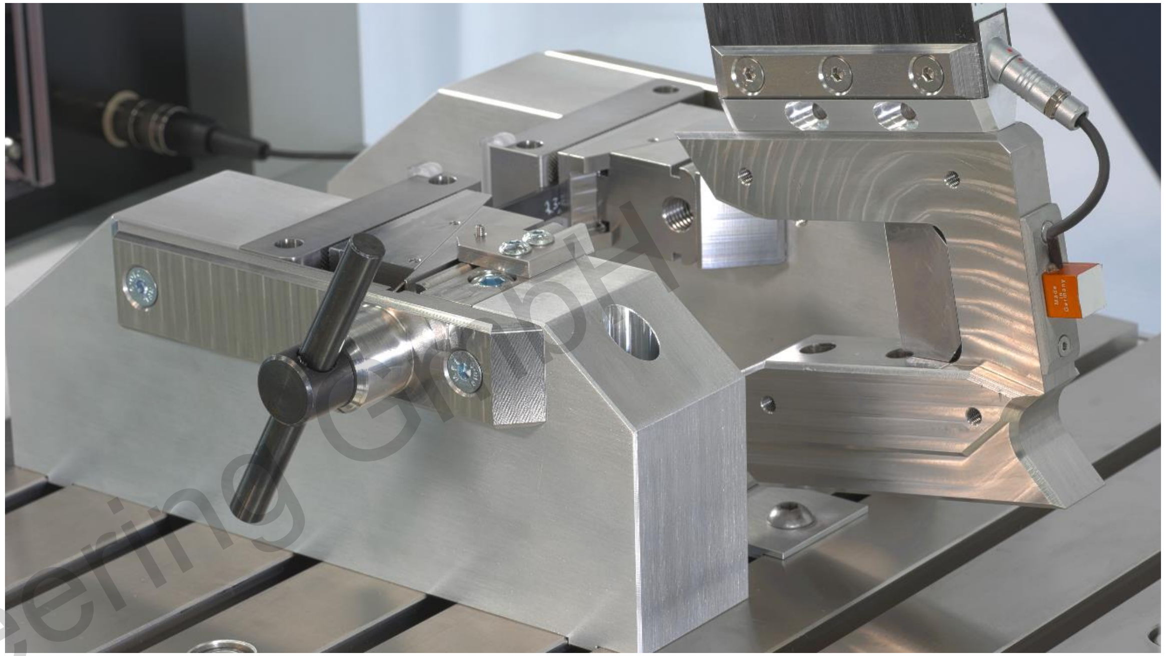


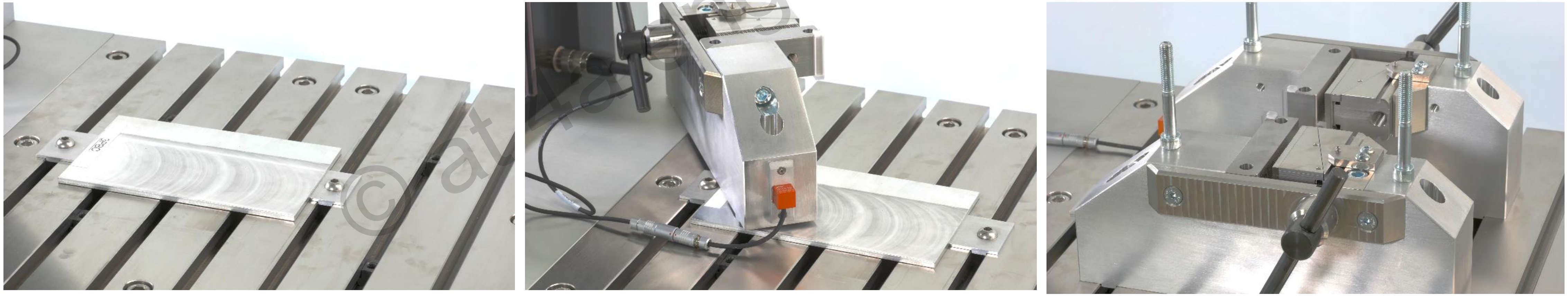
C_CT - standard setup compression test

C_3PBC - Tension Bending

YouTube setup video; highspeed video testing

- Put the distance plate in the testing room
- Fix the sensor on the counter bearing
- Place the two counter bearings on the T-nut field and fix it with 4 screws



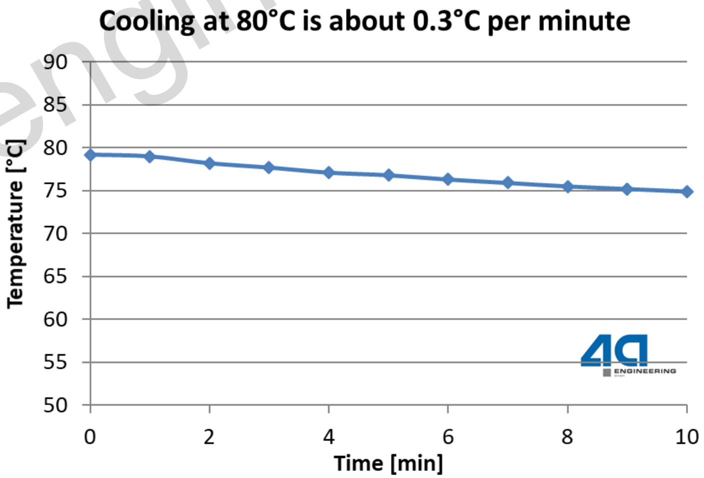


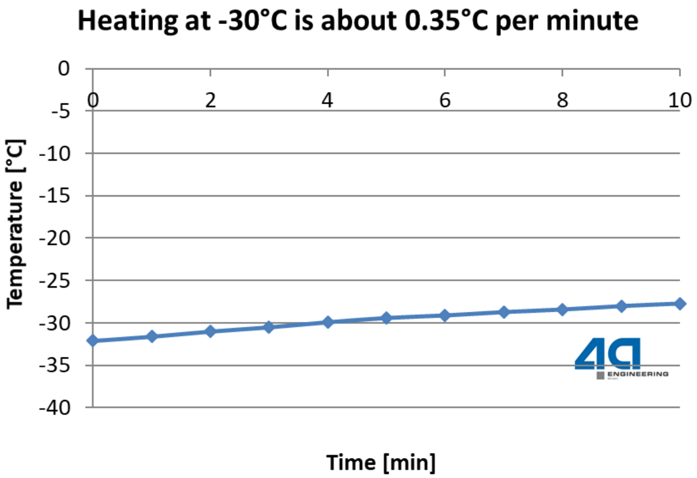
C_3PBC - standard setup tension bending

4a sample magazine

YouTube testing video

- Use the 4a sample magazine to perform temperature-based measurements from **-40°C** to **+90°C**
- With the 4a sample magazine each test can be conducted within **10 - 15 seconds**

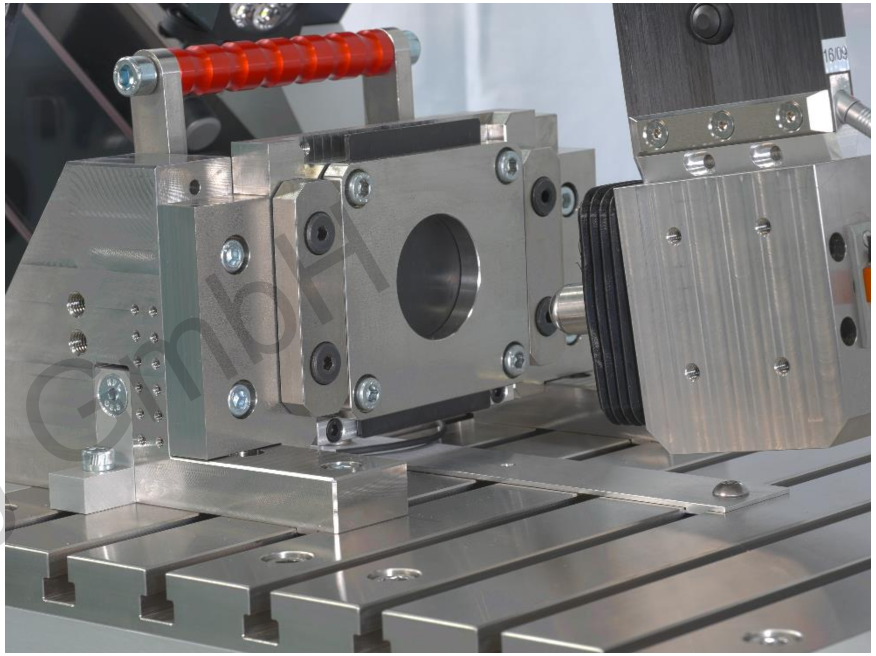

Cooling at 80°C is about 0.3°C per minute

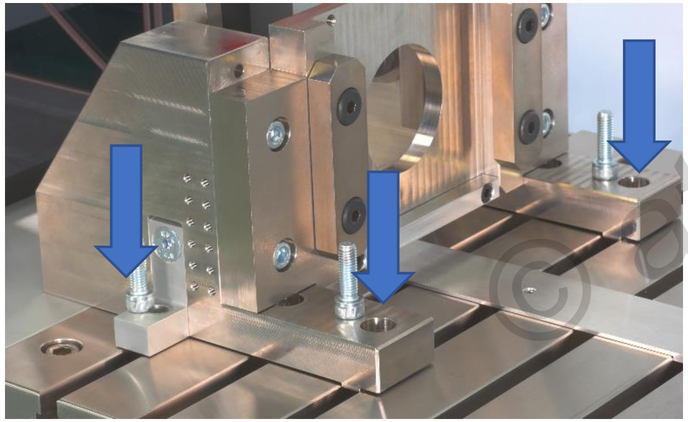

Heating at -30°C is about 0.35°C per minute

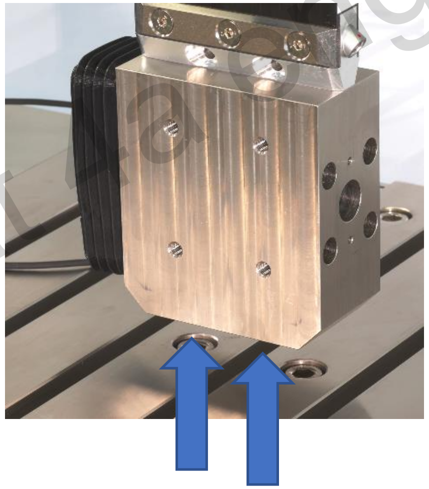
C_PT - Puncture test

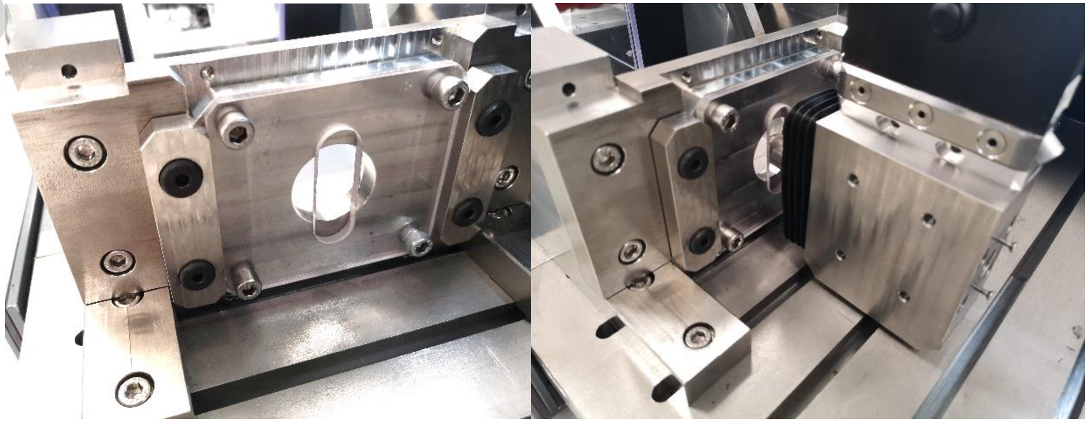
YouTube setup video; highspeed video testing

- Fix the Puncture-Test with 4 screws on the testing field (in the first step, the screws are not tightened to be able to move Puncture-Test sideways)
- Attach the pendulum head to the pendulum arm with 2 screws from the bottom up
  - For this purpose, the pestle must be removed from the pendulum head
- Now you center the counter bearing to the pendulum arm by using the centering plate mounted on a Puncture-Test insert-plate
- Then tighten the 4 screws in the T-nuts to fix the puncture test







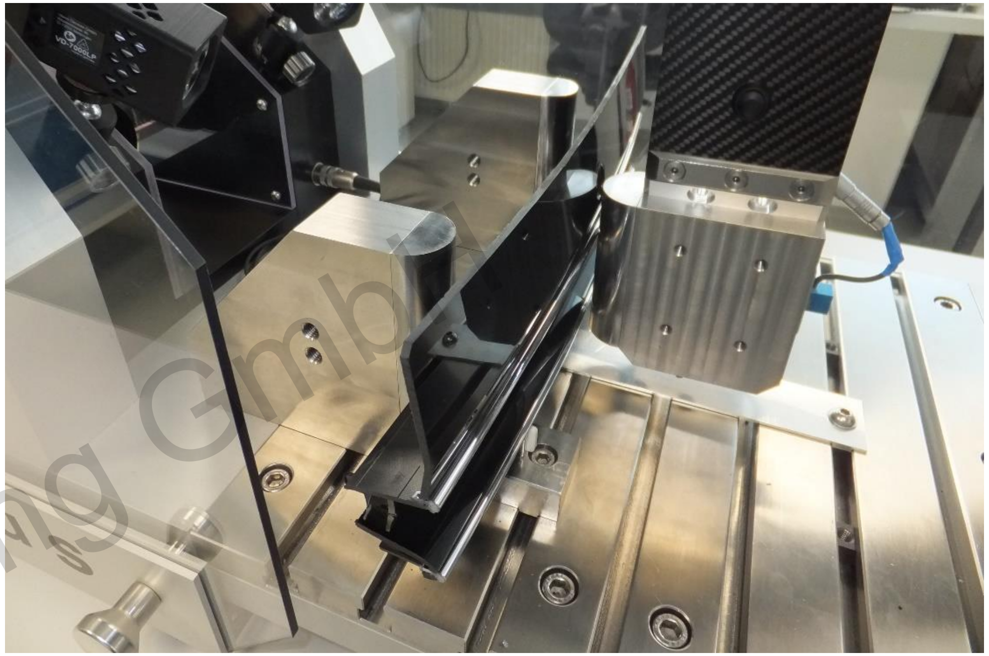


C_PT - additional setup puncture test (case 1/2)

C_PT - additional setup puncture test (case 2/2)

C_COT - component test

- Use the counter bearings from the Puncture-Test
- Remove the red handle from the counter bearing
- Mount the bending radius with the appropriate spacers to hit your component at about 0°
- Mount the fin on the pendulum head of the Puncture-Test

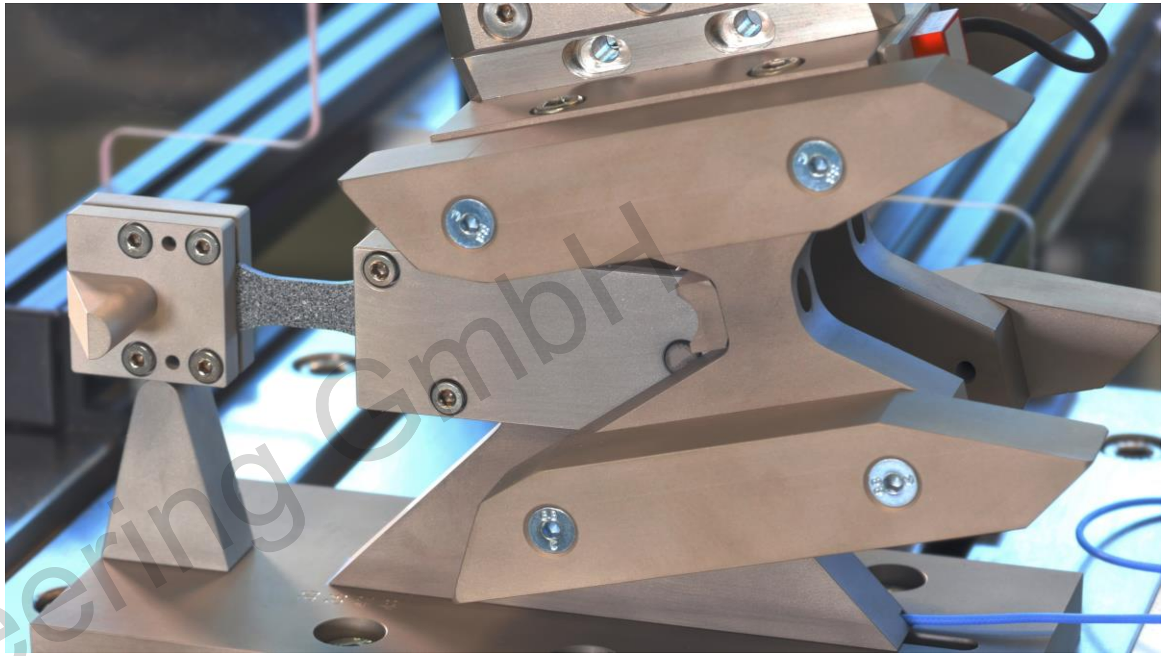


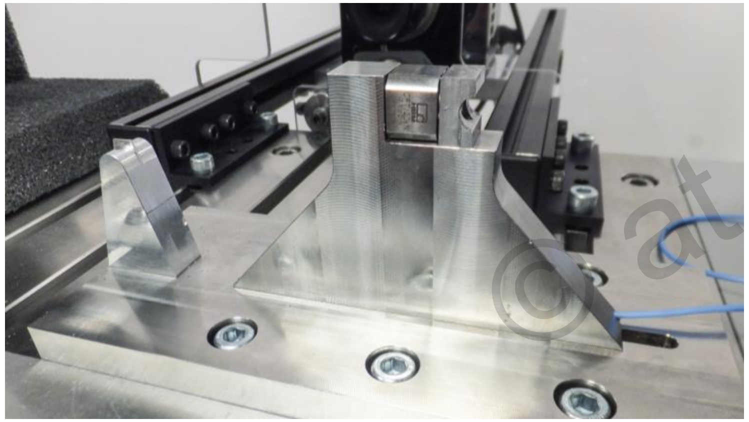
C_COT - additional setup component test

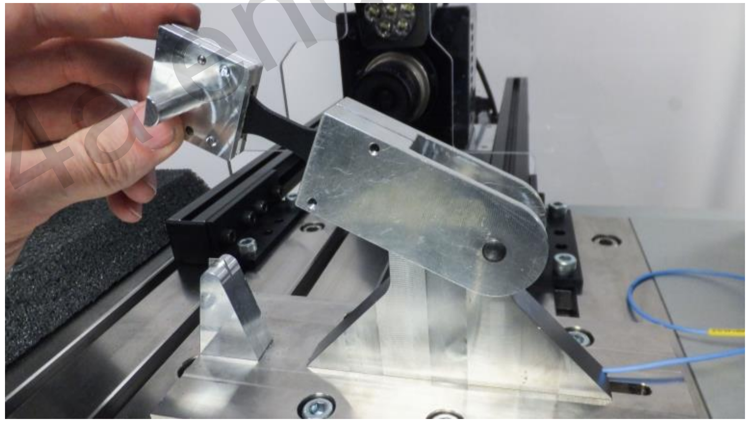
C_DTT – dynamic tensile test

YouTube setup video; highspeed video testing

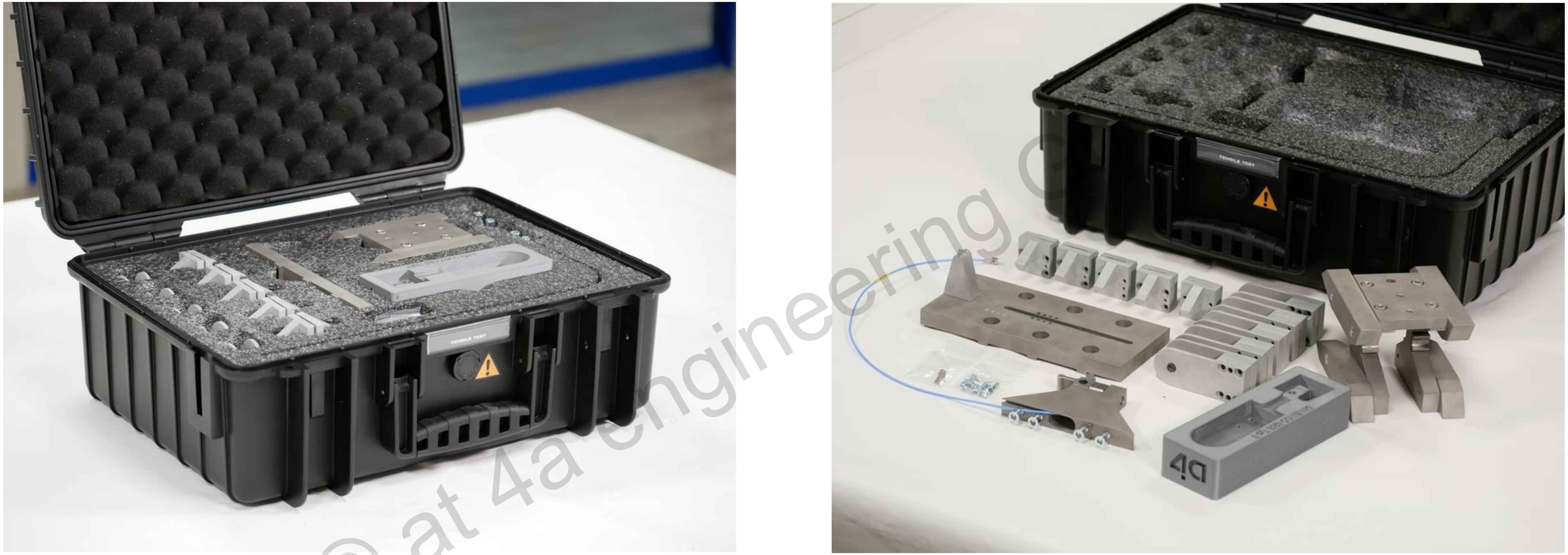
- Place the counter bearing with the load cell on the T-nut field and fix it with 6 screws
- Hang the clamped specimen in the load cell and set it down





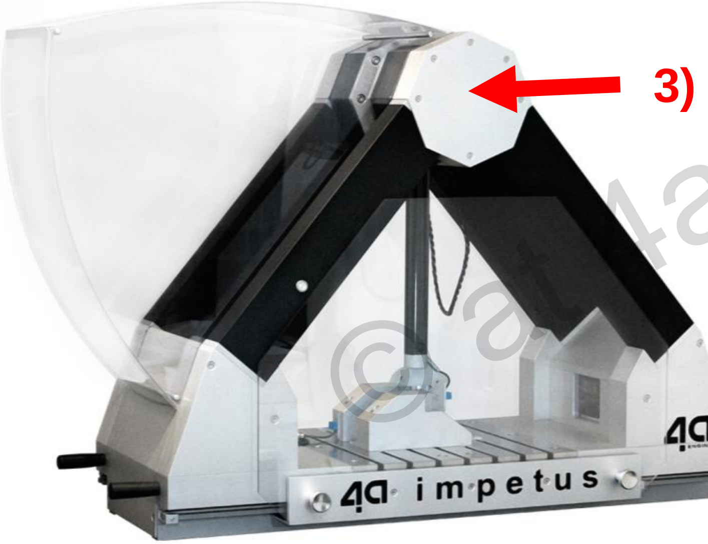


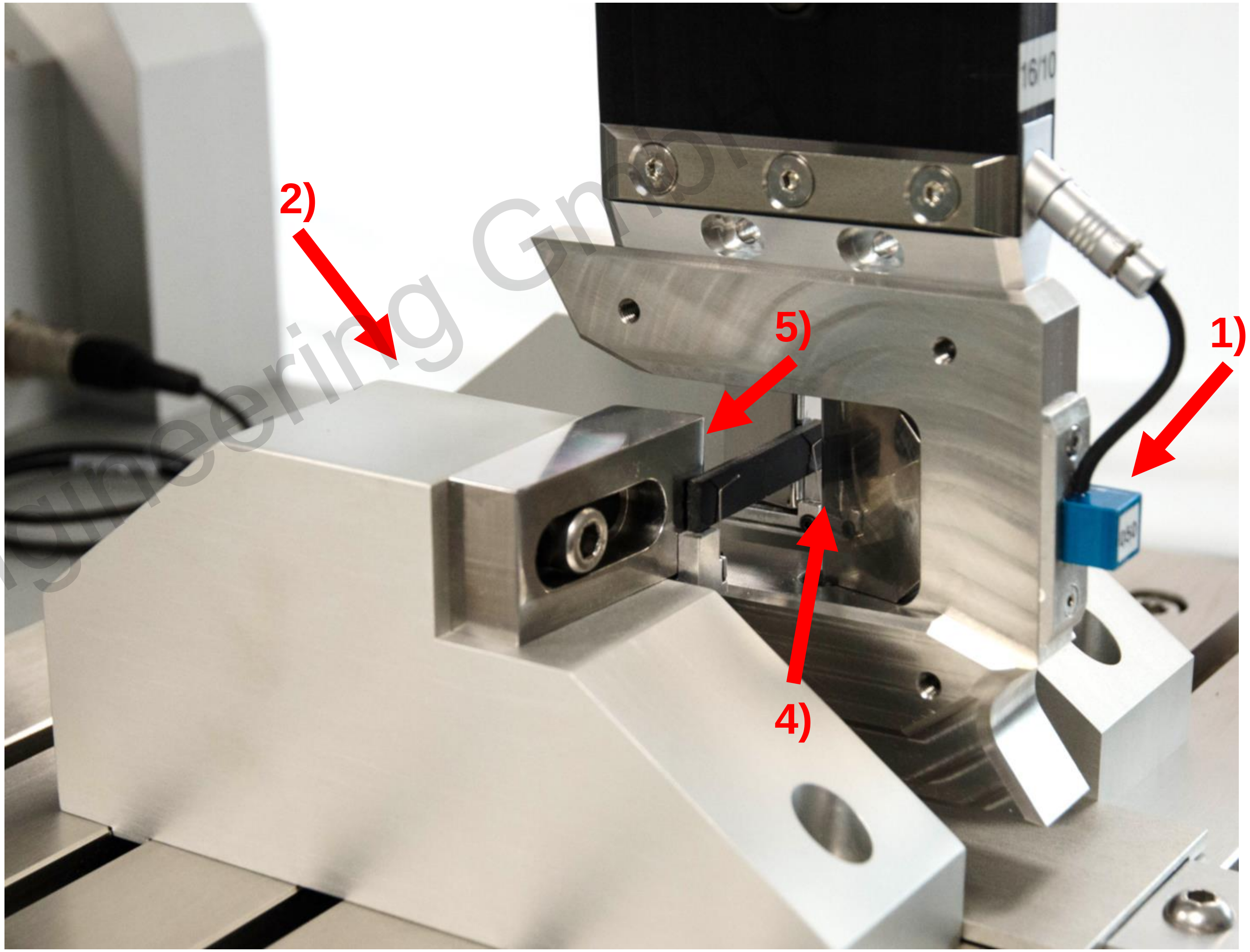
C_DTT – dynamic tensile test



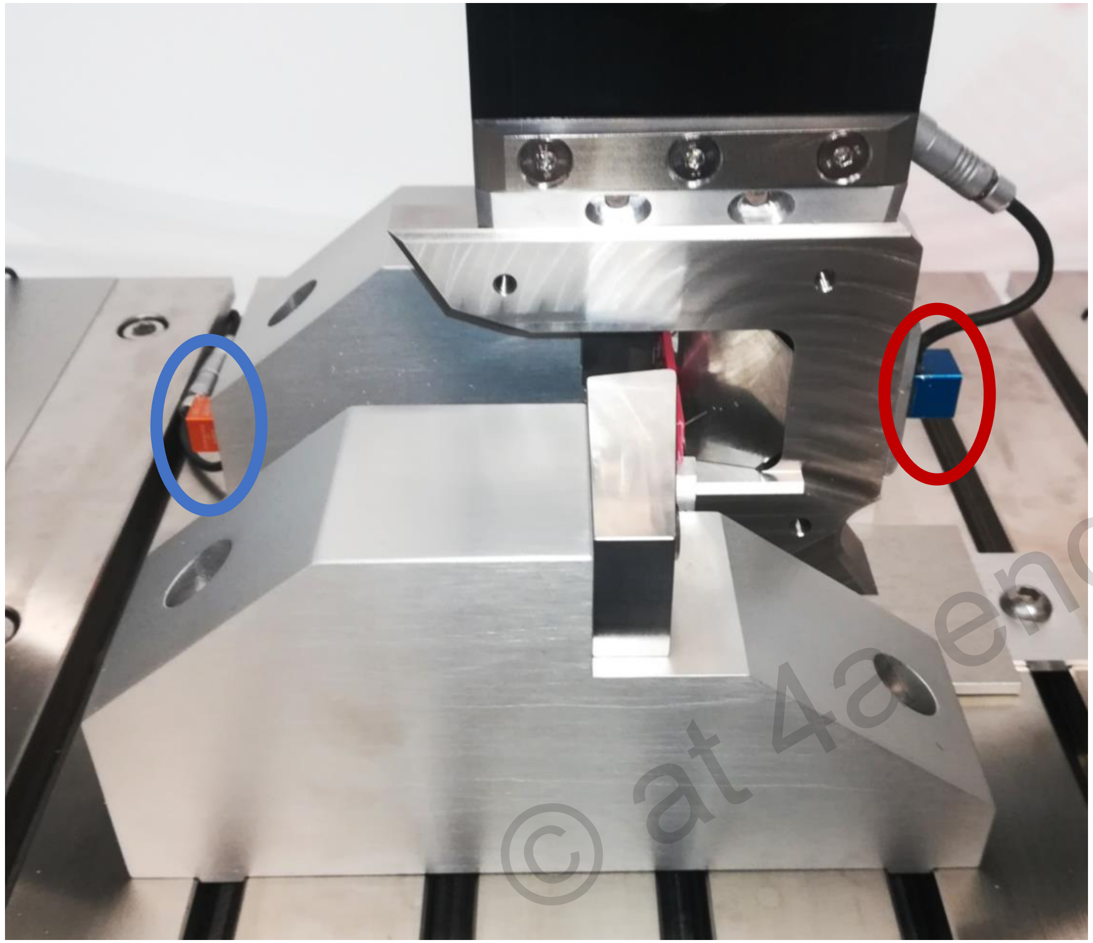
Test setup – IMPETUS 3-Point-Bending

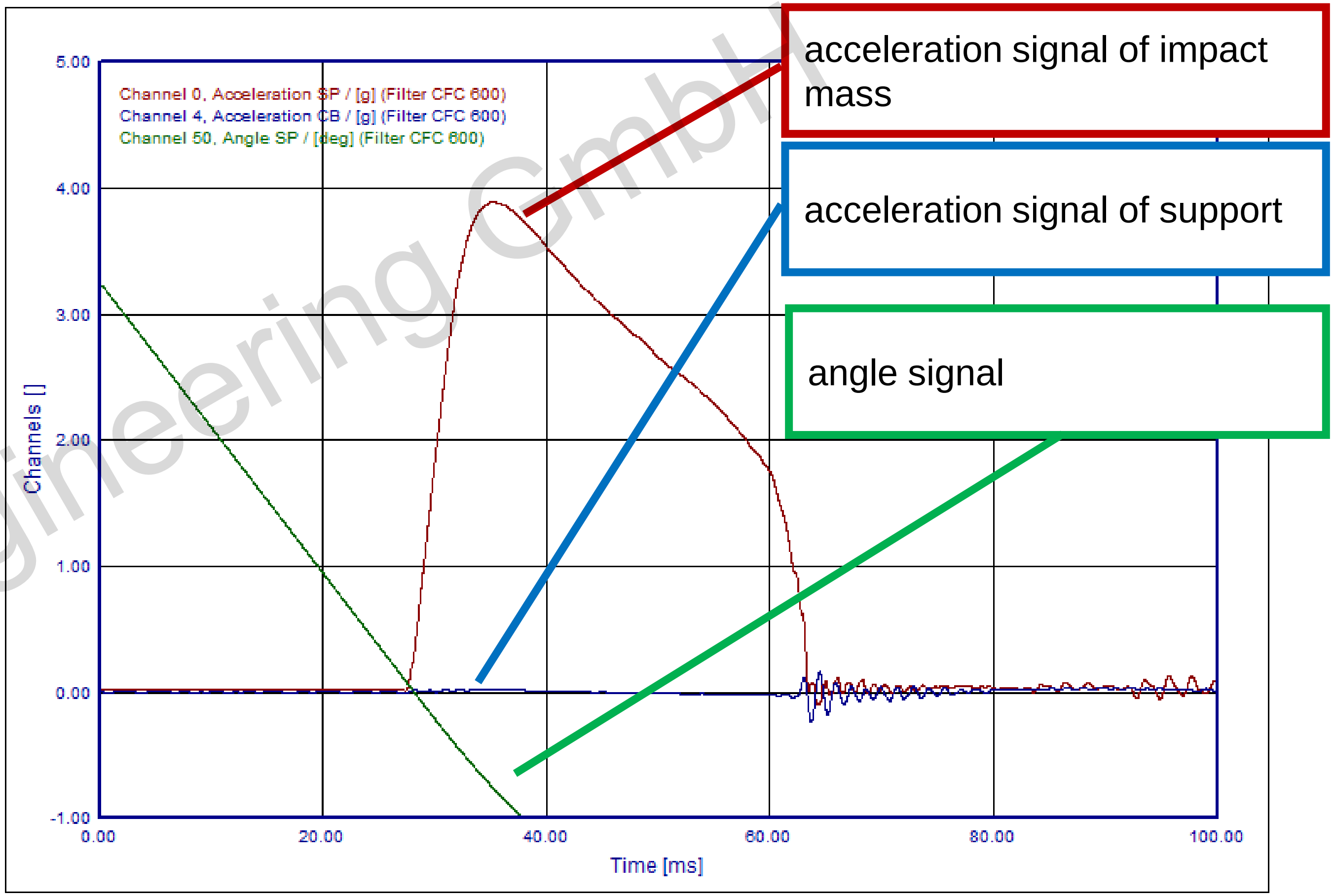
1) acceleration sensor on pendulum head
2) acceleration sensor on counter bearing
3) angle sensor
4) radius of the fin: 2 mm
5) support radius: 2 mm
6) swing hammer mass: 1580 g





Measurement signals – IMPETUS 3-Point-Bending





acceleration signal of impact mass

acceleration signal of support

angle signal

Measurement technique - Incremental rotary transmitter

- Very exact sensor resolution **320.000 points / turn**

  → theoretical resolution **0.01 mm** in the circular path of the pendulum

- Sensor doesn‘t have a dead range

- 0-pulse of the rotary transmitter can be used as trigger

  for the measurement

- possibility of evaluation: displacement out of the angle

  → calibration of the system

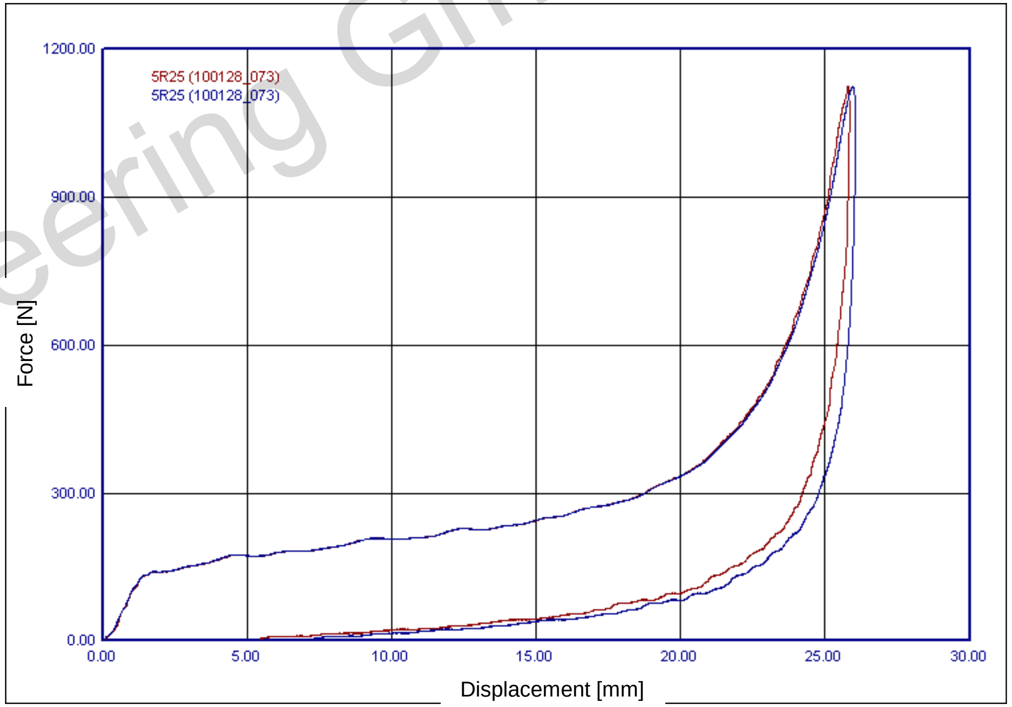
IMPETUS

Measurement technique - Incremental rotary transmitter

Calculation of the displacement

Evaluation out of the angle signal vs. acceleration signal

Checking of the system using the angle signal vs. acceleration signal is possible



3-point-bending test 1mps

compression test for foam 3.5mps

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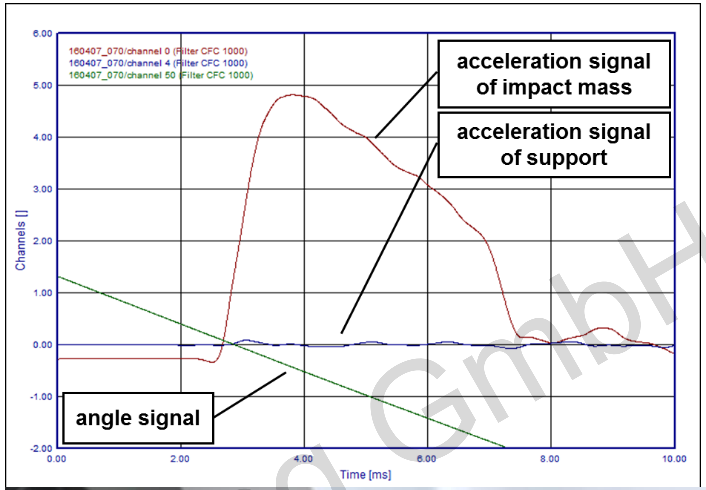
Dynamic 3-point-bending

EWH5

IMPETUS™

- sensor support: 5 g
- sensor on pendulum: 25 g
- test velocities: 1, 2.5 and 4 m/s
- swing hammer mass: 1580 g
- radius of fin and support: 2 mm
- acceleration & angle signals are measured
- HT/LT: temperature magazine is required



STANDARD IMPETUS™ - EWH5

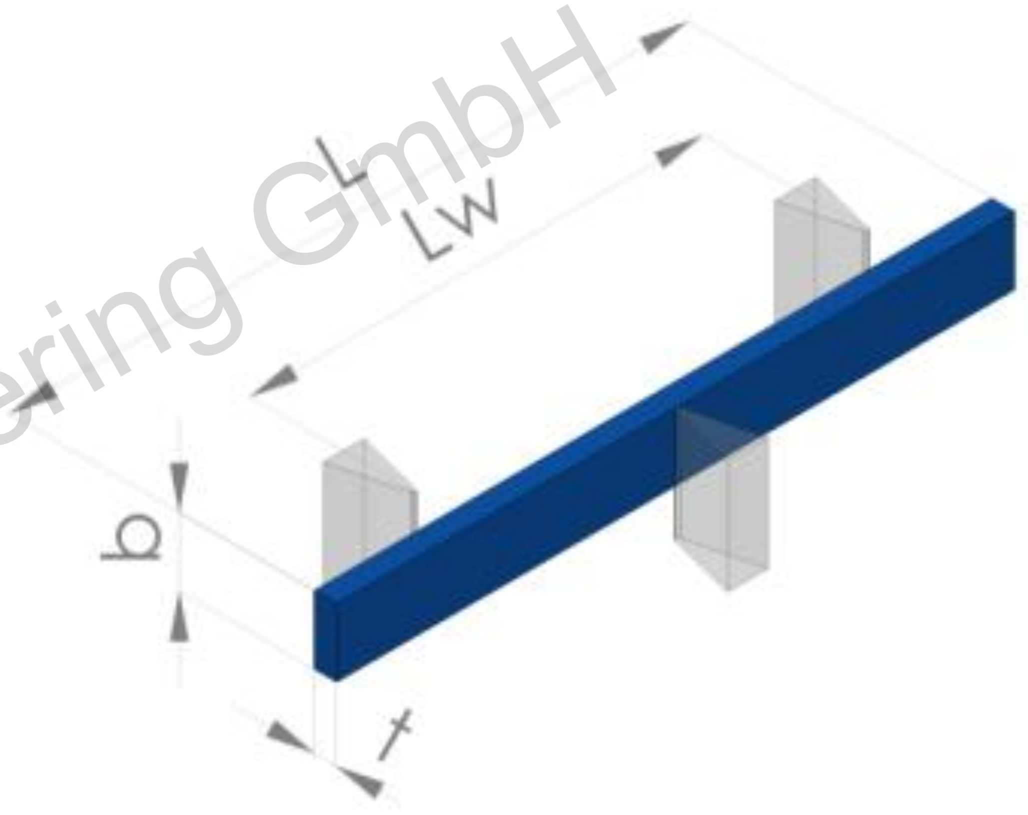
Dynamic 3-point-bending

- standard setup wall thickness 2 mm

Test-Setup	v_0 [m/s]	l_w [mm]	$m_{Pendulum}$ [g]	b [mm]	t [mm]	l [mm]	$\dot{\varepsilon}$ * [1/s]
dyn_low	1	40	1580	10	2	50	7.5
dyn_med	2.5	40	1580	10	2	50	18.75
dyn_high	4	30	1580	10	2	40	53.33

- standard setup wall thickness 3 mm

Test-Setup	v_0 [m/s]	l_w [mm]	$m_{Pendulum}$ [g]	b [mm]	t [mm]	l [mm]	$\dot{\varepsilon}$ * [1/s]
dyn_low	1	50	1580	10	3	60	7.2
dyn_med	2.5	50	1580	10	3	60	18
dyn_high	4	40	1580	10	3	50	45



Dynamic 3-point-bending - IMPETUS™

3-point-bending dynamic - evaluation

Using the acceleration signal of the pendulum and the following equation

$$F = m_{Pendulum} \cdot a_{Pendulum}$$

the force can be calculated.

The velocity can be calculated using the difference of the acceleration signal:

$$a_1 = (a_{Pendulum} - a_{0Pendulum}) + (a_{Support} - a_{0Support})$$

$$v_1 = v_0 + a_1 \cdot (t_1 - t_0)$$

The distance can be calculated either using the acceleration signal

$$s_1 = s_0 + v_1 \cdot (t_1 - t_0)$$

or using the angle signal:

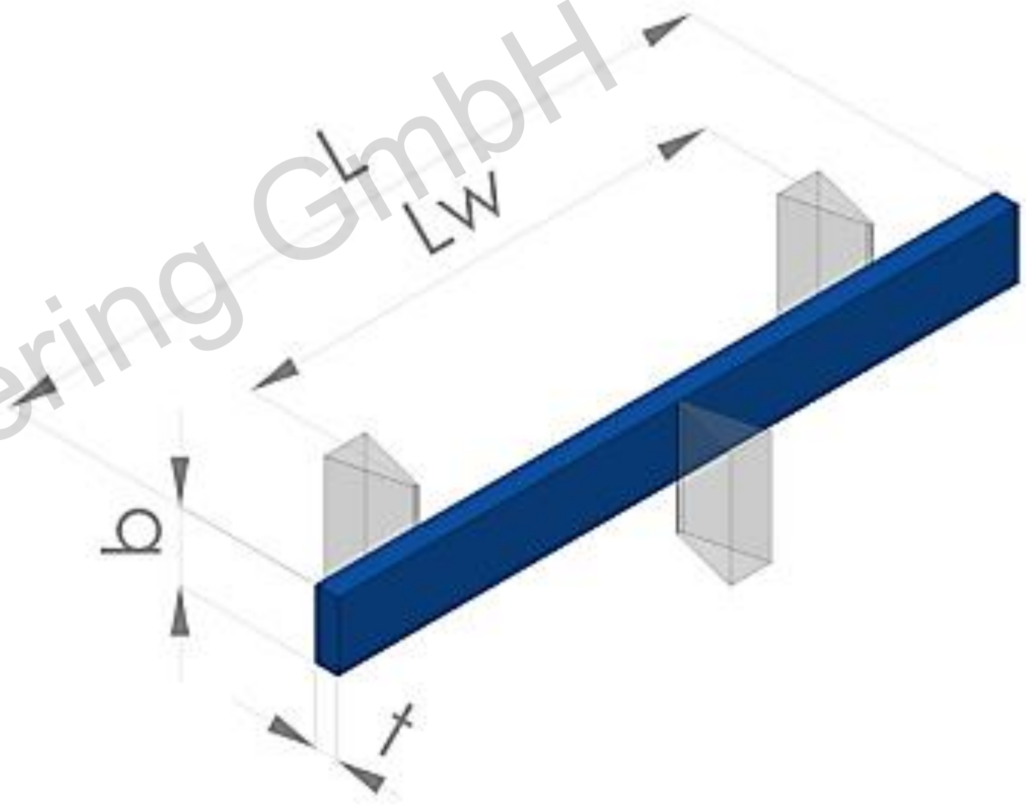
$$s_1 = s_0 + \frac{(\alpha_0 - \alpha_1) \cdot \pi}{180} \cdot L_p$$

STANDARD IMPETUS™ - EWH5

Evaluation 3-point-bending in IMPETUS™

3-point-bending - evaluation

Based on the bending beam theory
(assumption: Bernoulli Hypothesis, linear elastic)
the outer-fiber stress σ, strain ε and strain rate $\dot{\varepsilon}$ can be calculated.



$$\sigma = \frac{3 \cdot l_w \cdot F}{2 \cdot b \cdot t^2} \qquad \varepsilon = \frac{6 \cdot t \cdot s}{{l_w}^2} \qquad \dot{\varepsilon} = \frac{6 \cdot t \cdot v}{{l_w}^2}$$

l_w … $distance\ of\ support\ span\ (gauge)$

t … $specimen\ thickness$

b … $specimen\ width$

s … $displacement$

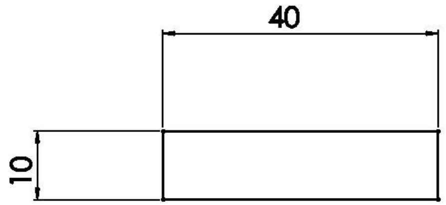
v … $velocity$

F … $Force$

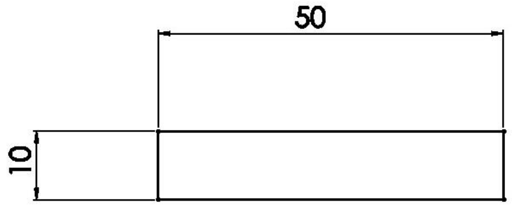
Evaluation in ISO 178 is analogue.

Static and dynamic 3-point-bending specimen geometries

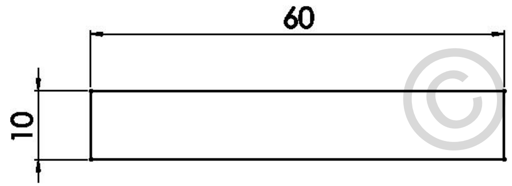
- The test specimen are milled out in various orientations, depending on the customer demands.



IMPETUS-BE-V1



IMPETUS-BE-V2



IMPETUS-BE-V3

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VALIMAT

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- Parameter identification:
  - for yield surface and flow rule i.e. *MAT_187
  - for damage and failure i.e. *MAT_ADD_EROSION
- Outlook on upcoming material models

15:30 - 16:30 Q&A

4a ENGINEERING

In cooperation with

JSOL CORPORATION AR BROWN Think Quality & Create Value

From test to material card

VALIMAT

plastics

engineering

production

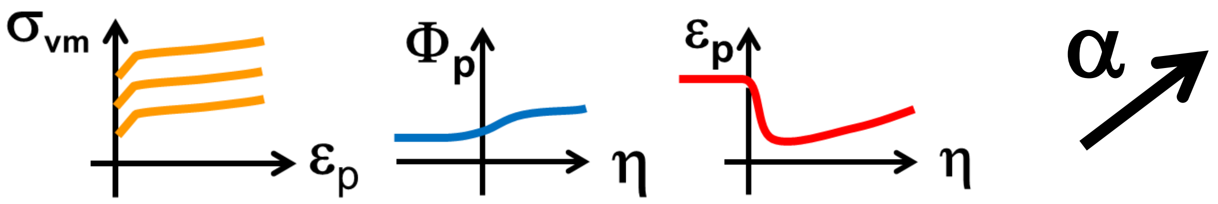
excellence in HANDS ON validation

concepts

simulation

lightweight

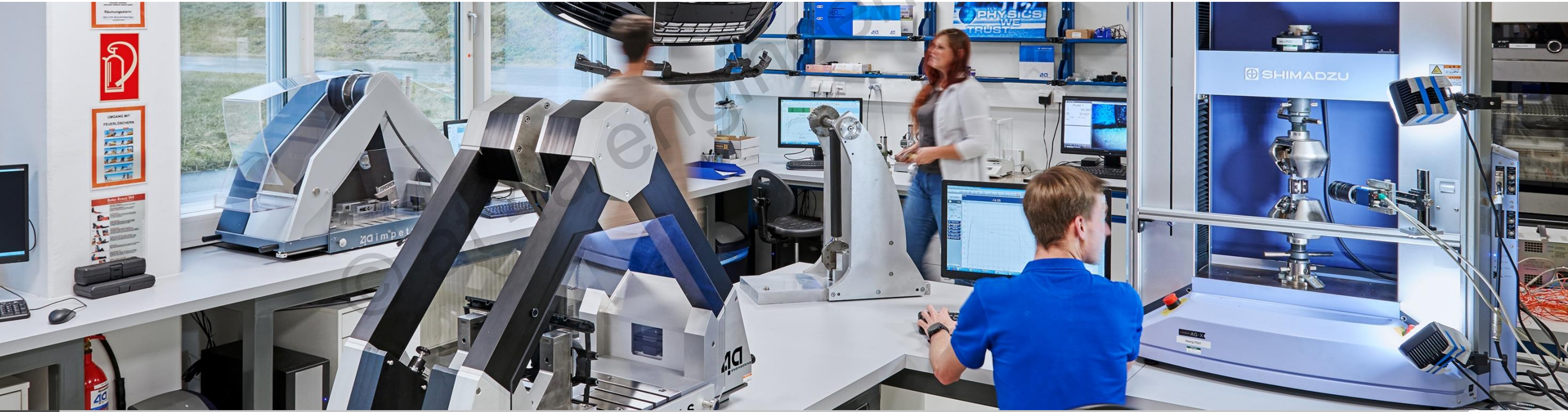
prototypes



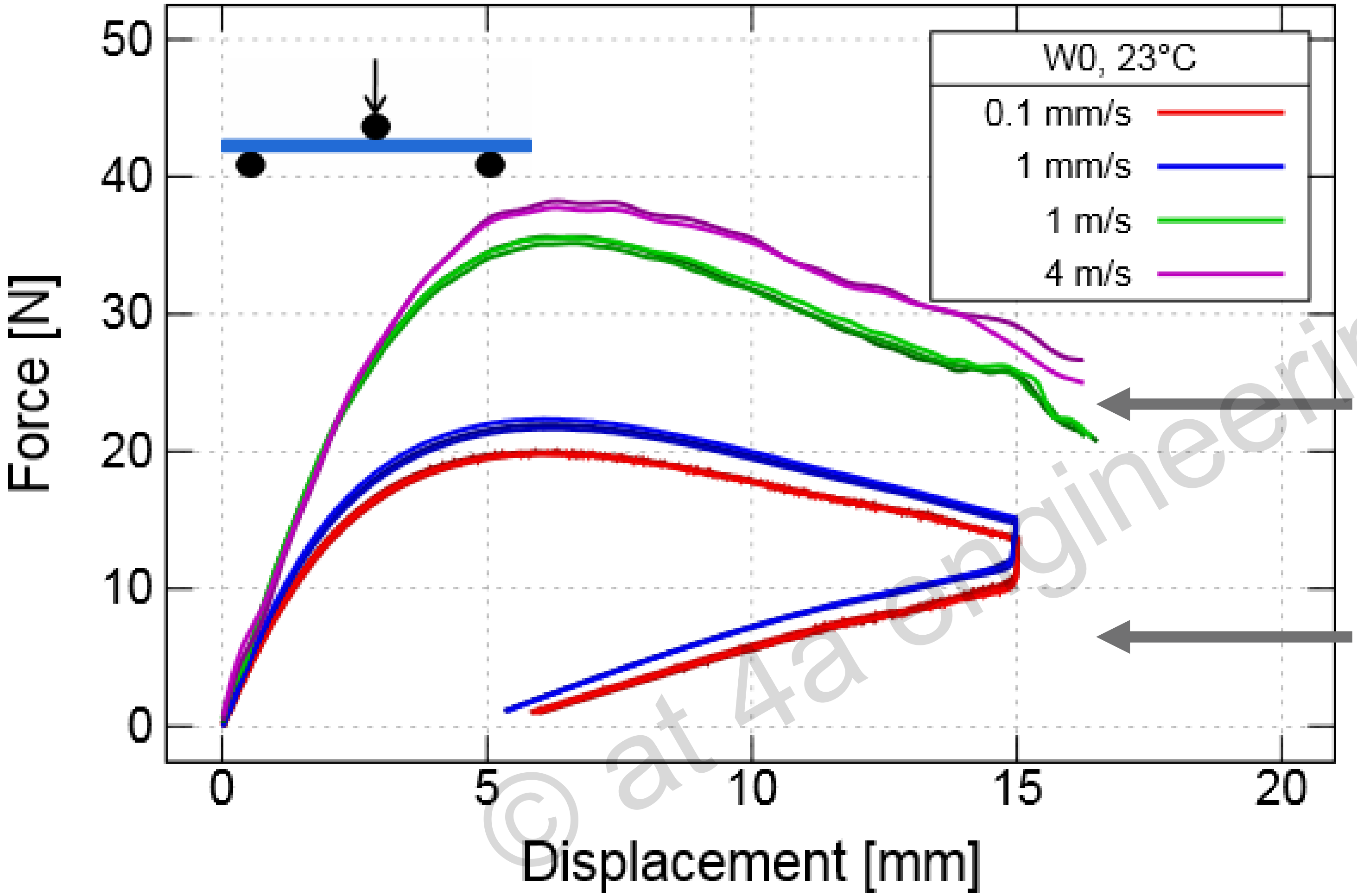
Hardening | Triaxiality | Damage/Failure | Anisotropic

Introduction MAT_024 AutoFit

Basis 3-Point-Bending



Efficient dynamic testing



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Universal static testing

MAT_024 introduction

***MAT_024** (*MAT_PIECEWISE_LINEAR_PLASTICITY) is the most commonly used material card for crash simulations in LS-DYNA.

- It is an elastic, viscoplastic material model
    - Von Mises yield surface
    - associated flow rule
- hardening curves can be defined arbitrarily for selected strain rates
- interpolation between the hardening curves of different strain rates can be performed either linear or logarithmic

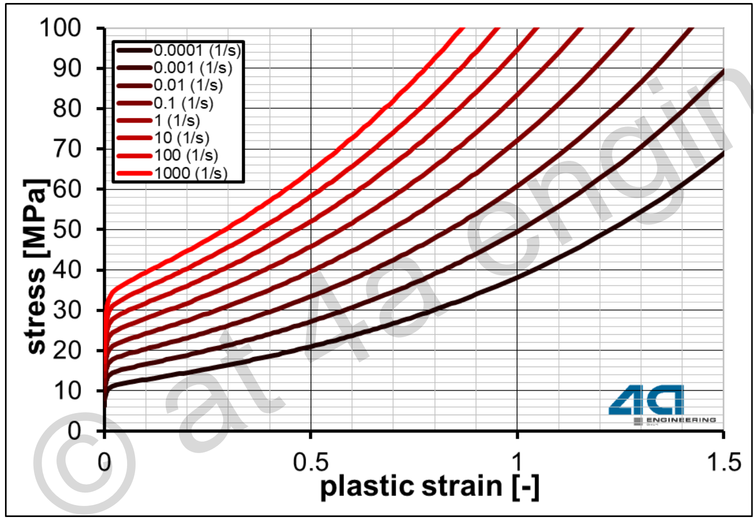
more information:

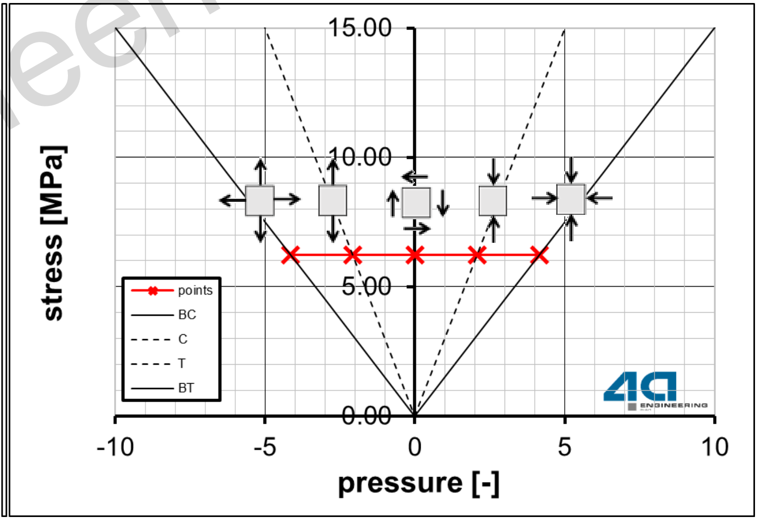
- "LS-DYNA_Manual_Volume_II_R11.pdf"

MAT_024 introduction

material card overview

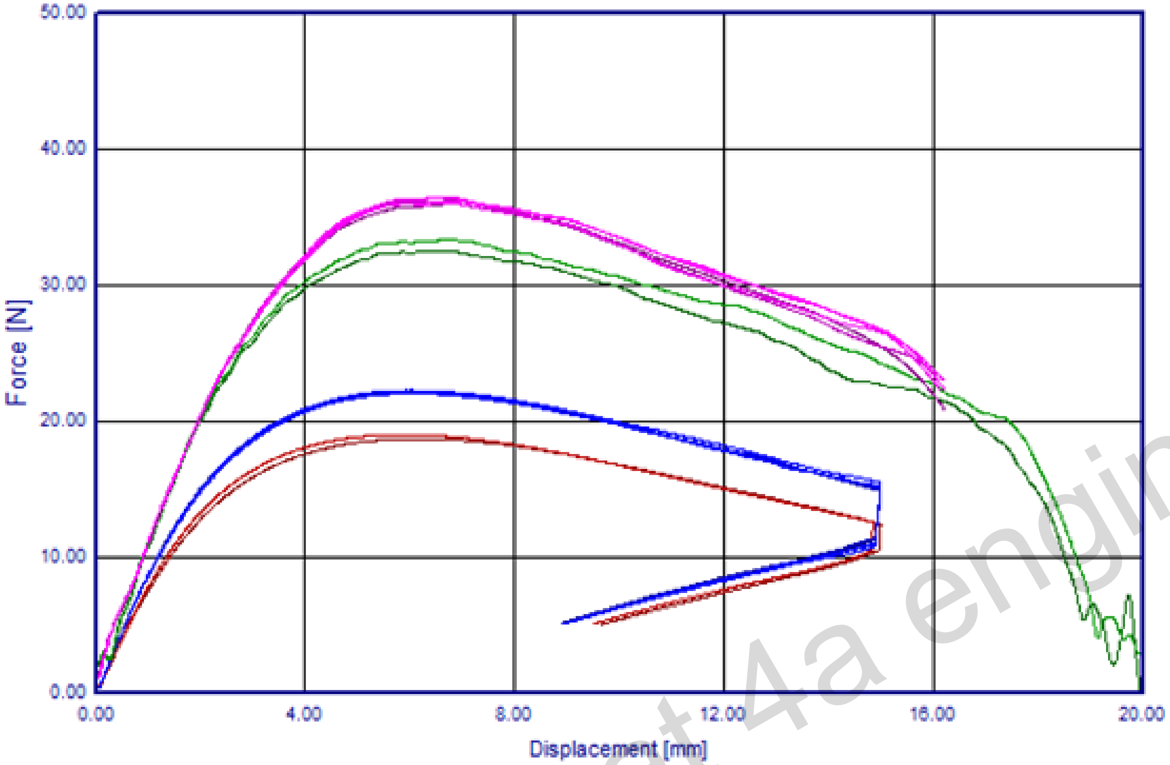
- ***Material:*** PPEG107HP
- ***MAT_024** material card:*
  - Deformation: elastic, viscoplastic
  - Von Mises yield surface
  - associated flow rule ➔ plastic deformation at constant volume



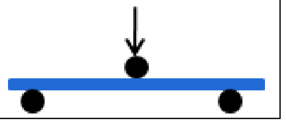


AutoFit

Data



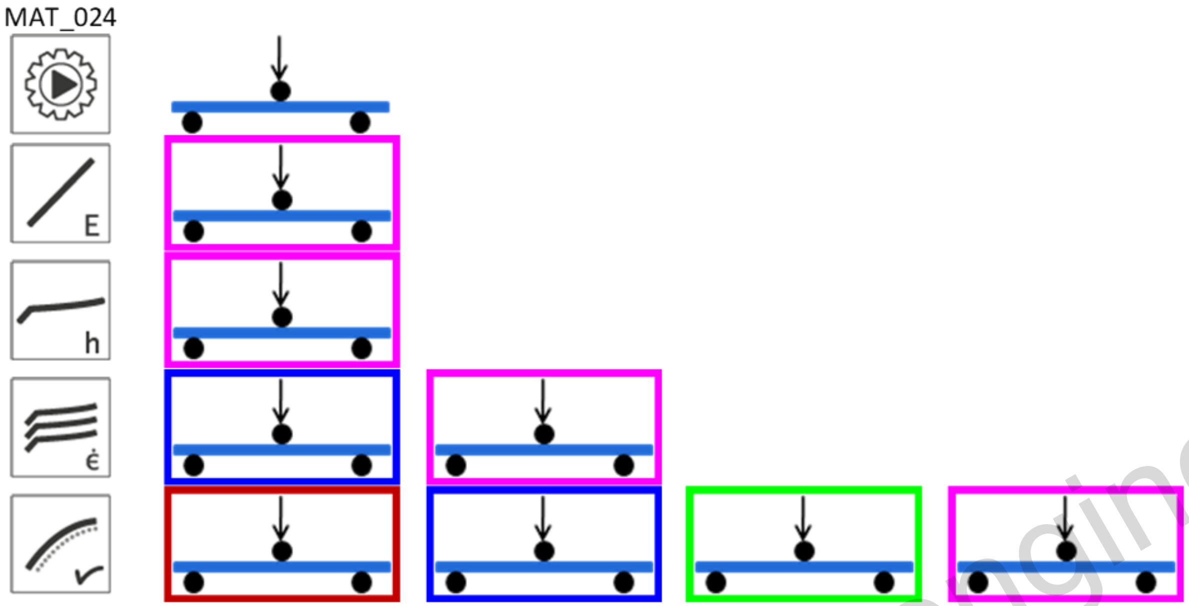
model 190912_019



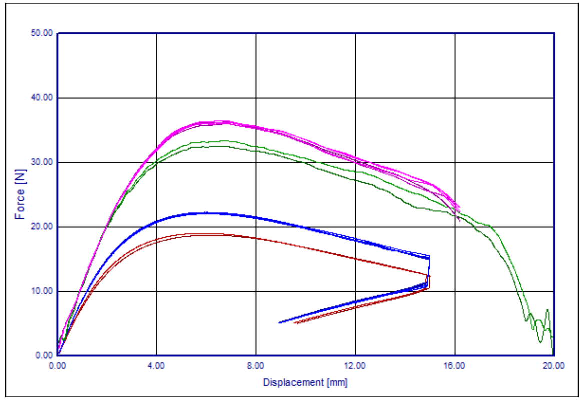
Case	v_0 [m/s]	l_w [mm]	$m_{Pendulum}$ [g]	b [mm]	t [mm]	l [mm]
3PB_V0p1_d00_I	**0.0001**	**40.01**	**0**	**9.93**	**1.99**	**49.75**
3PB_V1_d00_I	**0.001**	**40.01**	**0**	**9.91**	**2.00**	**50.06**
3PB_V1000_d00_I	**1**	**40.01**	**1580**	**9.91**	**1.99**	**50.10**
3PB_V2500_d00_I	**2.5**	**40.01**	**1580**	**9.91**	**1.99**	**49.94**

AutoFit

Strategy



without border all velocities
quasistatic low velocity
quasistatic high velocity
dynamic low velocity
dynamic medium velocity



- For crash card a dynamic case for the Young‘s modulus and hardening curve fit

AutoFit

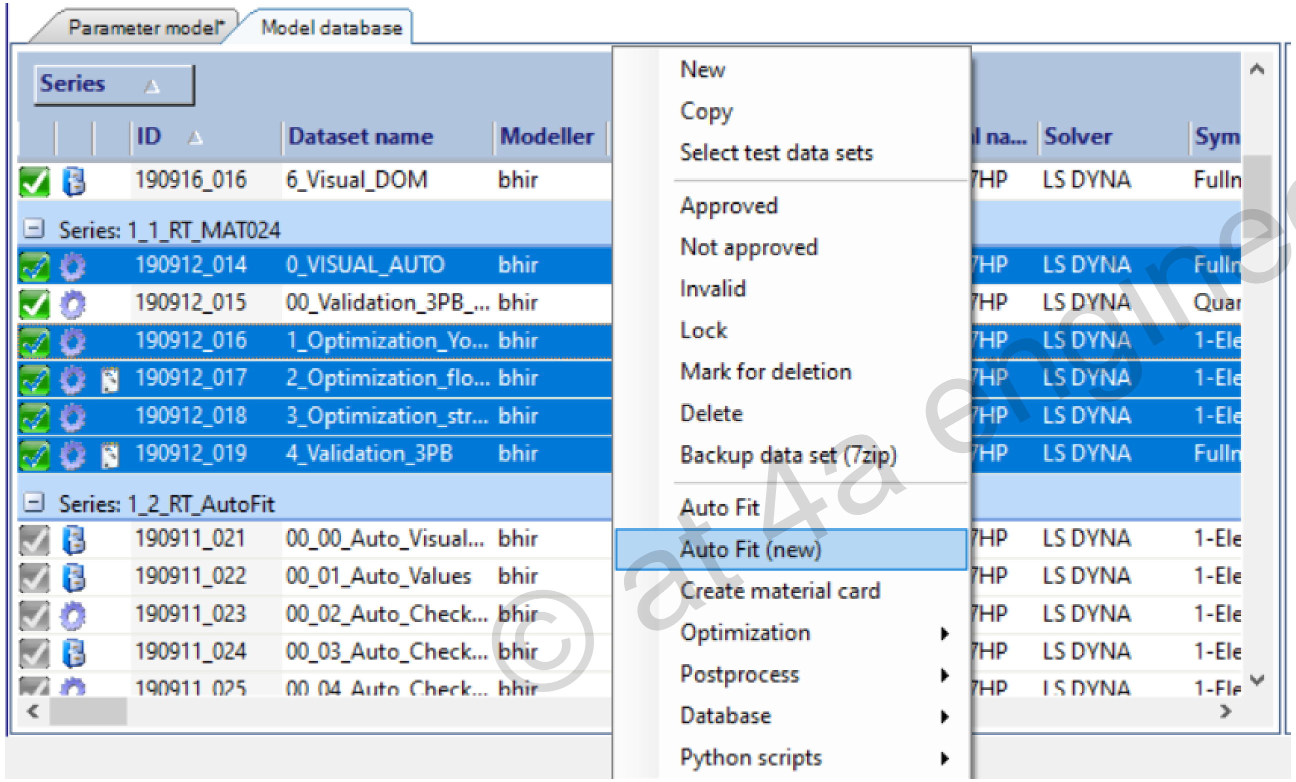
Database

- For the AutoFit function several methods have to be prepared.
- On the following slides the AutoFit function will be called on the training database.
- The model settings will be discussed as they appear in the workflow.

AutoFit
Database

To start the new Auto Fit

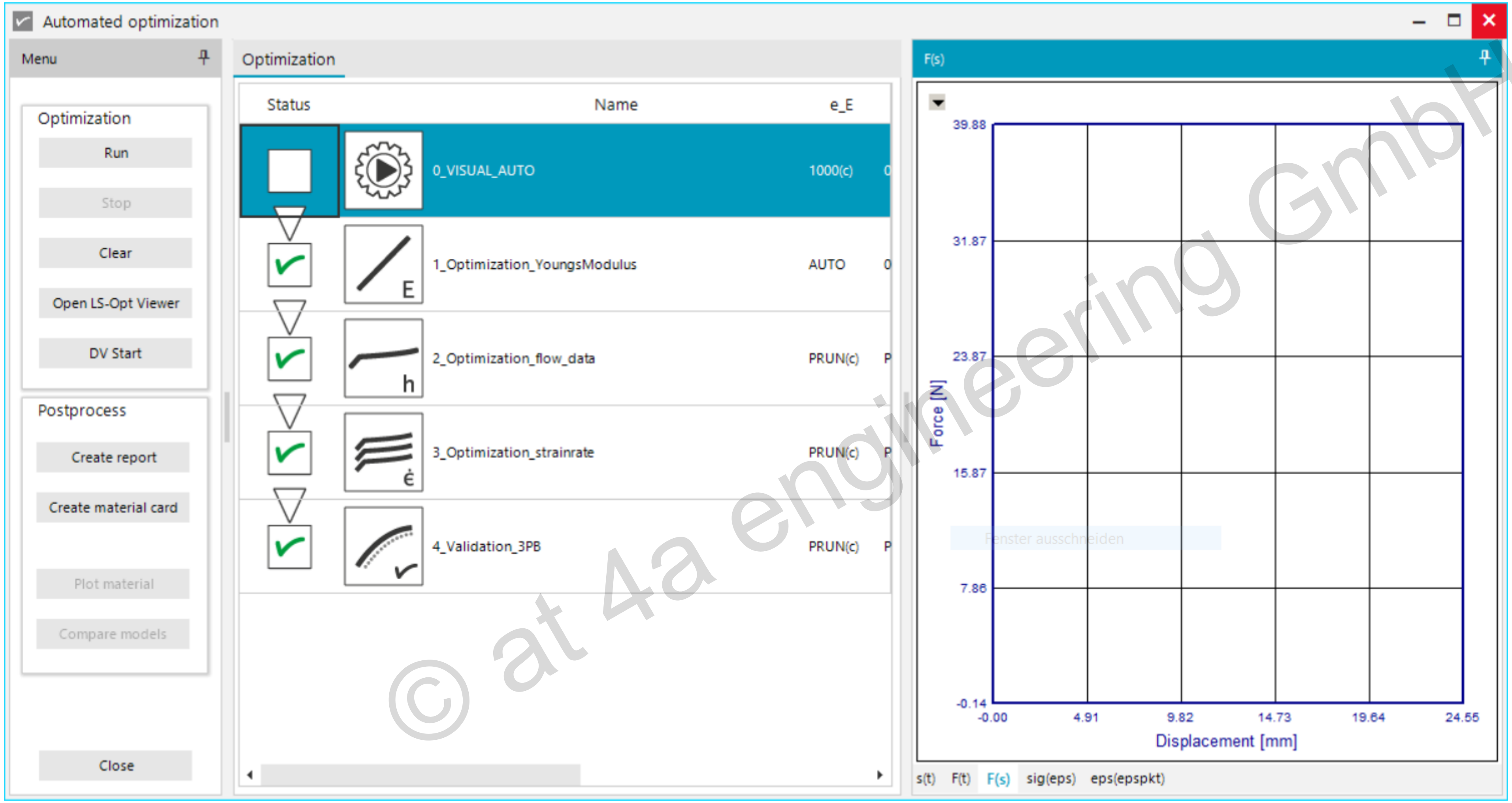
- Select the models
- Right Click Auto Fit (new)



	ID	Dataset name	Modeller	l na...	Solver	Sym
☑	190916_016	6_Visual_DOM	bhir	7HP	LS DYNA	Fulln
Series: 1_1_RT_MAT024						
☑	190912_014	0_VISUAL_AUTO	bhir	7HP	LS DYNA	Fulln
☑	190912_015	00_Validation_3PB_...	bhir	7HP	LS DYNA	Quar
☑	190912_016	1_Optimization_Yo...	bhir	7HP	LS DYNA	1-Ele
☑	190912_017	2_Optimization_flo...	bhir	7HP	LS DYNA	1-Ele
☑	190912_018	3_Optimization_str...	bhir	7HP	LS DYNA	1-Ele
☑	190912_019	4_Validation_3PB	bhir	7HP	LS DYNA	Fulln
Series: 1_2_RT_AutoFit						
☑	190911_021	00_00_Auto_Visual...	bhir	7HP	LS DYNA	1-Ele
☑	190911_022	00_01_Auto_Values	bhir	7HP	LS DYNA	1-Ele
☑	190911_023	00_02_Auto_Check...	bhir	7HP	LS DYNA	1-Ele
☑	190911_024	00_03_Auto_Check...	bhir	7HP	LS DYNA	1-Ele
☑	190911_025	00_04_Auto_Check...	bhir	7HP	LS DYNA	1-Ele

AutoFit

Auto Values



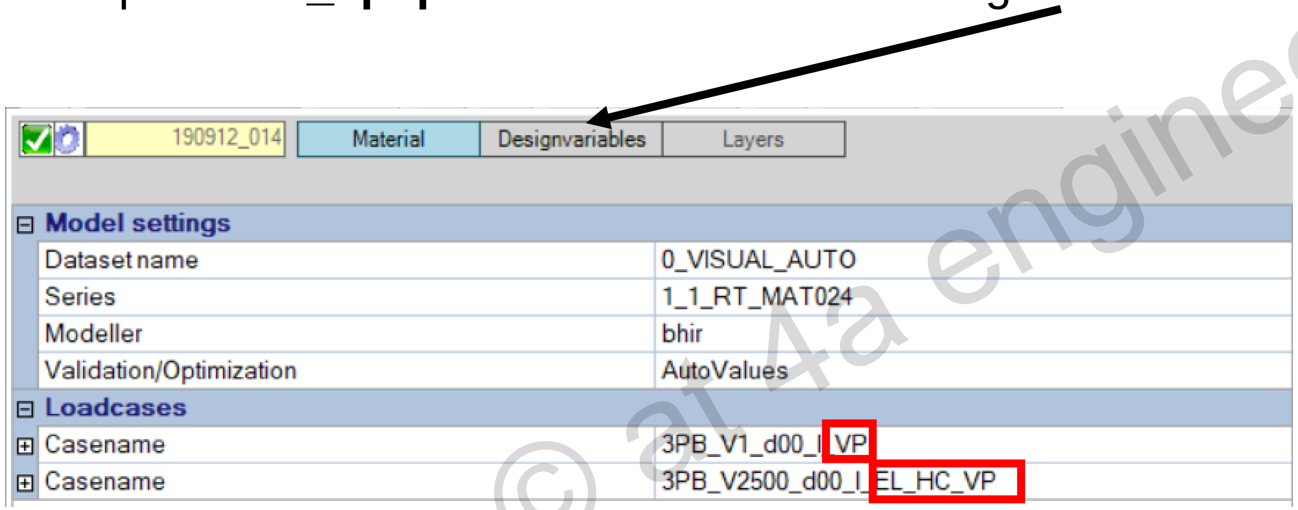
Status	Name	e_E
☐	0_VISUAL_AUTO	1000(c)
☑	1_Optimization_YoungsModulus	AUTO
☑	2_Optimization_flow_data	PRUN(c)
☑	3_Optimization_strainrate	PRUN(c)
☑	4_Validation_3PB	PRUN(c)

AutoFit

Auto Values

Validation/Optimization: **AutoValues** ➔ Model used for start value generation

- **_EL**: mean value of this case is Young’s Modulus e_E
- **_HC**: use this case for hardening curve parameter estimation
- **_VP**: use these cases to evaluate the strain rate dependency v_p
- important **v_epspkt** will be taken from Designvariables this is the reference strain rate

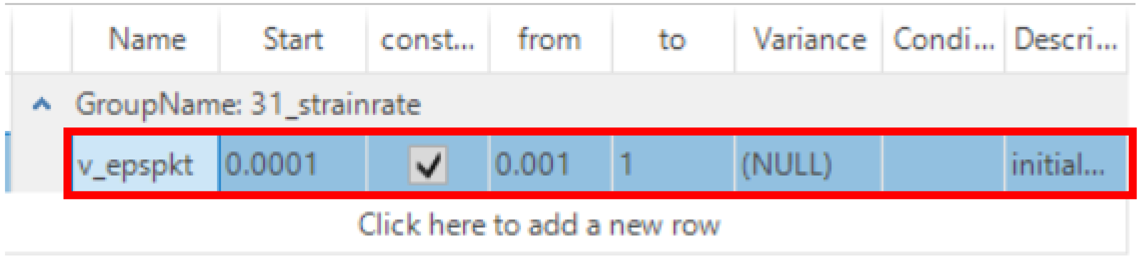


Model settings

Dataset name	0_VISUAL_AUTO
Series	1_1_RT_MAT024
Modeller	bhir
Validation/Optimization	AutoValues

Loadcases

Casename	3PB_V1_d00_I_VP
Casename	3PB_V2500_d00_I_EL_HC_VP



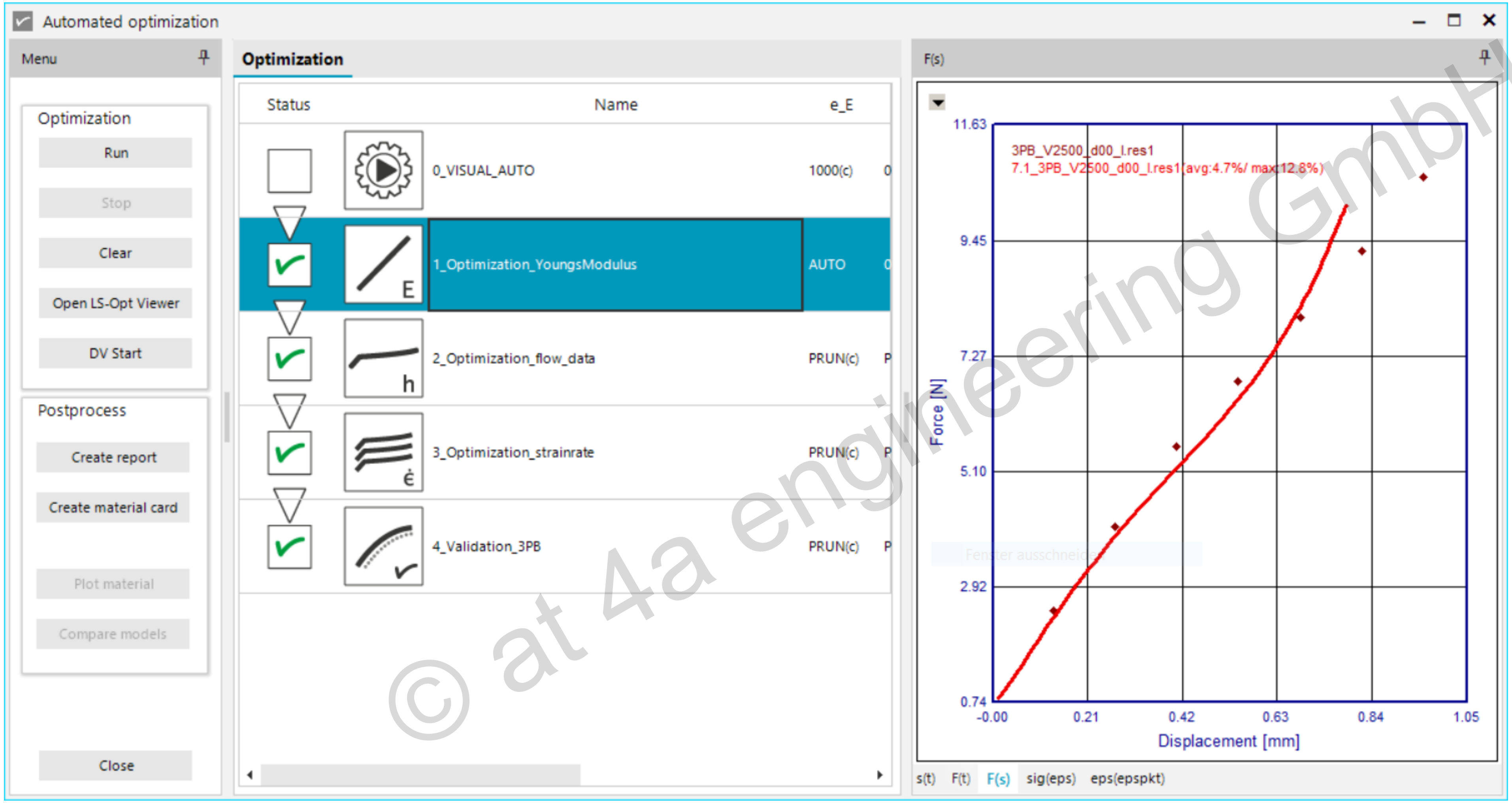
GroupName: 31_strainrate

Name	Start	const...	from	to	Variance	Condi...	Descri...
v_epspkt	0.0001	☑	0.001	1	(NULL)		initial...

Click here to add a new row

AutoFit

Optimization Young’s modulus



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

3PB_V2500_d00_l.res1
7.1_3PB_V2500_d00_l.res1(avg:4.7%/ max:12.8%)

<u>Checks:</u>

are oszillations too high?

curve long enough?

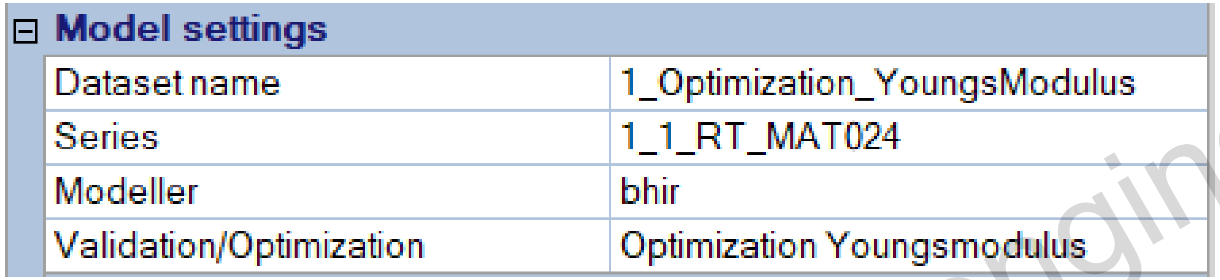
curve still linear elastic?

AutoFit

Optimization Young’s modulus

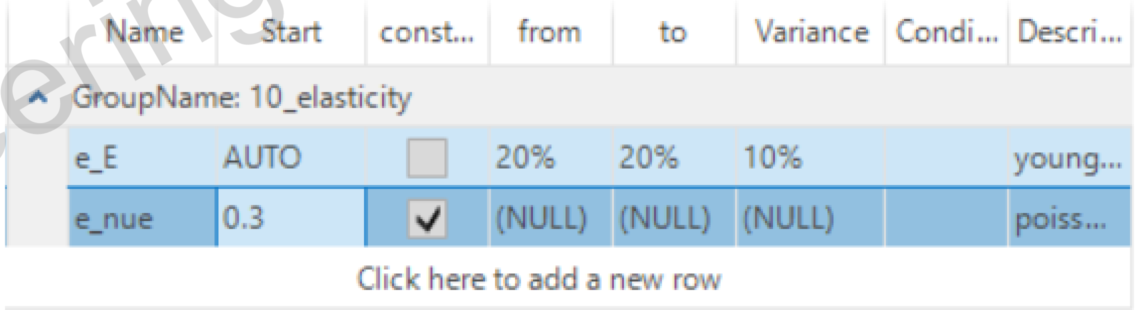
Validation/Optimization: **Optimization Youngsmodulus**

- Use only MAT_ELASTIC to Fit Young’s modulus for computational efficiency
- In design variables e_E is set to AUTO which will be replaced by script result of the Young’s modulus



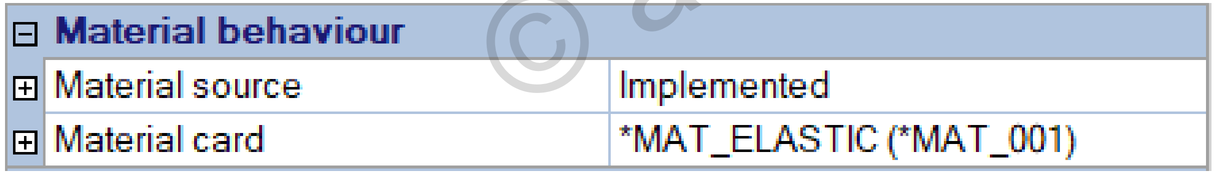
Model settings

Dataset name	1_Optimization_YoungsModulus
Series	1_1_RT_MAT024
Modeller	bhir
Validation/Optimization	Optimization Youngsmodulus



Name	Start	const...	from	to	Variance	Condi...	Descri...
GroupName: 10_elasticity							
e_E	AUTO	☐	20%	20%	10%		young...
e_nue	0.3	☑	(NULL)	(NULL)	(NULL)		poiss...

Click here to add a new row

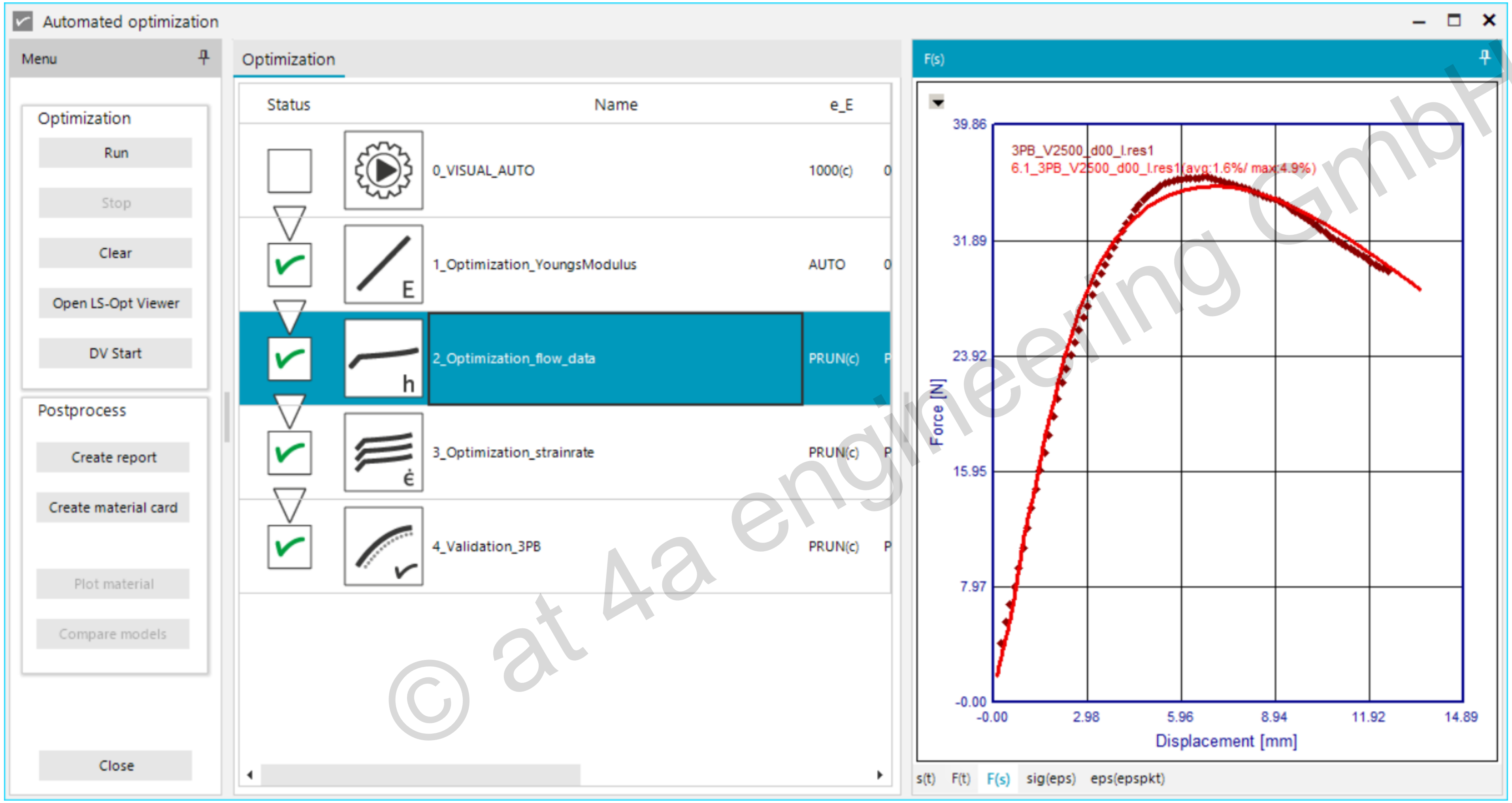


Material behaviour

Material source	Implemented
Material card	*MAT_ELASTIC (*MAT_001)

AutoFit

Optimization hardening



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)

<u>Checks:</u>
curve long enough?
good fit?

AutoFit

Optimization hardening

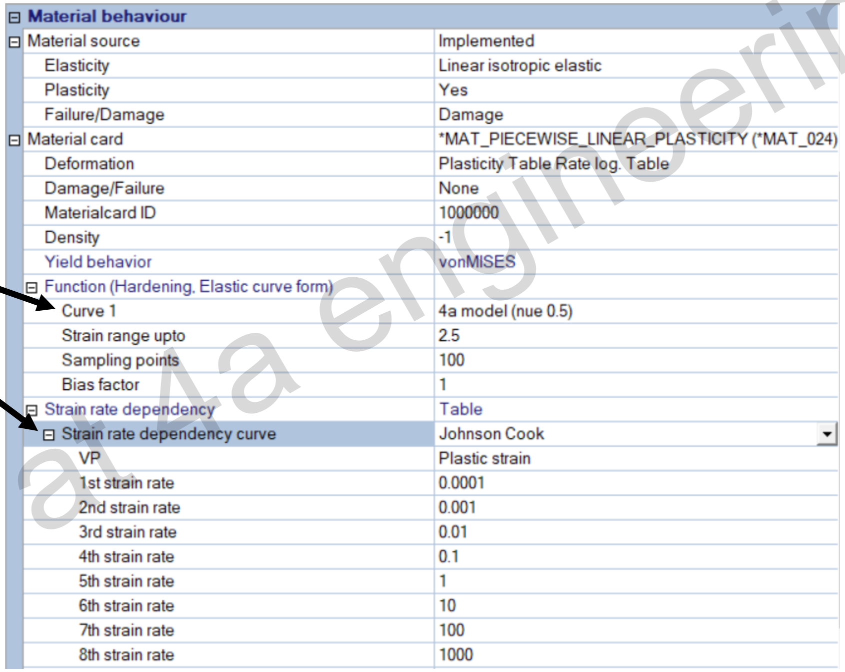
Validation/Optimization: **Optimization hardening**

- a parametrized model is used for the hardening curve and the strain rate dependency
- Optimized Parameters are set to PRUN
- New Parameters are set to AUTO

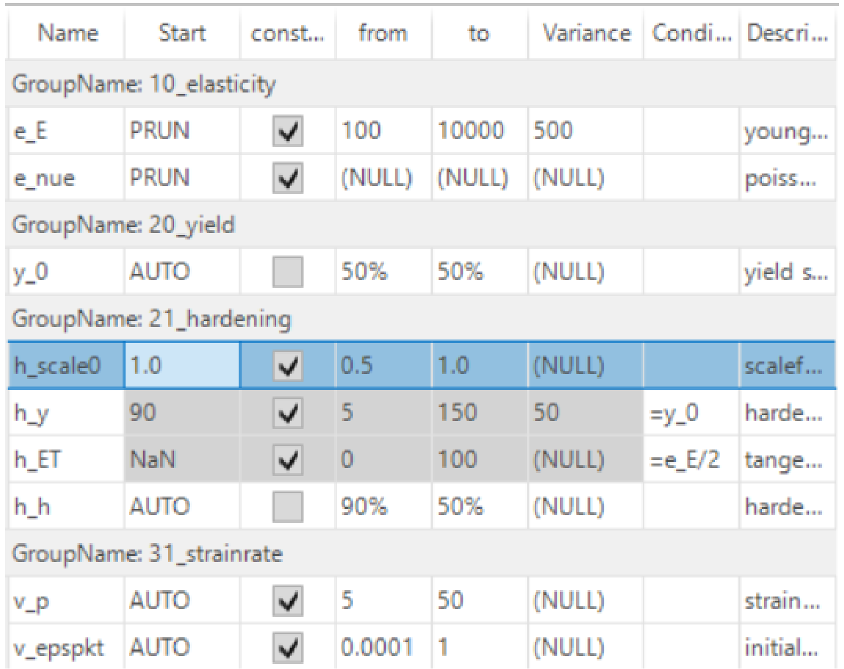
hardening model

strain rate dependency model

strain rates for strain rate dependency used in the material card



Material behaviour	
Material source	Implemented
Elasticity	Linear isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
Material card	*MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_024)
Deformation	Plasticity Table Rate log. Table
Damage/Failure	None
Materialcard ID	1000000
Density	-1
Yield behavior	vonMISES
Function (Hardening, Elastic curve form)	
Curve 1	4a model (nue 0.5)
Strain range upto	2.5
Sampling points	100
Bias factor	1
Strain rate dependency	Table
Strain rate dependency curve	Johnson Cook
VP	Plastic strain
1st strain rate	0.0001
2nd strain rate	0.001
3rd strain rate	0.01
4th strain rate	0.1
5th strain rate	1
6th strain rate	10
7th strain rate	100
8th strain rate	1000



Name	Start	const...	from	to	Variance	Condi...	Descri...
GroupName: 10_elasticity							
e_E	PRUN	☑	100	10000	500		young...
e_nue	PRUN	☑	(NULL)	(NULL)	(NULL)		poiss...
GroupName: 20_yield							
y_0	AUTO	☐	50%	50%	(NULL)		yield s...
GroupName: 21_hardening							
h_scale0	1.0	☑	0.5	1.0	(NULL)		scalef...
h_y	90	☑	5	150	50	=y_0	harde...
h_ET	NaN	☑	0	100	(NULL)	=e_E/2	tange...
h_h	AUTO	☐	90%	50%	(NULL)		harde...
GroupName: 31_strainrate							
v_p	AUTO	☑	5	50	(NULL)		strain...
v_epspkt	AUTO	☑	0.0001	1	(NULL)		initial...

AutoFit

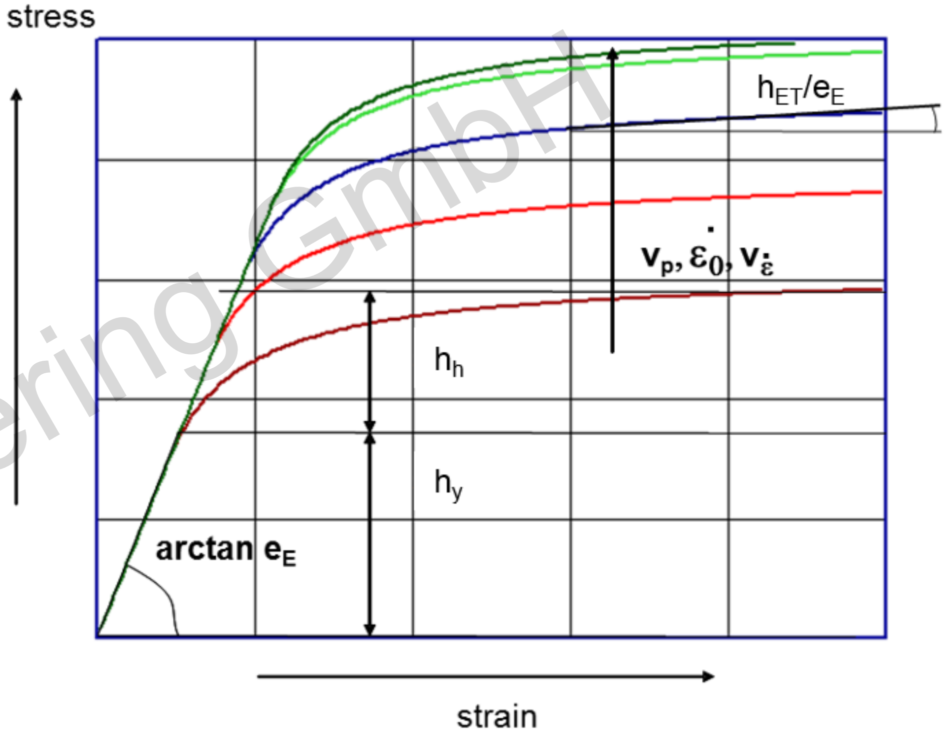
Optimization hardening – 4a model

- LS Dyna - ***MAT_024***
- plastic behavior described using the meta model of Schmachtenberg

$$hy + e_E \cdot \varepsilon_{pl} \cdot \frac{1 + \dfrac{h_{ET} \cdot \varepsilon_{pl}}{e_E}}{1 + \dfrac{e_E \cdot \varepsilon_{pl}}{h_h}}$$

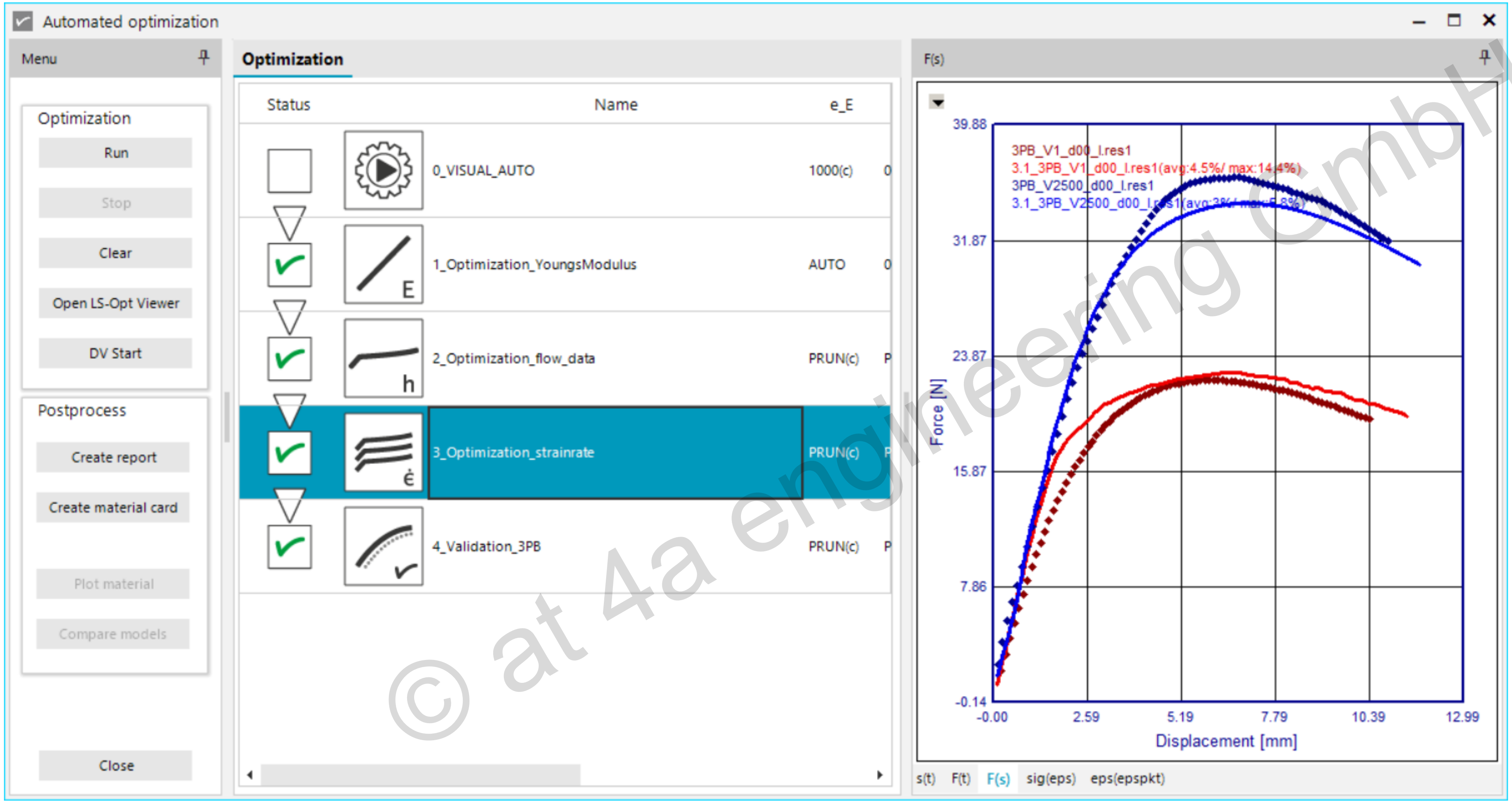
- hardening linear increased by coefficient h_{ET}/e_E
- strain rate dependency based on Johnson- Cook.

$$1 + \frac{1}{v_p} \cdot \log\left(\frac{\max(\dot{\varepsilon}\ ,\ v_{\dot{\varepsilon}})}{v_{\dot{\varepsilon}}}\right)$$



AutoFit

Optimization strain rate dependency

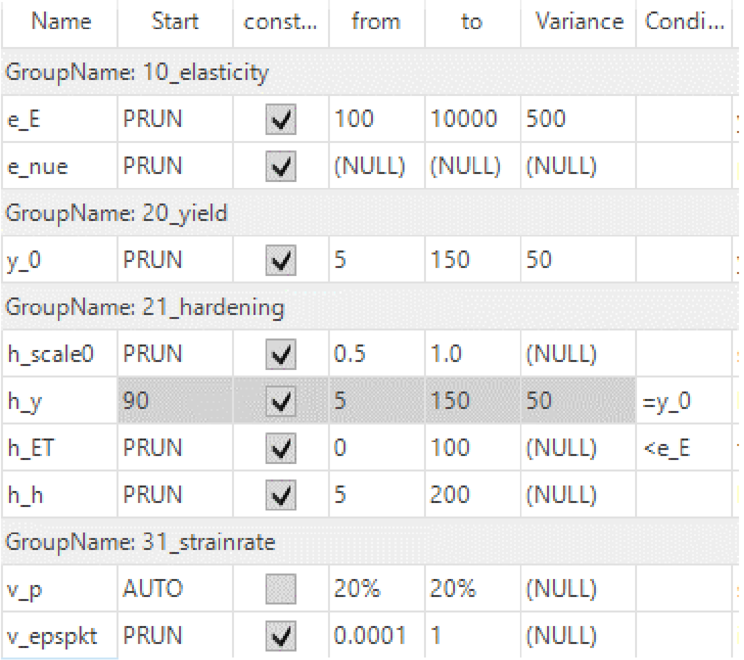


Status	Name	e_E	
☐	0_VISUAL_AUTO	1000(c)	0
☑	1_Optimization_YoungsModulus	AUTO	0
☑	2_Optimization_flow_data	PRUN(c)	P
☑	3_Optimization_strainrate	PRUN(c)	P
☑	4_Validation_3PB	PRUN(c)	P

AutoFit
Optimization strain rate dependency

Validation/Optimization: **Optimization strainrate**

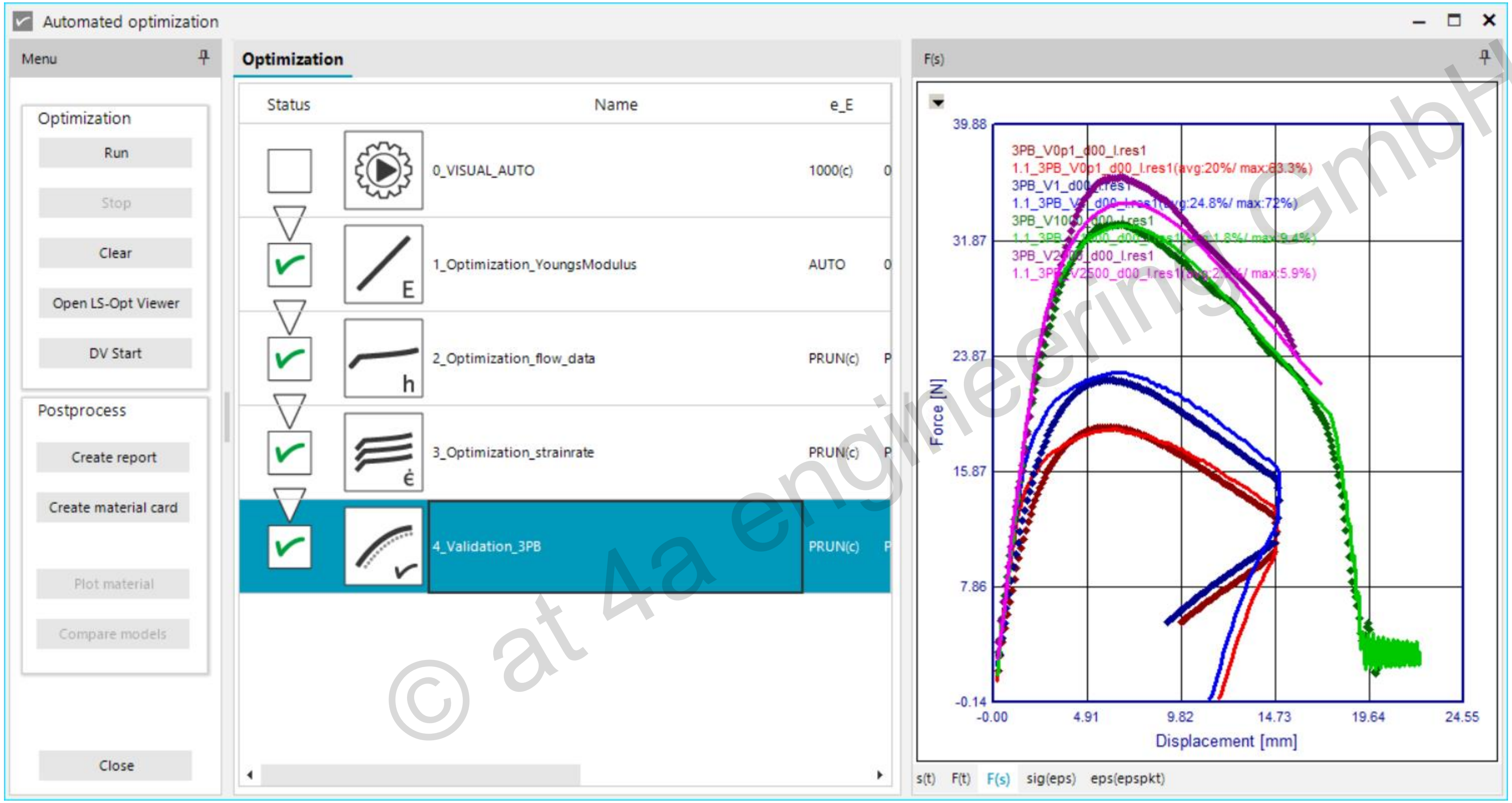
- a parametrized model is used for the hardening curve and the strain rate dependency
- Optimized Parameters are set to PRUN
- New Parameters are set to AUTO



Name	Start	const...	from	to	Variance	Condi...
GroupName: 10_elasticity						
e_E	PRUN	☑	100	10000	500	
e_nue	PRUN	☑	(NULL)	(NULL)	(NULL)	
GroupName: 20_yield						
y_0	PRUN	☑	5	150	50	
GroupName: 21_hardening						
h_scale0	PRUN	☑	0.5	1.0	(NULL)	
h_y	90	☑	5	150	50	=y_0
h_ET	PRUN	☑	0	100	(NULL)	<e_E
h_h	PRUN	☑	5	200	(NULL)	
GroupName: 31_strainrate						
v_p	AUTO	☐	20%	20%	(NULL)	
v_epspkt	PRUN	☑	0.0001	1	(NULL)	

AutoFit

Validation



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

SEMINAR AGENDA

10:00 - 10:45 INTRODUCTION

Material behavior for plastics

Introduction to VALIMAT™ - workflow for generating material cards

10:45 - 12:15 IMPETUS™ HANDS ON

Hardware introduction and hands on testing

13:15 - 14:45 VALIMAT™ HANDS ON

Evaluation of test data and organizing databases

AUTOFIT: *MAT_024 parameter identification using the new feature

14:45 - 15:30 ADVANCED TOPICS

Parameter identification:
- for yield surface and flow rule i.e. *MAT_187
- for damage and failure i.e. *MAT_ADD_EROSION

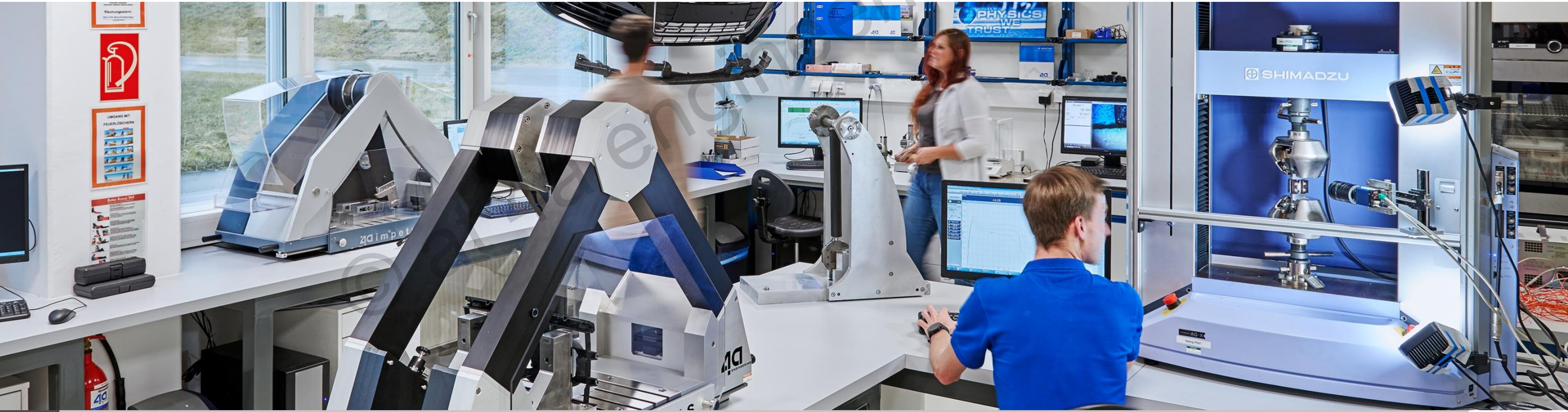
Outlook on upcoming material models

15:30 - 16:30 Q&A

In cooperation with

Introduction MAT_187 AutoFit

Basis 3-Point-Bending



MAT_187 introduction

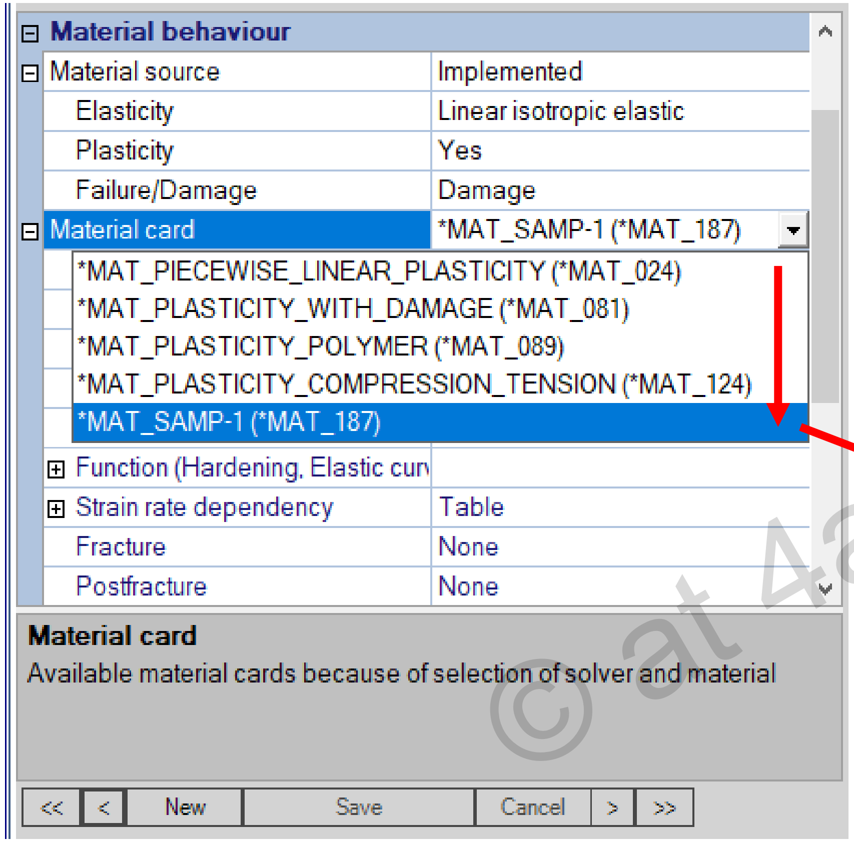
***MAT_187/*MAT_SAMP-1** (*Semi-Analytical Model for Polymers)

- It is a viscoelastic, viscoplastic material model (R10.0.0)
  - multiple yield surface definitions
  - associated flow rule or non associated flow rule defined by plastic Poisson's ratio
  - hardening curves can be defined arbitrarily for selected strain rates
  - interpolation between the hardening curves of different strain rates can be performed either linear or logarithmically (R9.0.1)
  - only available for explicit➔timescaling!

MAT_187 introduction

Time Scaling

When switching from implicit available Material cards like MAT_024, you need to change the time scaling settings of the static tests.



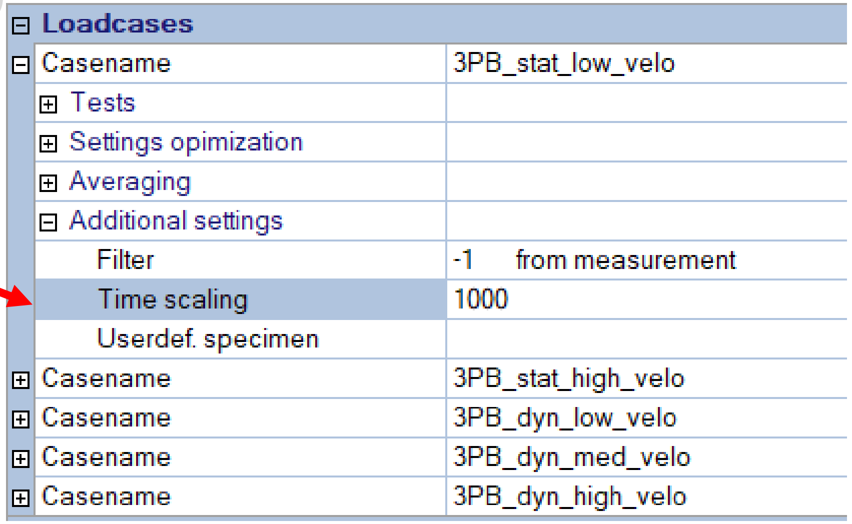
Material behaviour	
Material source	Implemented
Elasticity	Linear isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
Material card	*MAT_SAMP-1 (*MAT_187)
	*MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_024) *MAT_PLASTICITY_WITH_DAMAGE (*MAT_081) *MAT_PLASTICITY_POLYMER (*MAT_089) *MAT_PLASTICITY_COMPRESSION_TENSION (*MAT_124) *MAT_SAMP-1 (*MAT_187)
Function (Hardening, Elastic curv	
Strain rate dependency	Table
Fracture	None
Postfracture	None

Material card

Available material cards because of selection of solver and material

MAT_SAMP only available for **explicit** simulations

Quasistatic tests have to be **time scaled**!



Loadcases	
Casename	3PB_stat_low_velo
Tests	
Settings opimization	
Averaging	
Additional settings	
Filter	-1 from measurement
Time scaling	1000
Userdef. specimen	
Casename	3PB_stat_high_velo
Casename	3PB_dyn_low_velo
Casename	3PB_dyn_med_velo
Casename	3PB_dyn_high_velo

MAT_187 introduction

yield surface – notes about notation

- Stress Tensor:

$$\boldsymbol{\sigma} = \begin{pmatrix} \sigma_x & \tau_{xy} & \tau_{zx} \\ \tau_{xy} & \sigma_y & \tau_{yz} \\ \tau_{zx} & \tau_{yz} & \sigma_z \end{pmatrix} \rightarrow \begin{pmatrix} \sigma_x \\ \sigma_y \\ \sigma_z \\ \tau_{xy} \\ \tau_{yz} \\ \tau_{zx} \end{pmatrix}$$

- Hydrostatic pressure

$$p = -\frac{1}{3}\left(\sigma_x + \sigma_y + \sigma_z\right)$$

- Von Mises stress:

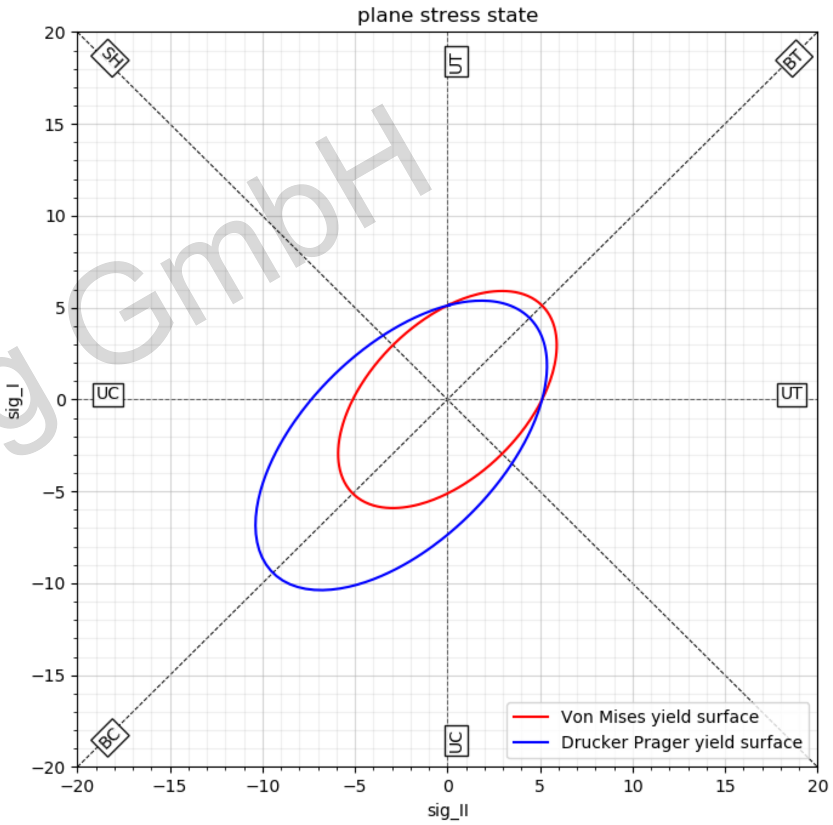
$$q = \sigma_{VM} = \sqrt{{\sigma_x}^2 + {\sigma_y}^2 + {\sigma_z}^2 - \sigma_x\sigma_y - \sigma_y\sigma_z - \sigma_z\sigma_x + 3\left({\tau_{xy}}^2 + {\tau_{yz}}^2 + {\tau_{zx}}^2\right)}$$

- Triaxiality: $\eta = -\frac{p}{q}$

MAT_187 introduction

yield surface

- Yield Surface defines the elastic limit
- general materials: function of all 9 stress components
- isotropic materials: function reduced to 3 principal stresses
- Shell Elements ➔ Plane stress state allows plotting of a curve



BT: Biaxial Tension
UT: Uniaxial Tension
SH: Shear
UC: Uniaxial Compression
BC: Biaxial Compression

Common Yield criteria:

- Von Mises:

$$f(\boldsymbol{\sigma}) = q - \sigma_0$$

- Drucker Prager:

$$f(\boldsymbol{\sigma}) = q - b \cdot p - a$$

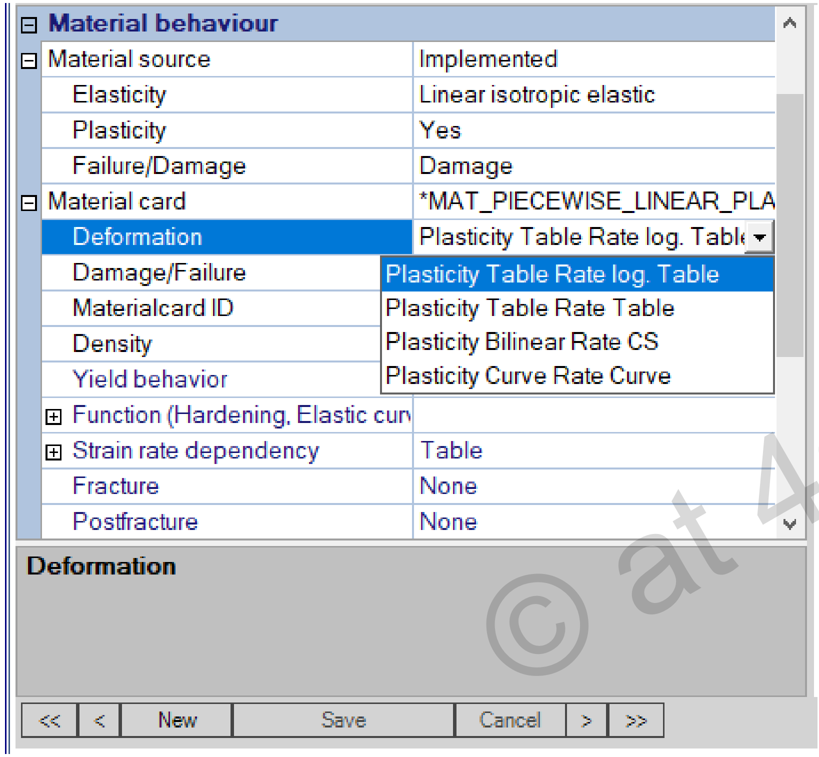
MAT_187 introduction

yield surface

Change of options in the Deformation menu

MAT_024 provides options for the strain rate scaling

MAT_187 provides options for the yield surface shape

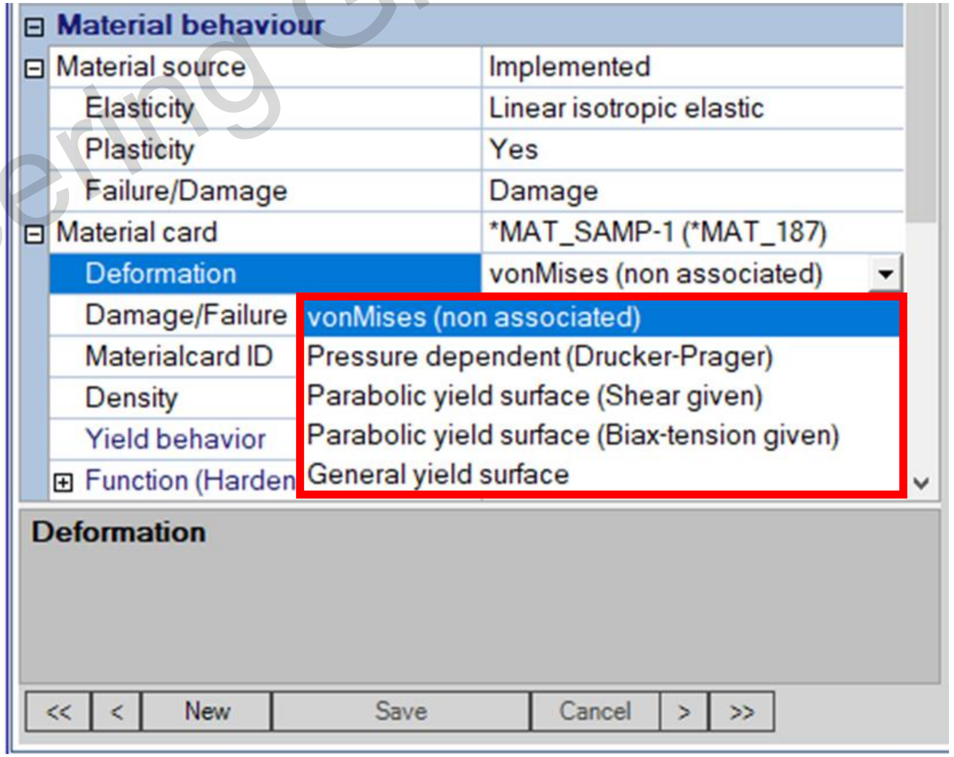


Material behaviour

Material source	Implemented
Elasticity	Linear isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
Material card	*MAT_PIECEWISE_LINEAR_PLA
Deformation	Plasticity Table Rate log. Table
Damage/Failure	
Materialcard ID	
Density	
Yield behavior	
Function (Hardening, Elastic curv	
Strain rate dependency	Table
Fracture	None
Postfracture	None

Plasticity Table Rate log. Table
Plasticity Table Rate Table
Plasticity Bilinear Rate CS
Plasticity Curve Rate Curve

Deformation



Material behaviour

Material source	Implemented
Elasticity	Linear isotropic elastic
Plasticity	Yes
Failure/Damage	Damage
Material card	*MAT_SAMP-1 (*MAT_187)
Deformation	vonMises (non associated)
Damage/Failure	
Materialcard ID	
Density	
Yield behavior	
Function (Harden	

vonMises (non associated)
Pressure dependent (Drucker-Prager)
Parabolic yield surface (Shear given)
Parabolic yield surface (Biax-tension given)
General yield surface

Deformation

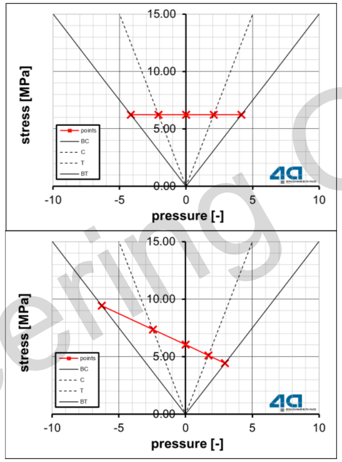
MAT_187 introduction

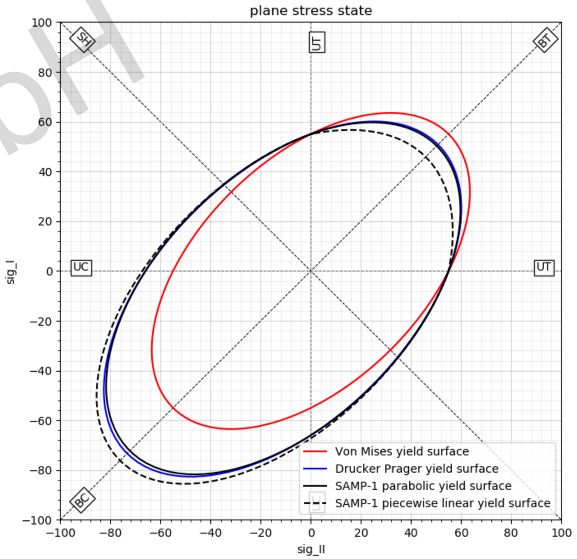
yield surface

Other Criteria

- Von Mises: $f(\boldsymbol{\sigma}) = q - \sigma_0$
- Drucker Prager: $f(\boldsymbol{\sigma}) = q - b \cdot p - a$
- Parabolic: $f(\boldsymbol{\sigma}) = q^2 - c \cdot p^2 - b \cdot p - a$
- piecewise linear yield surface: $f(\boldsymbol{\sigma}) = q - b_i \cdot p - a_i; i = 1 \ldots 4$

Meridian Cut:





BT: Biaxial Tension
UT: Uniaxial Tension
SH: Shear
UC: Uniaxial Compression
BC: Biaxial Compression

MAT_187 introduction

flow rule

Flow rule defines the direction of the plastic strain increment

- associated (normality rule): plastic potential = yield criterion
  - Von Mises with associated flow rule ➔ no Volume change under plastic deformation
- non-associated
  - linear approach (Drucker Prager)

$$d\varepsilon_{ij}^{pl} = d\lambda \frac{\partial g}{\partial \sigma_{ij}}$$

$$g = f$$

$$g = q - \beta p$$

For SAMP the plastic potential is defined by the plastic Poisson's ratio

The plastic Poisson's ratio is determined in the tensile tests

$$\nu_p = -\frac{\varepsilon_y^p}{\varepsilon_x^p}$$

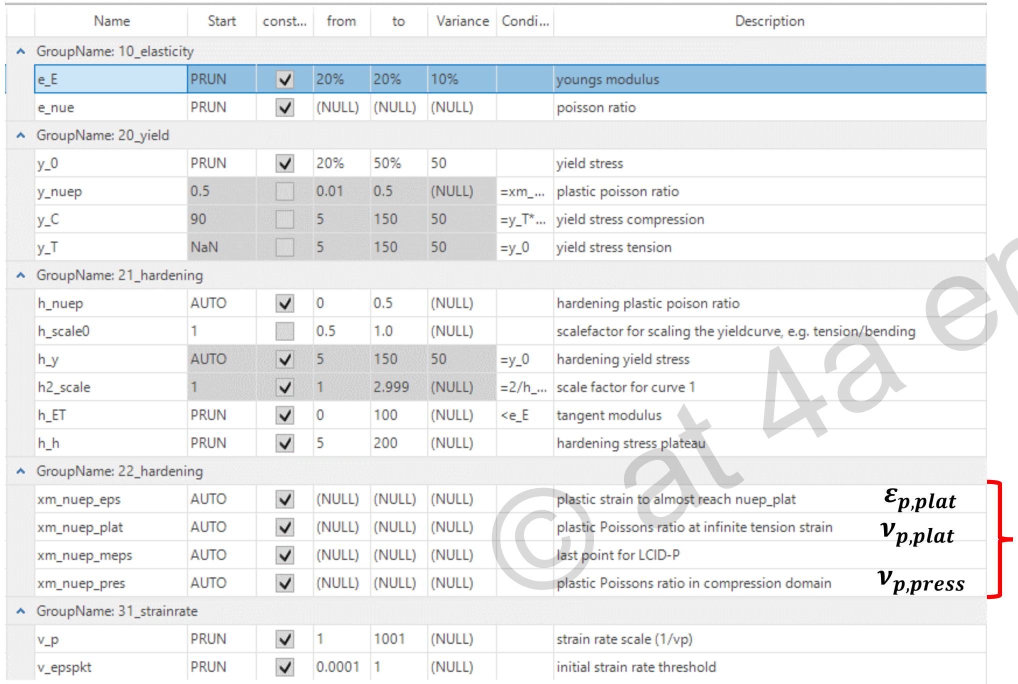
MAT_187 introduction

flow rule

New parameters in Designvariables tab

These parameters define a simple model to describe the relationship between the plastic Poisson's ratio and the equivalent plastic strain

These parameters are used for the plastic potential



Name	Start	const...	from	to	Variance	Condi...	Description
GroupName: 10_elasticity							
e_E	PRUN	☑	20%	20%	10%		youngs modulus
e_nue	PRUN	☑	(NULL)	(NULL)	(NULL)		poisson ratio
GroupName: 20_yield							
y_0	PRUN	☑	20%	50%	50		yield stress
y_nuep	0.5	☐	0.01	0.5	(NULL)	=xm_...	plastic poisson ratio
y_C	90	☐	5	150	50	=y_T*...	yield stress compression
y_T	NaN	☐	5	150	50	=y_0	yield stress tension
GroupName: 21_hardening							
h_nuep	AUTO	☑	0	0.5	(NULL)		hardening plastic poison ratio
h_scale0	1	☐	0.5	1.0	(NULL)		scalefactor for scaling the yieldcurve, e.g. tension/bending
h_y	AUTO	☑	5	150	50	=y_0	hardening yield stress
h2_scale	1	☑	1	2.999	(NULL)	=2/h_...	scale factor for curve 1
h_ET	PRUN	☑	0	100	(NULL)	<e_E	tangent modulus
h_h	PRUN	☑	5	200	(NULL)		hardening stress plateau
GroupName: 22_hardening							
xm_nuep_eps	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic strain to almost reach nuep_plat
xm_nuep_plat	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio at infinite tension strain
xm_nuep_meps	AUTO	☑	(NULL)	(NULL)	(NULL)		last point for LCID-P
xm_nuep_pres	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio in compression domain
GroupName: 31_strainrate							
v_p	PRUN	☑	1	1001	(NULL)		strain rate scale (1/vp)
v_epspkt	PRUN	☑	0.0001	1	(NULL)		initial strain rate threshold

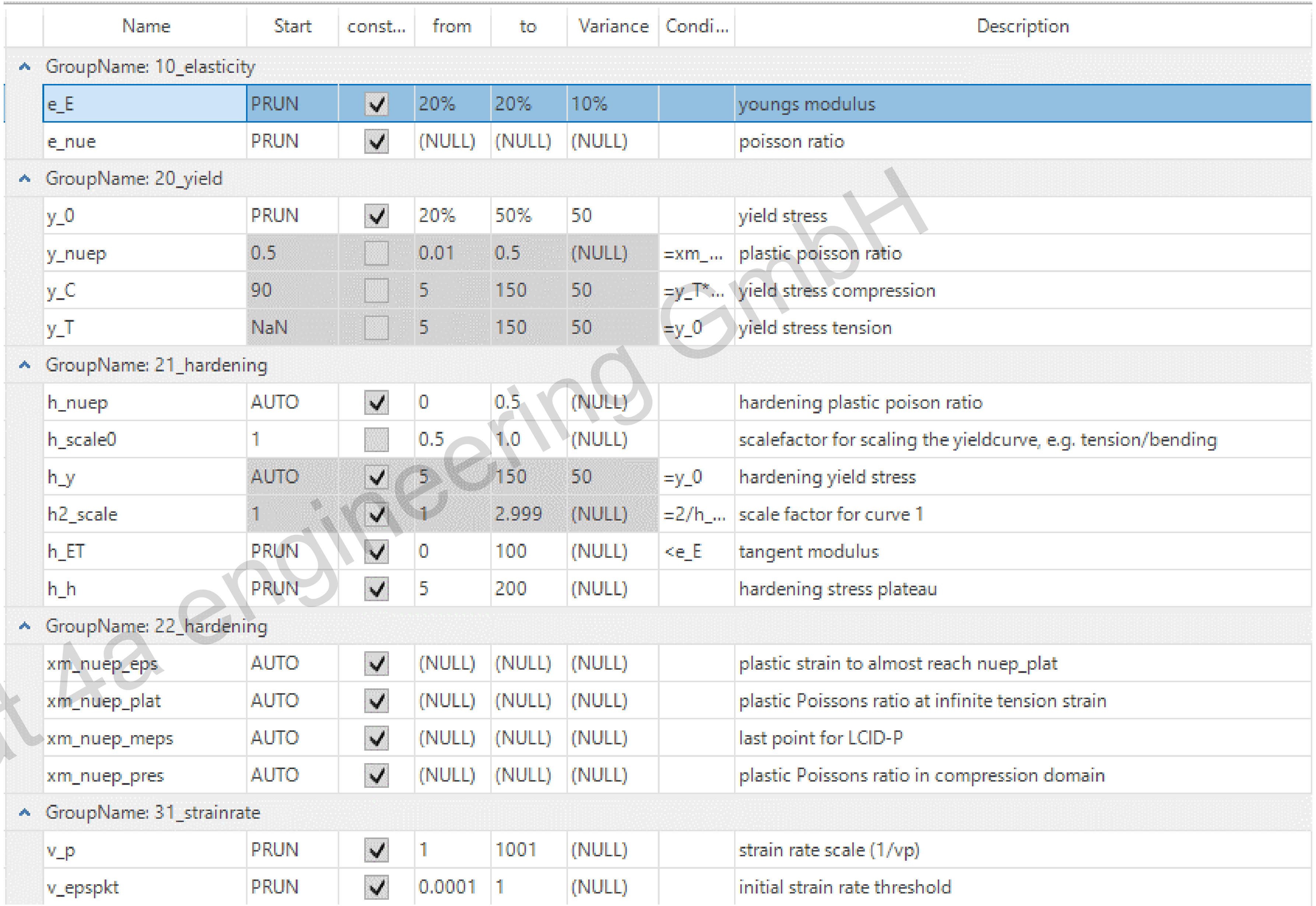
plastic Poisson's ratio law parameters

True Stress	$\sigma_T = \frac{\sigma'_T}{(1 - \nu' \varepsilon'_T)^2}$
True Strain	$\varepsilon_T = \ln(1 + \varepsilon'_T)$
True Transverse Strain	$\varepsilon_t = \ln(1 + \varepsilon'_t)$
Nominal Poisson's Ratio	$\nu' = -\frac{\varepsilon'_t}{\varepsilon'_T}$
Young's Modulus	$E = \frac{\sigma_T}{\varepsilon^e_T}$
True Poisson's Ratio	$\nu = -\frac{\varepsilon_t}{\varepsilon_T}$
True Plastic Strain	$\varepsilon^P_T = \varepsilon_T - \ln\left(1 + \frac{\sigma_T}{E}\right)$
True Transverse Plastic Strain	$\varepsilon^P_t = \varepsilon_t - \ln\left(1 - \nu' \frac{\sigma_T}{E}\right)$
True Plastic Poisson's Ratio	$\nu^P = -\frac{\varepsilon^P_t}{\varepsilon^P_T}$

Q: NPL: Manual for the Calculation of Elastic-Plastic Materials Models Parameters, © Crown copyright 2007

MAT_187 introduction

Designvariable



Name	Start	const...	from	to	Variance	Condi...	Description
GroupName: 10_elasticity							
e_E	PRUN	☑	20%	20%	10%		youngs modulus
e_nue	PRUN	☑	(NULL)	(NULL)	(NULL)		poisson ratio
GroupName: 20_yield							
y_0	PRUN	☑	20%	50%	50		yield stress
y_nuep	0.5	☐	0.01	0.5	(NULL)	=xm_...	plastic poisson ratio
y_C	90	☐	5	150	50	=y_T*...	yield stress compression
y_T	NaN	☐	5	150	50	=y_0	yield stress tension
GroupName: 21_hardening							
h_nuep	AUTO	☑	0	0.5	(NULL)		hardening plastic poison ratio
h_scale0	1	☐	0.5	1.0	(NULL)		scalefactor for scaling the yieldcurve, e.g. tension/bending
h_y	AUTO	☑	5	150	50	=y_0	hardening yield stress
h2_scale	1	☑	1	2.999	(NULL)	=2/h_...	scale factor for curve 1
h_ET	PRUN	☑	0	100	(NULL)	<e_E	tangent modulus
h_h	PRUN	☑	5	200	(NULL)		hardening stress plateau
GroupName: 22_hardening							
xm_nuep_eps	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic strain to almost reach nuep_plat
xm_nuep_plat	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio at infinite tension strain
xm_nuep_meps	AUTO	☑	(NULL)	(NULL)	(NULL)		last point for LCID-P
xm_nuep_pres	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio in compression domain
GroupName: 31_strainrate							
v_p	PRUN	☑	1	1001	(NULL)		strain rate scale (1/vp)
v_epspkt	PRUN	☑	0.0001	1	(NULL)		initial strain rate threshold

$\varepsilon_{p,plat}$

$\nu_{p,plat}$

$\nu_{p,press}$

AutoFit

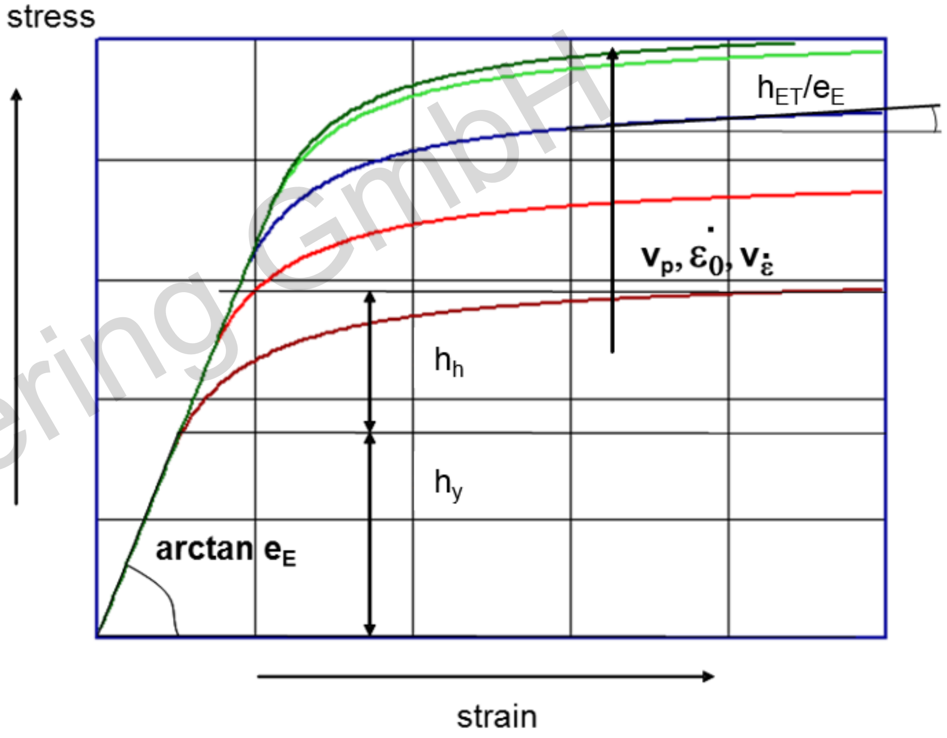
Optimization hardening – 4a model

- LS Dyna - ***MAT_024**
- plastic behavior described using the meta model of Schmachtenberg

$$h_y + e_E \cdot \varepsilon_{pl} \cdot \frac{1 + \frac{h_{ET} \cdot \varepsilon_{pl}}{e_E}}{1 + \frac{e_E \cdot \varepsilon_{pl}}{h_h}}$$

- hardening linear increased by coefficient h_{ET}/e_E
- strain rate dependency based on Johnson- Cook.

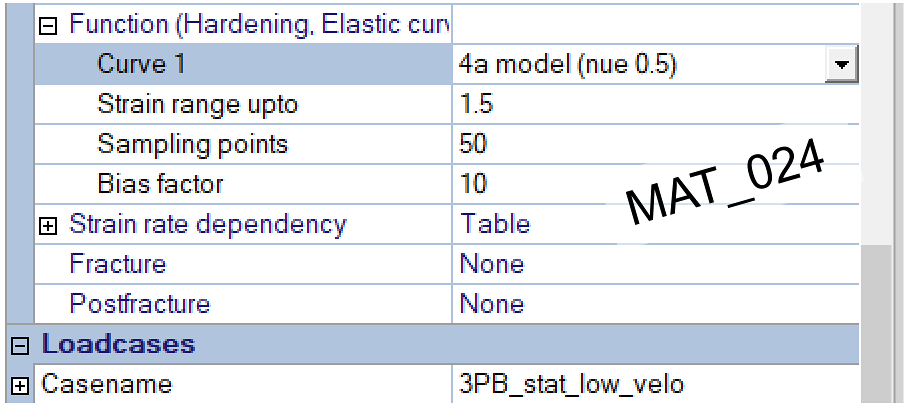
$$1 + \frac{1}{v_p} \cdot \log\left(\frac{\max(\dot{\varepsilon}\ ,\ v_{\dot{\varepsilon}})}{v_{\dot{\varepsilon}}} \right)$$



AutoFit

Optimization yield surface – Drucker Prager

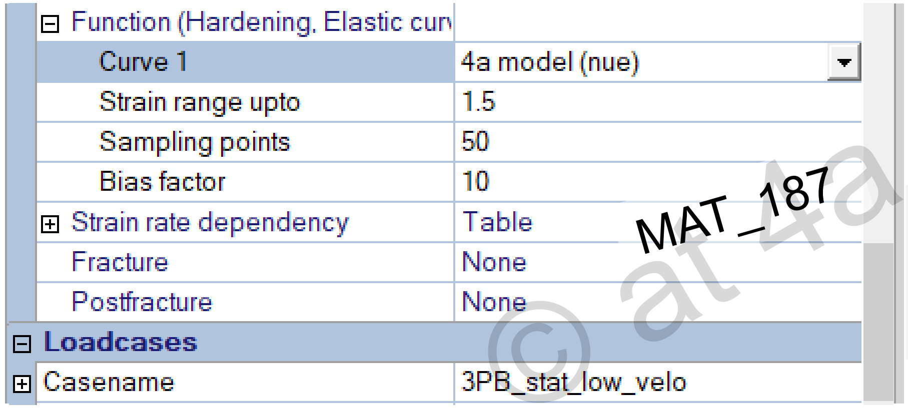
The change of the flow rule must be considered in the hardening law



⊟ Function (Hardening, Elastic curv	
Curve 1	4a model (nue 0.5)
Strain range upto	1.5
Sampling points	50
Bias factor	10
⊞ Strain rate dependency	Table
Fracture	None
Postfracture	None
⊟ **Loadcases**	
⊞ Casename	3PB_stat_low_velo

MAT_024

$$\left[hy + e_E \cdot \varepsilon_{pl} \cdot \frac{1+\frac{h_{BT}\cdot\varepsilon_{pl}}{e_B}}{1+\frac{e_B\cdot\varepsilon_{pl}}{h_s}} \right] \cdot e^{\varepsilon_{pl}\cdot 2\cdot \overset{\overset{0.5}{\downarrow}}{hnuep}} \cdot h_{scale0}$$



⊟ Function (Hardening, Elastic curv	
Curve 1	4a model (nue)
Strain range upto	1.5
Sampling points	50
Bias factor	10
⊞ Strain rate dependency	Table
Fracture	None
Postfracture	None
⊟ **Loadcases**	
⊞ Casename	3PB_stat_low_velo

MAT_187

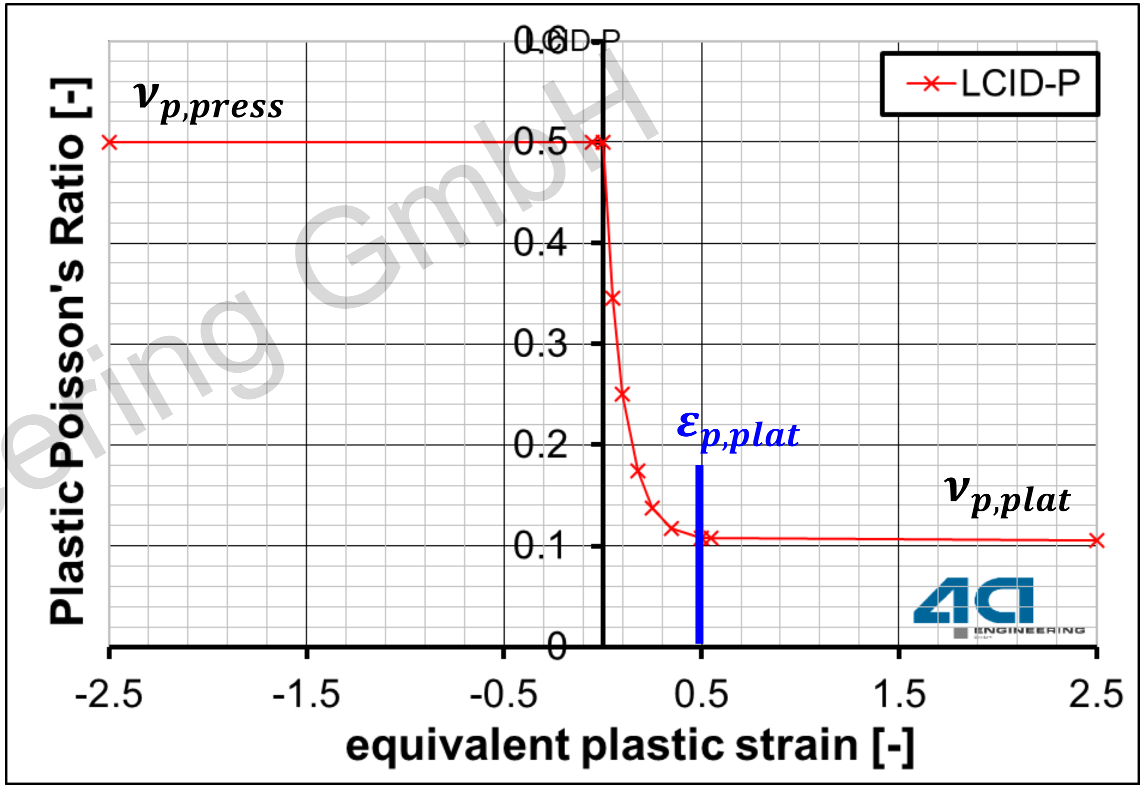
$$\left[hy + e_E \cdot \varepsilon_{pl} \cdot \frac{1+\frac{h_{BT}\cdot\varepsilon_{pl}}{e_B}}{1+\frac{e_B\cdot\varepsilon_{pl}}{h_s}} \right] \cdot e^{\varepsilon_{pl}\cdot 2\cdot \overset{\overset{xm\_nuep\_plat}{\downarrow}}{hnuep}} \cdot h_{scale0}$$

Somewhat taken into account
Should use law and a
compression curve

MAT_187 introduction

flow rule – Plastic Poisson's ratio law

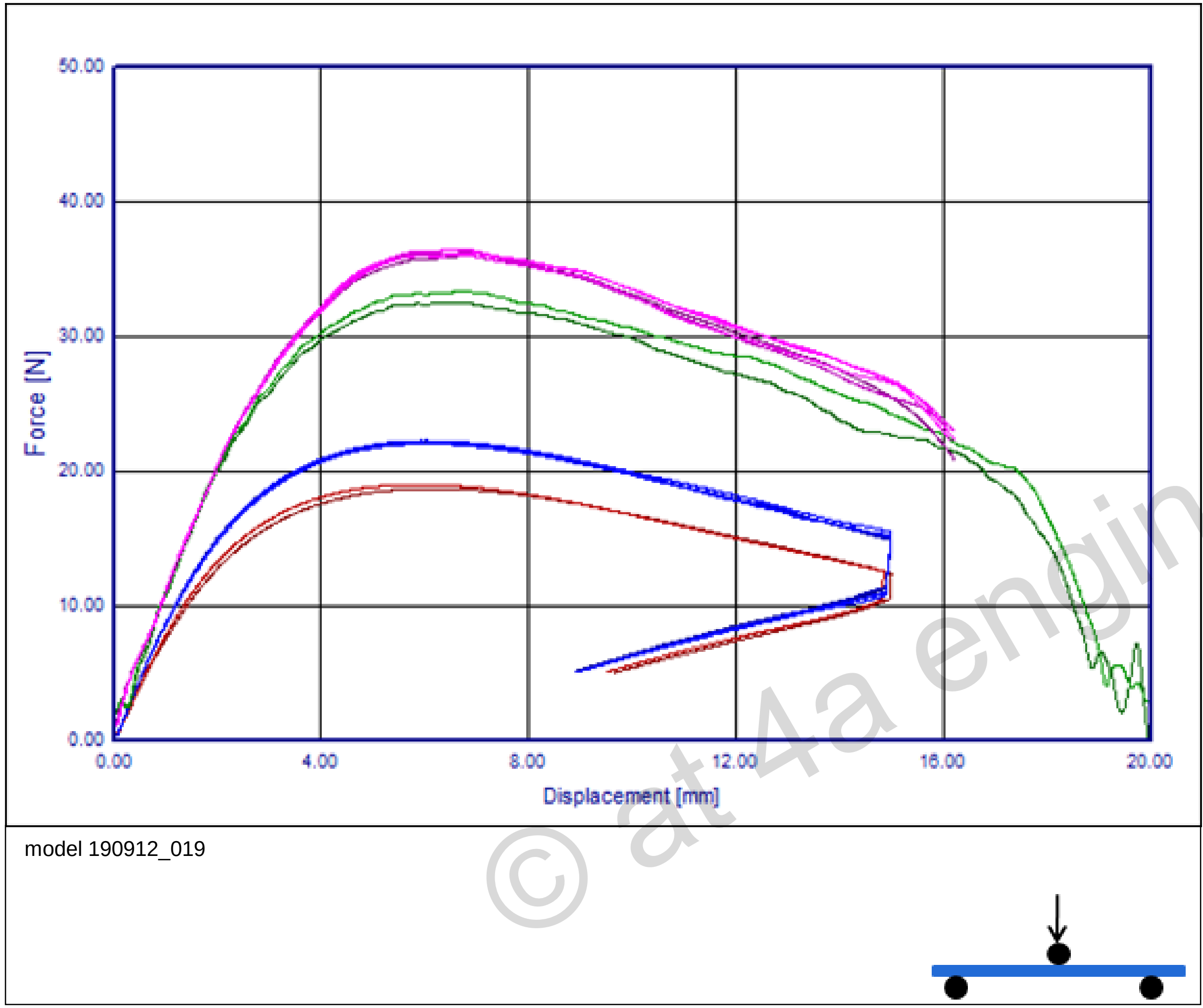
- plastic Poisson's ratio over equivalent plastic strain ➔ expressed with a simple model
- Model assumes exponential decay from compression side to a plateau on the tensile side
- $\boldsymbol{\varepsilon_{p,plat}}$ defines the value where ~99% of the difference between compression and tension is subtracted
- $\boldsymbol{\nu_{p,press}}$ Plastic Poisson's Ratio in compression
- $\boldsymbol{\nu_{p,plat}}$ Plastic Poisson's Ratio Plateau in tension



$$\nu_p = \boldsymbol{\nu_{p,plat}} - \left(\boldsymbol{\nu_{p,plat}} - \boldsymbol{\nu_{p,press}}\right) * e^{\min\left(\frac{-5*\varepsilon_p}{\boldsymbol{\varepsilon_{p,plat}}};0\right)}$$

AutoFit

Data – 3-point-bending

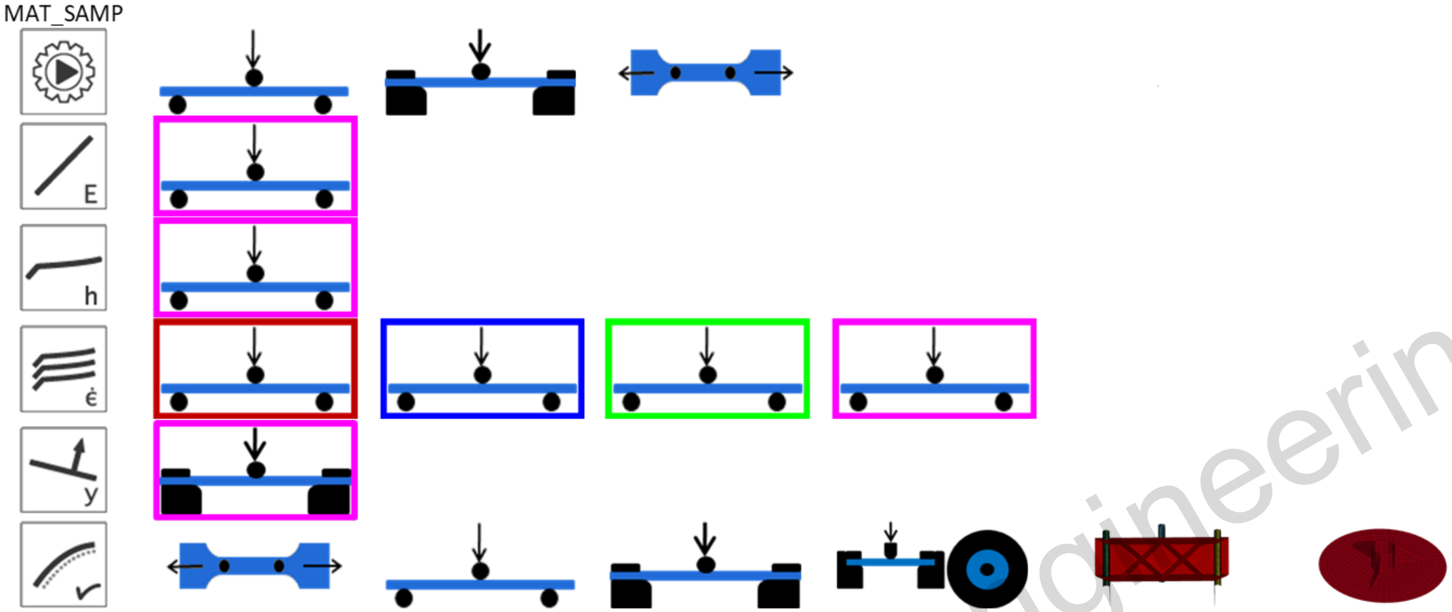


model 190912_019

Case	v_0 [m/s]	l_w [mm]	$m_{Pendulum}$ [g]	b [mm]	t [mm]	l [mm]
3PB_V0p1_d00_l	**0.0001**	**40.01**	**0**	**9.93**	**1.99**	**49.75**
3PB_V1_d00_l	**0.001**	**40.01**	**0**	**9.91**	**2.00**	**50.06**
3PB_V1000_d00_l	**1**	**40.01**	**1580**	**9.91**	**1.99**	**50.10**
3PB_V2500_d00_l	**2.5**	**40.01**	**1580**	**9.91**	**1.99**	**49.94**

AutoFit

Strategy



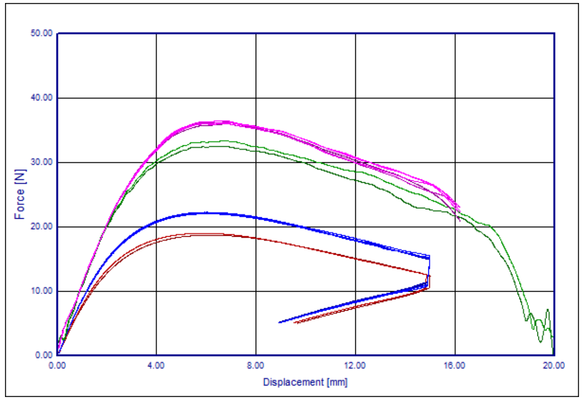
without border all velocities

quasistatic low velocity

quasistatic high velocity

dynamic low velocity

dynamic medium velocity



- For crash card a dynamic case for the Young‘s modulus and hardening curve fit

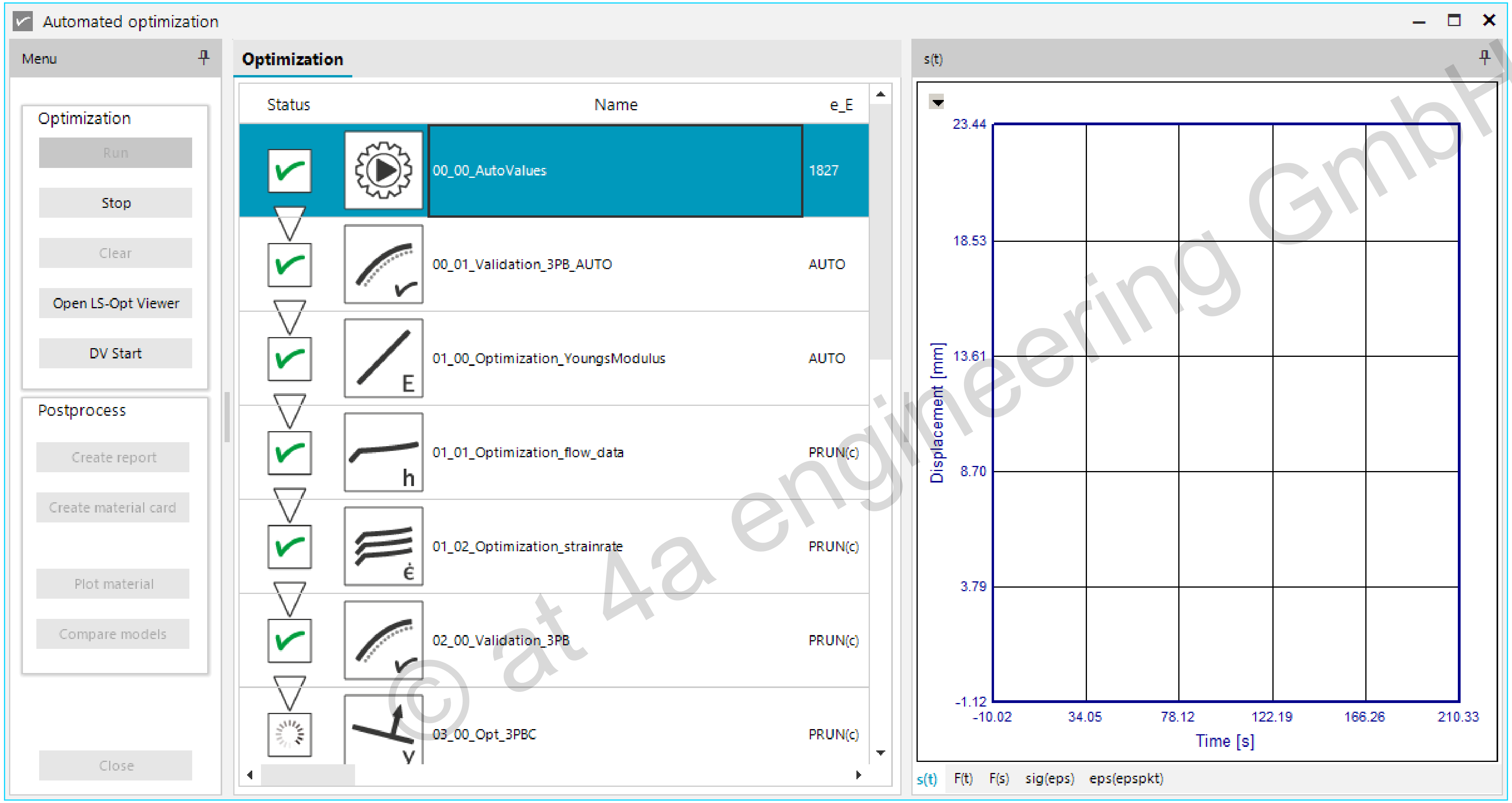
AutoFit

Database

- For the AutoFit function several methods have to be prepared.
- On the following slides the AutoFit function will be called on the training database.
- The model settings will be discussed as they appear in the workflow.

AutoFit

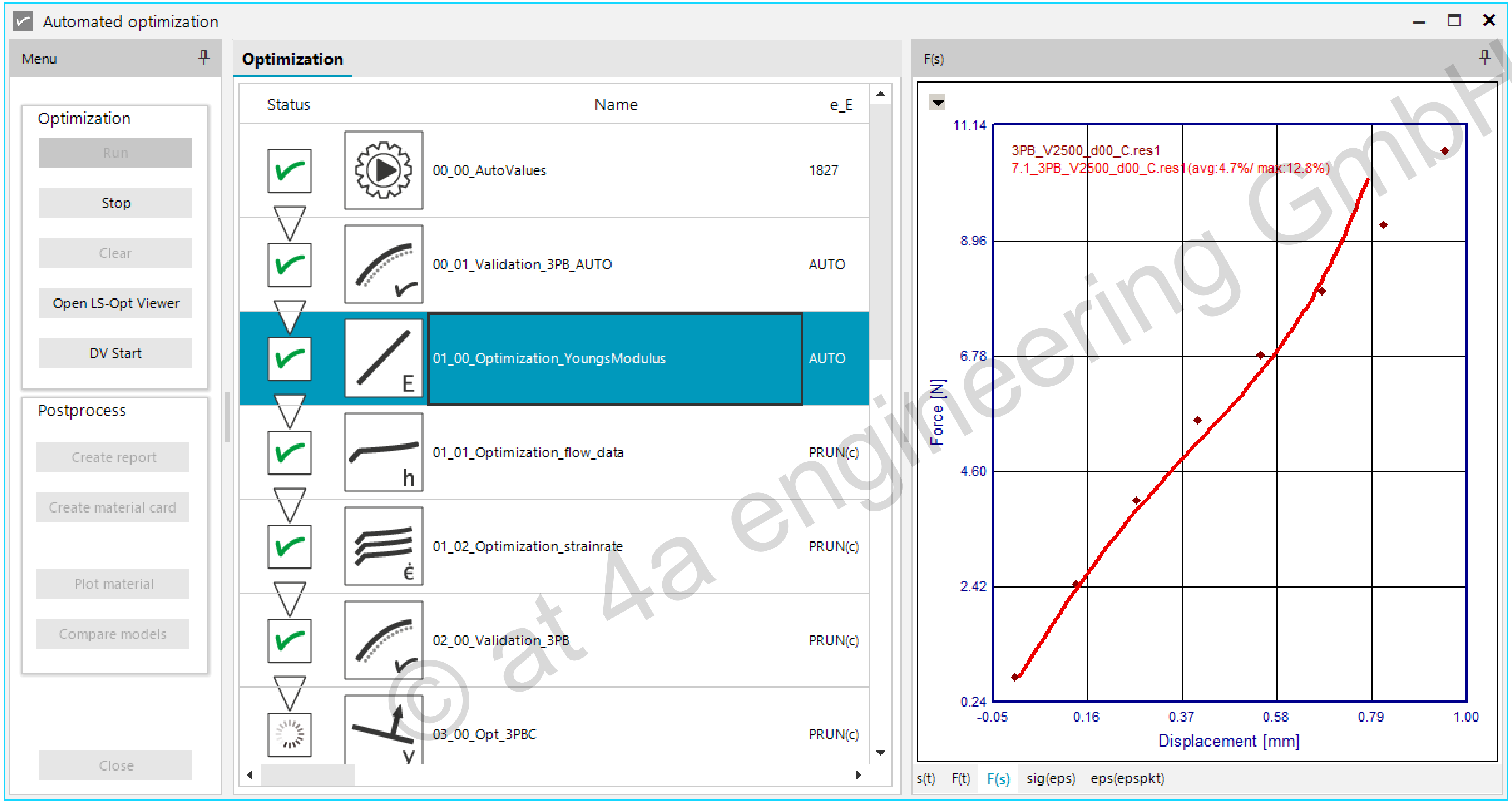
Auto Values



Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
	03_00_Opt_3PBC	PRUN(c)

AutoFit

Optimization Young's modulus

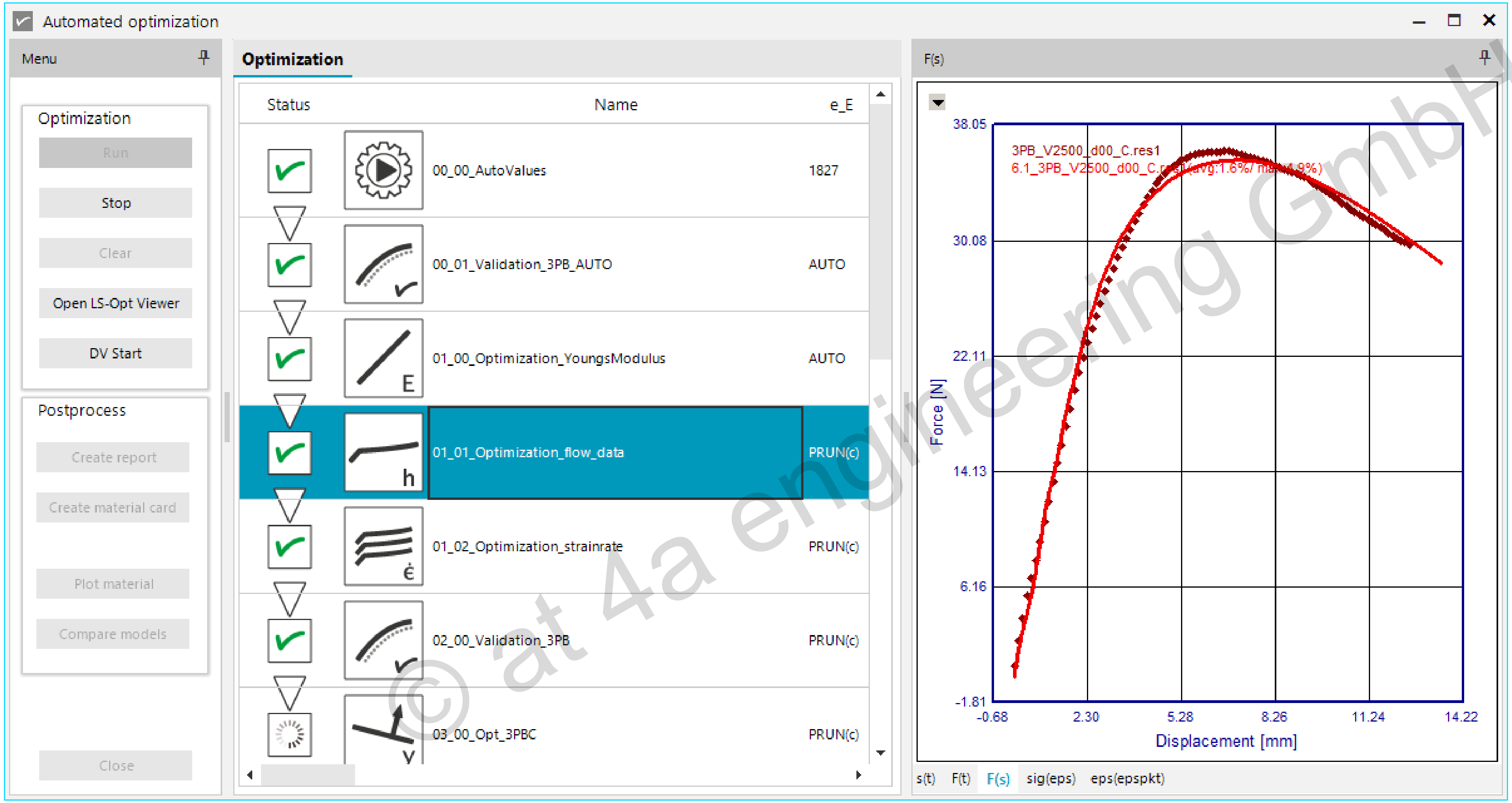


Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
	03_00_Opt_3PBC	PRUN(c)

<u>Checks:</u>
are oscillations too high?
curve long enough?
curve still linear elastic?

AutoFit

Optimization hardening



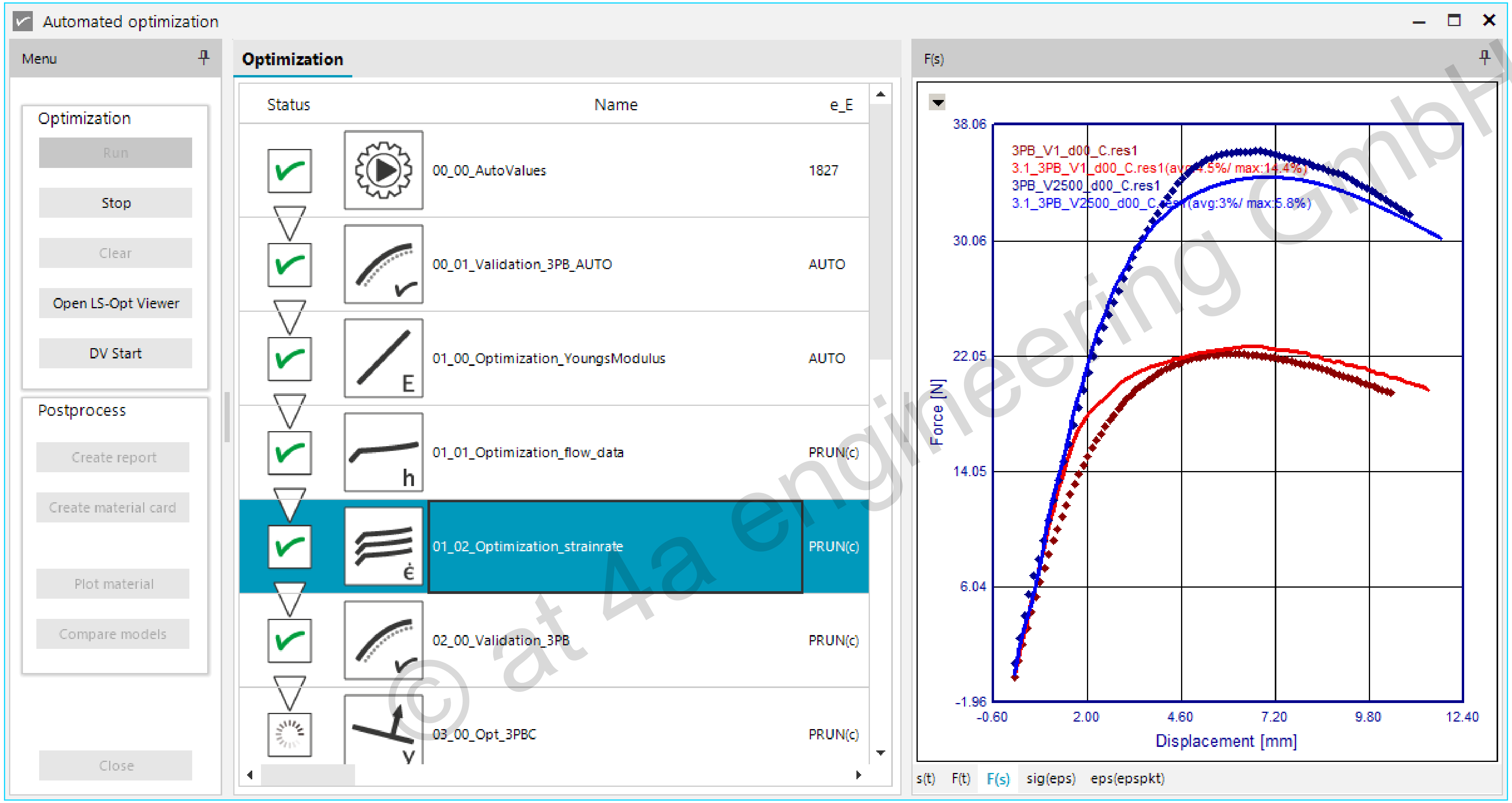
Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
	03_00_Opt_3PBC	PRUN(c)

3PB_V2500_d00_C.res1
6.1_3PB_V2500_d00_C.res1(avg:1.6%/ max:4.9%)

Checks:
curve long enough?
good fit?

AutoFit

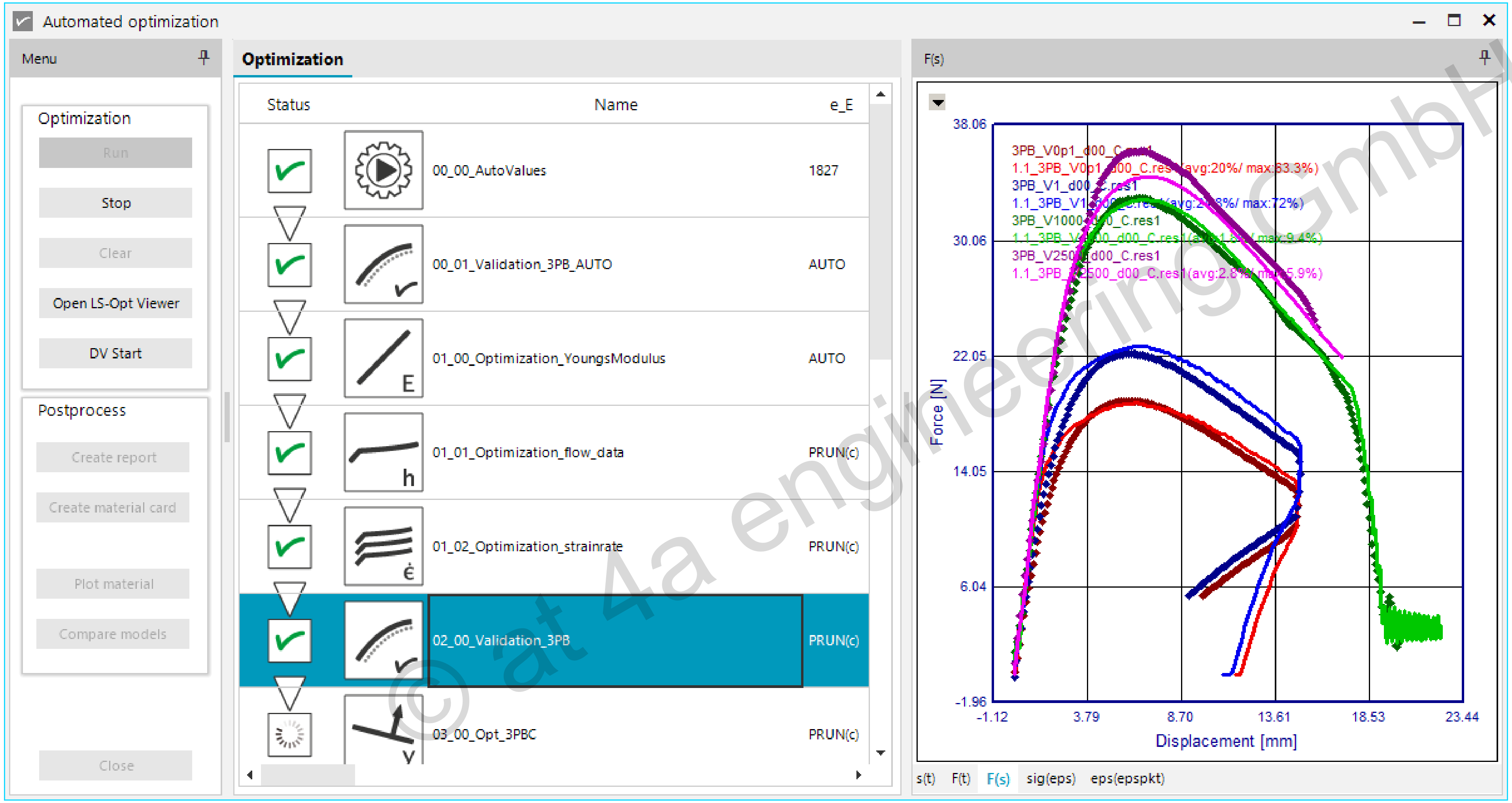
Optimization strain rate dependency



Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
	03_00_Opt_3PBC	PRUN(c)

AutoFit

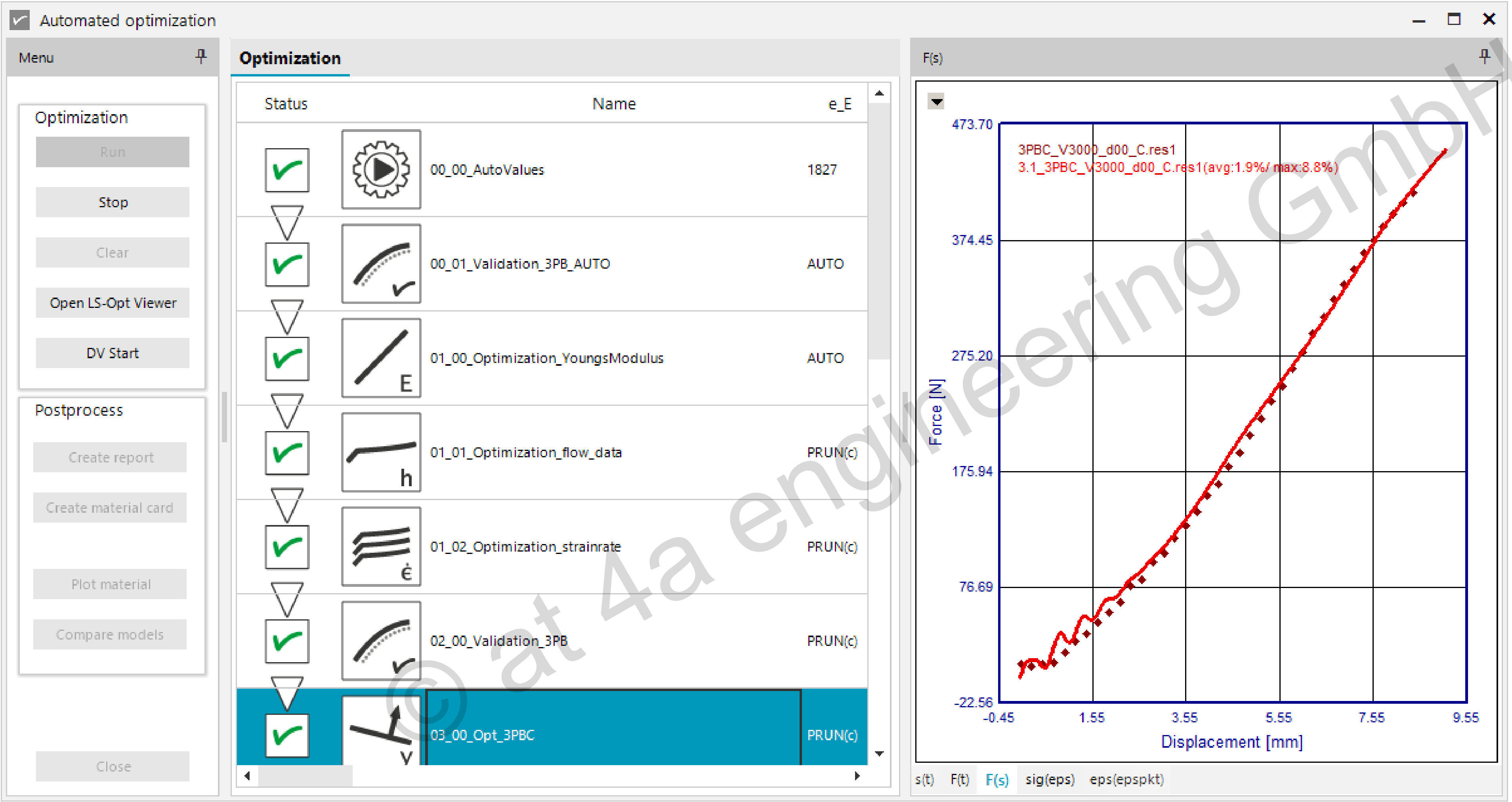
Validation – MAT_024



Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
	03_00_Opt_3PBC	PRUN(c)

AutoFit

Optimization yield surface – Drucker Prager



Status	Name	e_E
✓	00_00_AutoValues	1827
✓	00_01_Validation_3PB_AUTO	AUTO
✓	01_00_Optimization_YoungsModulus	AUTO
✓	01_01_Optimization_flow_data	PRUN(c)
✓	01_02_Optimization_strainrate	PRUN(c)
✓	02_00_Validation_3PB	PRUN(c)
✓	03_00_Opt_3PBC	PRUN(c)

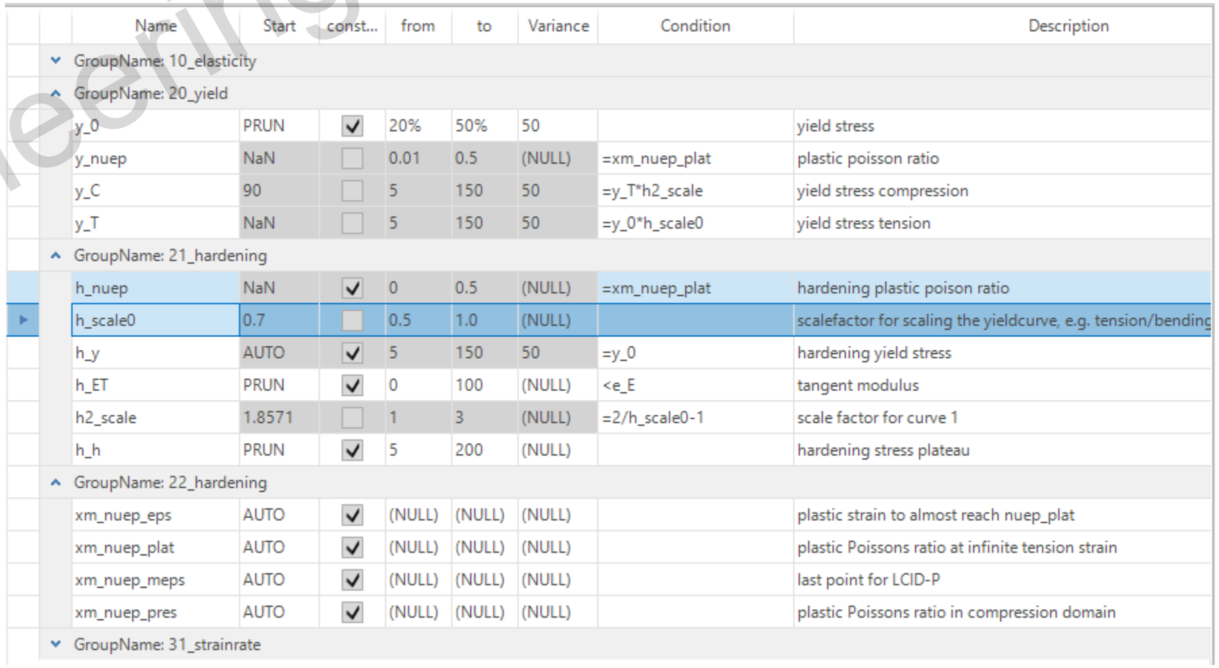
3PBC_V3000_d00_C.res1
3.1_3PBC_V3000_d00_C.res1(avg:1.9%/ max:8.8%)

AutoFit

Optimization yield surface – Drucker Prager

Validation/Optimization: **Optimization Yieldsurface**

- Drucker/Prager parameters introduced
- Optimized Parameters are set to PRUN
- New Parameters
  - h_scale0: from 3PB ➔ TT
  - h2_scale: from TT ➔ CT



Name	Start	const...	from	to	Variance	Condition	Description
GroupName: 10_elasticity							
GroupName: 20_yield							
y_0	PRUN	☑	20%	50%	50		yield stress
y_nuep	NaN	☐	0.01	0.5	(NULL)	=xm_nuep_plat	plastic poisson ratio
y_C	90	☐	5	150	50	=y_T*h2_scale	yield stress compression
y_T	NaN	☐	5	150	50	=y_0*h_scale0	yield stress tension
GroupName: 21_hardening							
h_nuep	NaN	☑	0	0.5	(NULL)	=xm_nuep_plat	hardening plastic poison ratio
h_scale0	0.7	☐	0.5	1.0	(NULL)		scalefactor for scaling the yieldcurve, e.g. tension/bending
h_y	AUTO	☑	5	150	50	=y_0	hardening yield stress
h_ET	PRUN	☑	0	100	(NULL)	<e_E	tangent modulus
h2_scale	1.8571	☐	1	3	(NULL)	=2/h_scale0-1	scale factor for curve 1
h_h	PRUN	☑	5	200	(NULL)		hardening stress plateau
GroupName: 22_hardening							
xm_nuep_eps	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic strain to almost reach nuep_plat
xm_nuep_plat	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio at infinite tension strain
xm_nuep_meps	AUTO	☑	(NULL)	(NULL)	(NULL)		last point for LCID-P
xm_nuep_pres	AUTO	☑	(NULL)	(NULL)	(NULL)		plastic Poissons ratio in compression domain
GroupName: 31_strainrate							

AutoFit

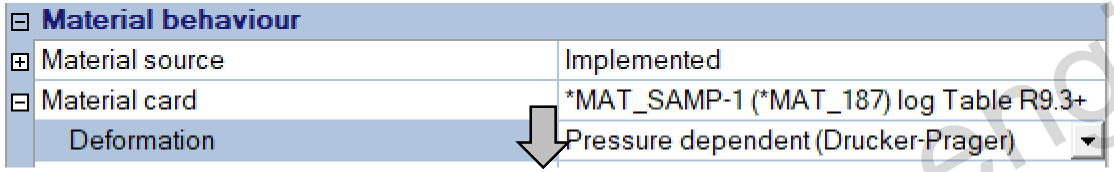
Optimization yield surface – Drucker Prager

MAT_024:

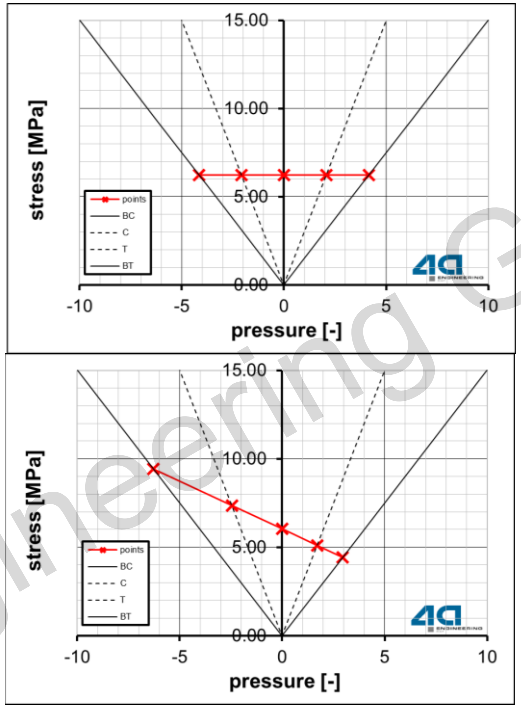
- Von Mises: $f(\boldsymbol{\sigma}) = q - \sigma_0$

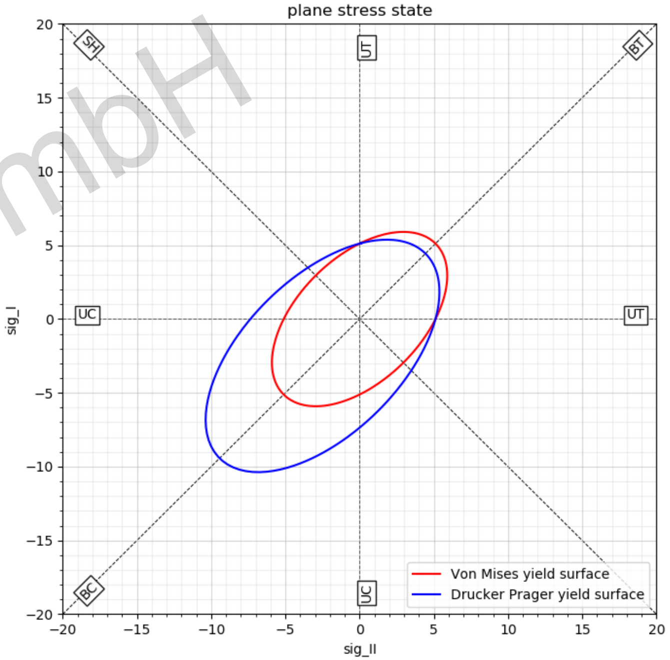
MAT_187:

- Drucker Prager: $f(\boldsymbol{\sigma}) = q - b \cdot p - a$



Material behaviour	
Material source	Implemented
Material card	*MAT_SAMP-1 (*MAT_187) log Table R9.3+
Deformation	Pressure dependent (Drucker-Prager)





- Designvariables:

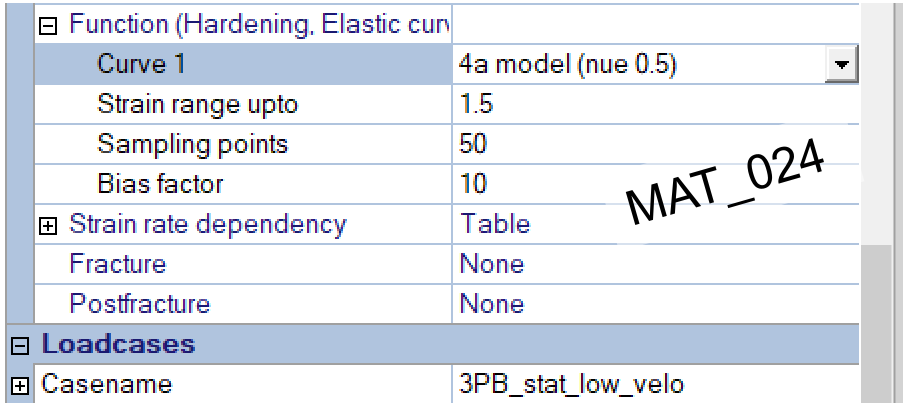
Name	Start	constant	from	to	Variance	Condition
h_scale0	0.7	False	0.5	1.0	(NULL)	
y_T	NaN	False	5	150	50	=y_0*h_scale0
y_C	90	False	5	150	50	=y_T*h2_scale
y_0	PRUN	True	20%	50%	50	
h2_scale	1.8571	False	1	3	(NULL)	=2/h_scale0-1

BT: Biaxial Tension
UT: Uniaxial Tension
SH: Shear
UC: Uniaxial Compression
BC: Biaxial Compression

AutoFit

Optimization yield surface – Drucker Prager

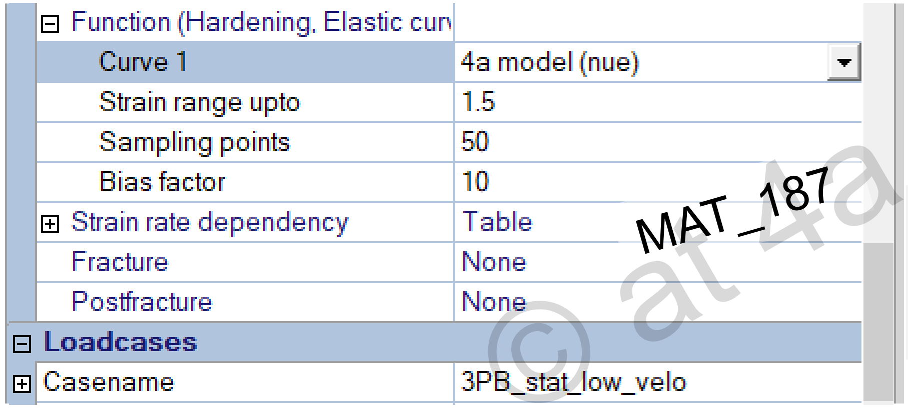
The change of the flow rule must be considered in the hardening law



MAT_024

⊟ Function (Hardening, Elastic curv	
Curve 1	4a model (nue 0.5)
Strain range upto	1.5
Sampling points	50
Bias factor	10
⊞ Strain rate dependency	Table
Fracture	None
Postfracture	None
⊟ Loadcases	
⊞ Casename	3PB_stat_low_velo

$$\left[hy + e_E \cdot \varepsilon_{pl} \cdot \frac{1+\frac{h_{BT}\cdot\varepsilon_{pl}}{e_B}}{1+\frac{e_B\cdot\varepsilon_{pl}}{h_b}}\right] \cdot e^{\varepsilon_{pl}\cdot 2\cdot \overset{\overset{0.5}{\downarrow}}{hnuep}} \cdot hscale0$$



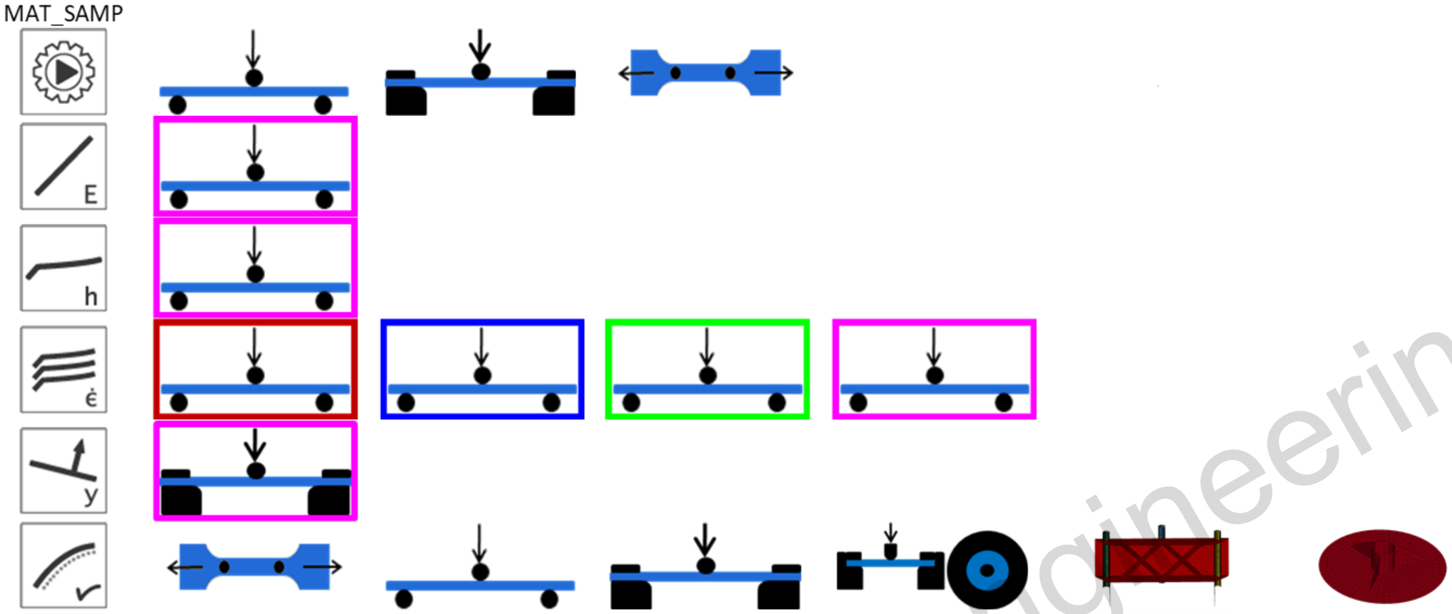
MAT_187

⊟ Function (Hardening, Elastic curv	
Curve 1	4a model (nue)
Strain range upto	1.5
Sampling points	50
Bias factor	10
⊞ Strain rate dependency	Table
Fracture	None
Postfracture	None
⊟ Loadcases	
⊞ Casename	3PB_stat_low_velo

$$\left[hy + e_E \cdot \varepsilon_{pl} \cdot \frac{1+\frac{h_{BT}\cdot\varepsilon_{pl}}{e_B}}{1+\frac{e_B\cdot\varepsilon_{pl}}{h_b}}\right] \cdot e^{\varepsilon_{pl}\cdot 2\cdot \overset{\overset{xm\_nuep\_plat}{\downarrow}}{hnuep}} \cdot hscale0$$

Somewhat taken into account
Should use law and a compression curve

AutoReport



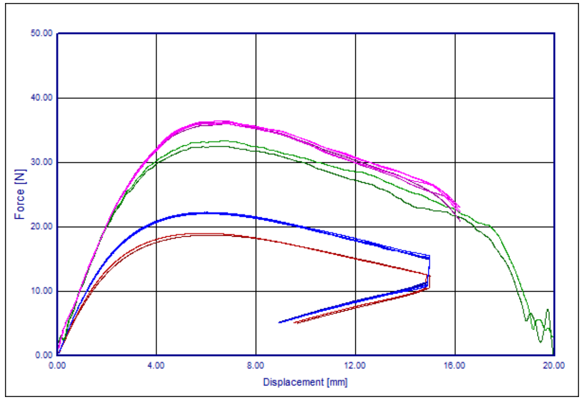
without border all velocities

quasistatic low velocity

quasistatic high velocity

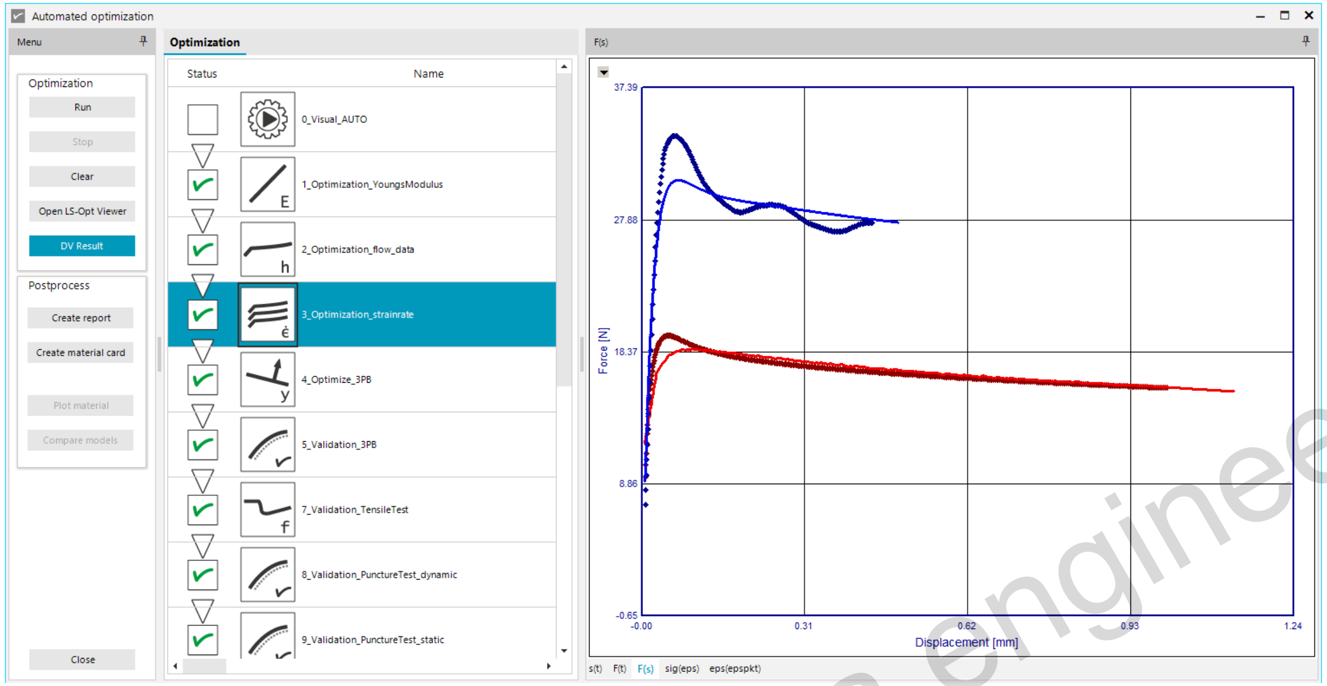
dynamic low velocity

dynamic medium velocity



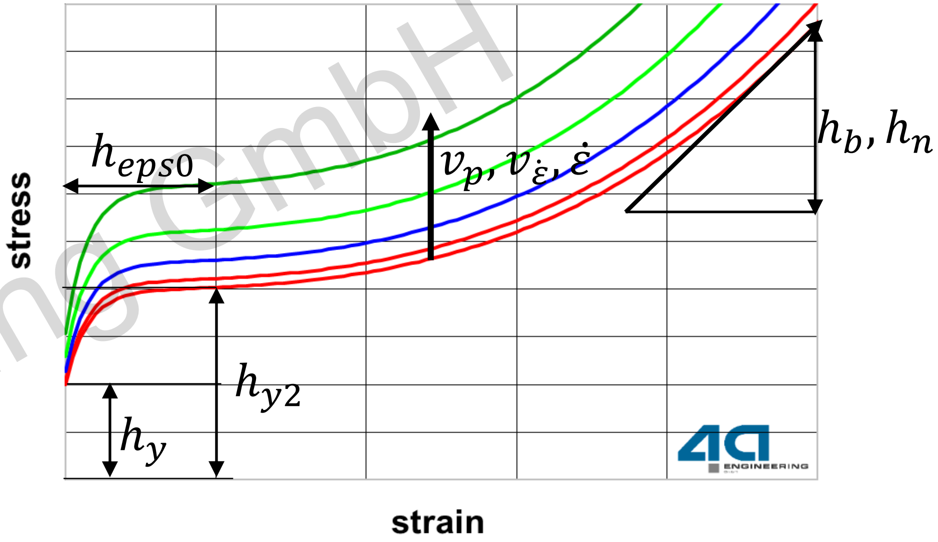
- For an overview of the behavior of the material card one can use the AutoReport feature of VALIMAT
- The following slide is the template for the AutoReport

Workflow for material card generation - AUTOFIT

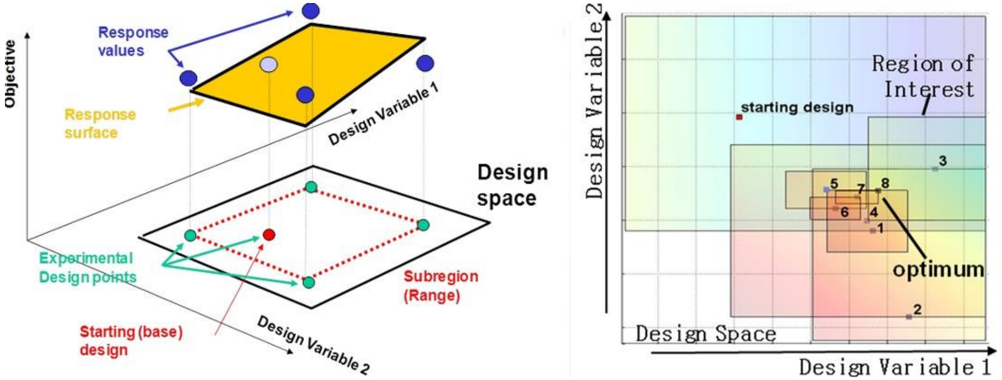


☐ 0_Visual_AUTO
☑ 1_Optimization_YoungsModulus
☑ 2_Optimization_flow_data
☑ 3_Optimization_strainrate
☑ 4_Optimize_3PB
☑ 5_Validation_3PB
☑ 7_Validation_TensileTest
☑ 8_Validation_PunctureTest_dynamic
☑ 9_Validation_PunctureTest_static

parametrized material card

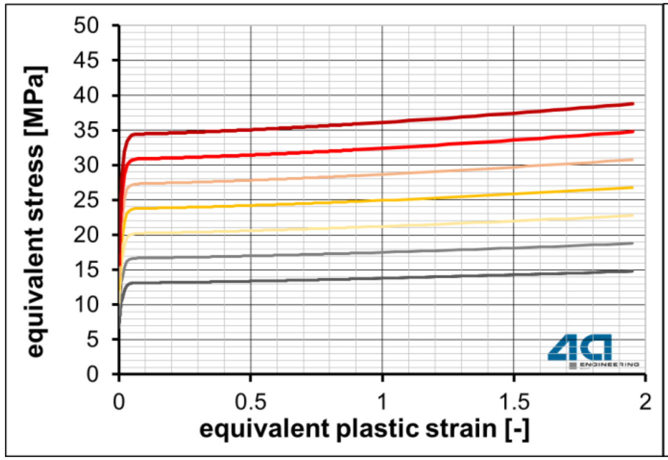


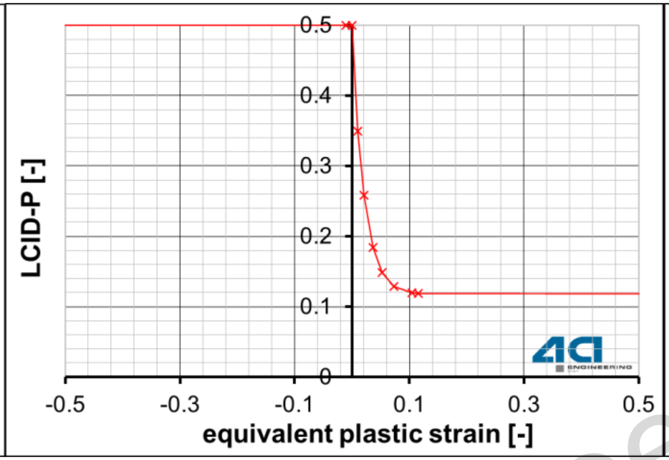
optimization – successive response surface method

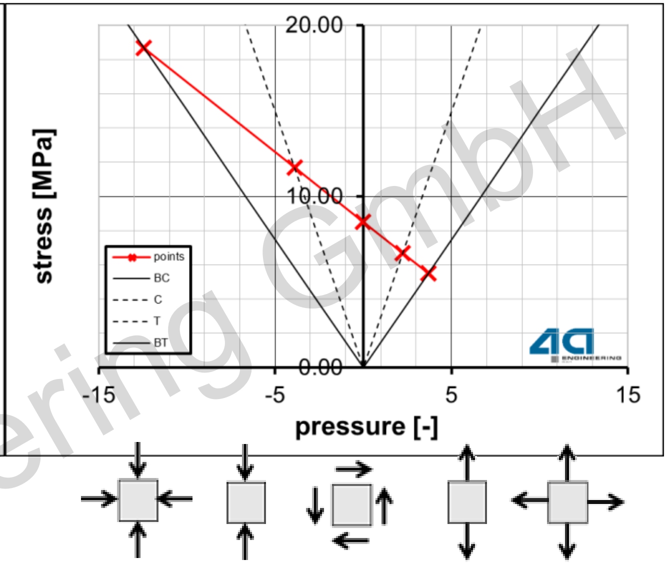


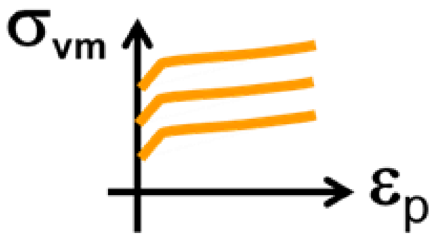
[redacted]

*MAT-SAMP 1 with internal FM – result AUTOFIT

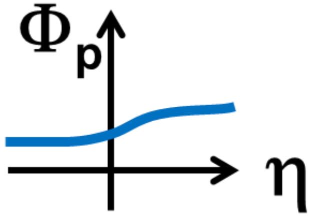








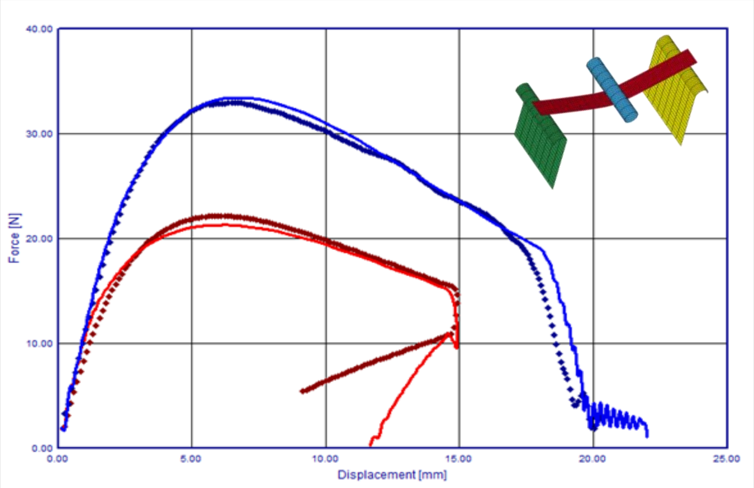
Hardening



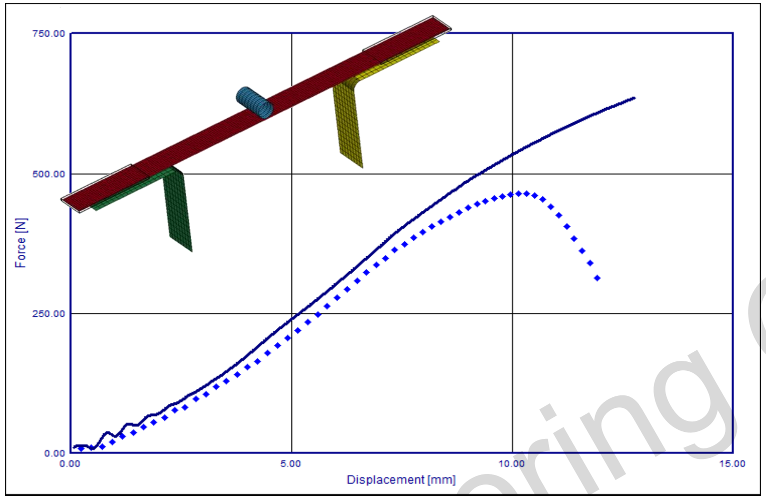
Triaxiality

source: Benjamin Hirschmann, master thesis

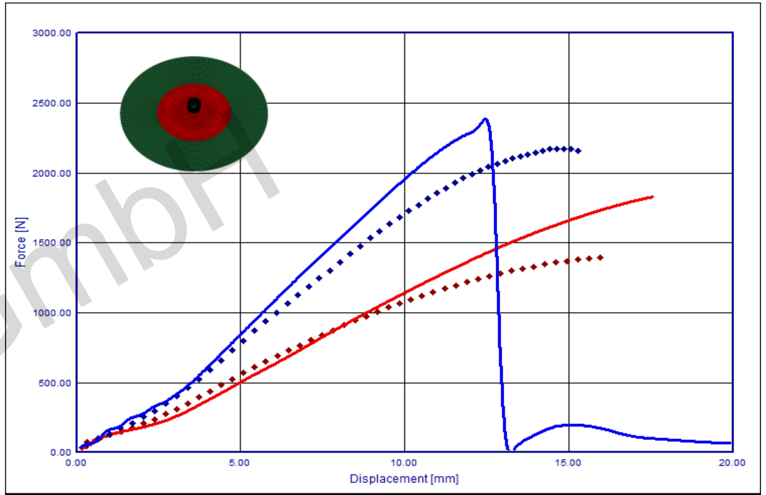
*MAT-SAMP 1 with internal failure model - validation



3 POINT BENDING



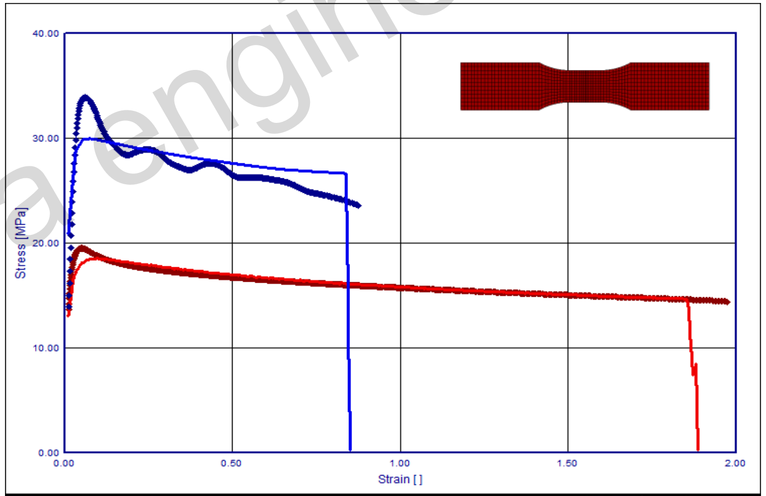
TENSION BENDING



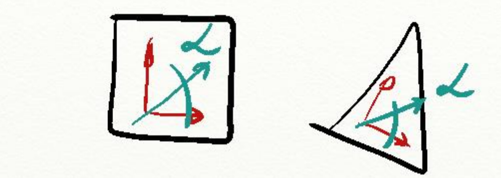
PUNCTURE TEST

IMPETUS™ ~ 3 m/s

static ~ 1mm/s



TENSION TEST

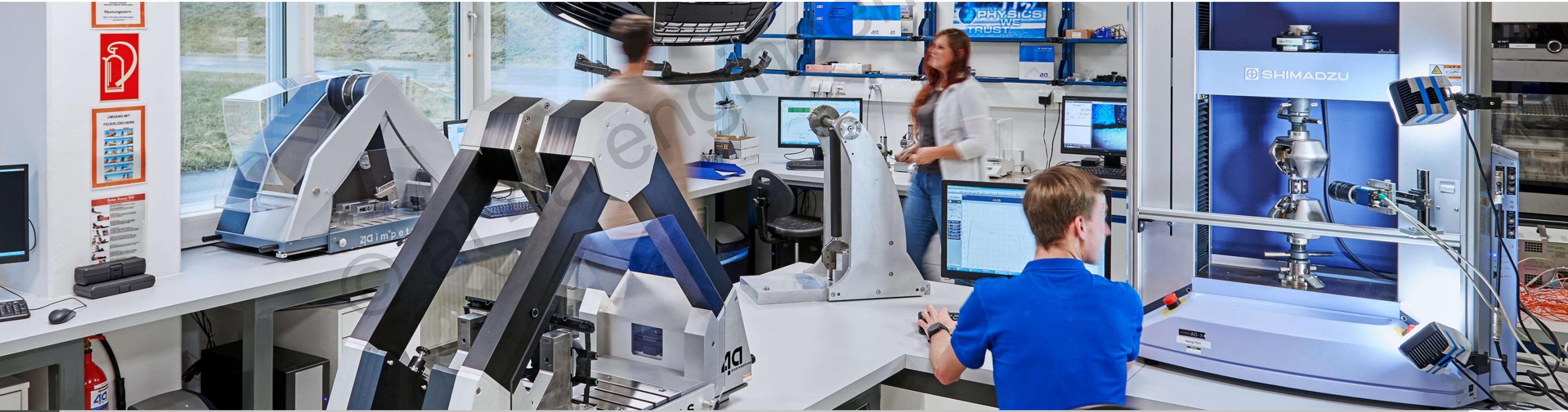


···· averaged test curves

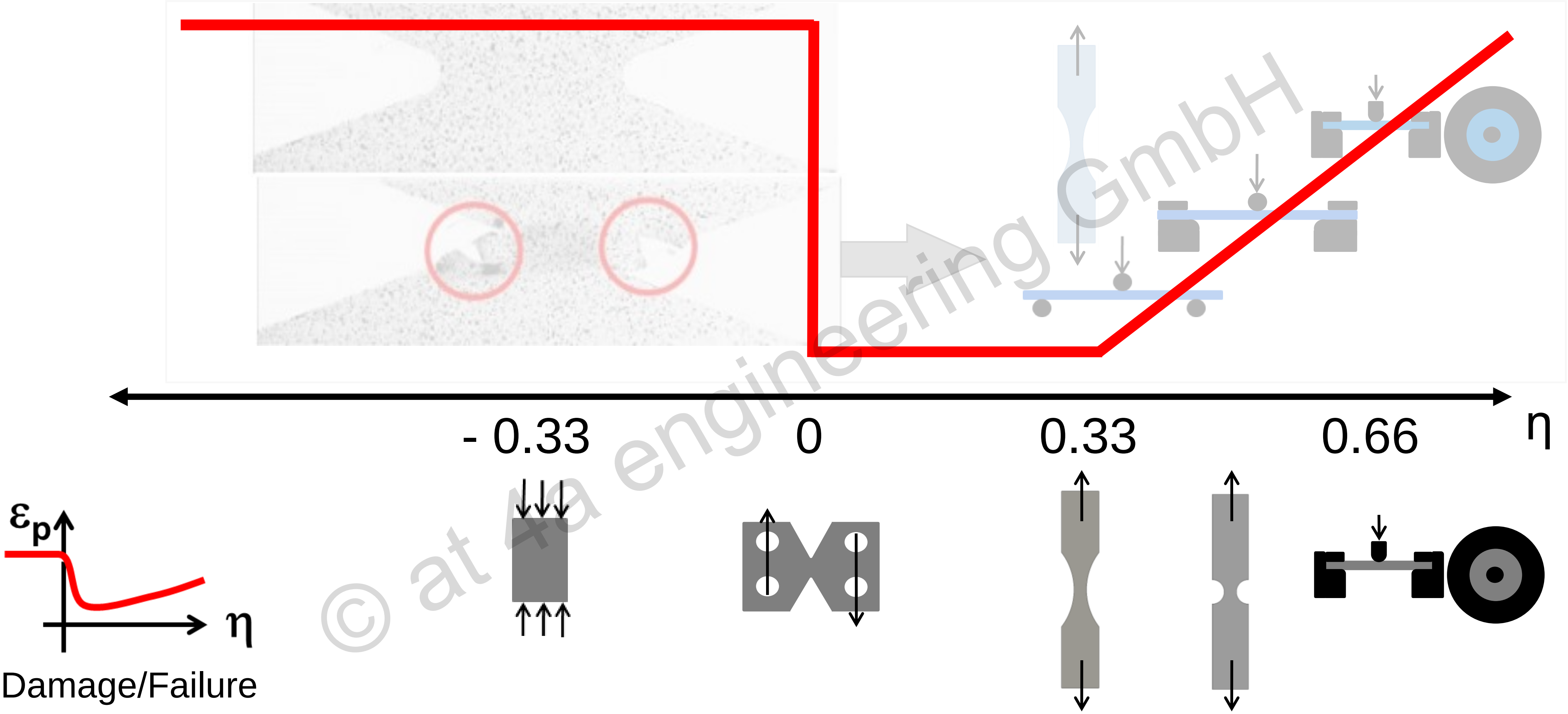
— result of simulation

source: Benjamin Hirschmann, master thesis

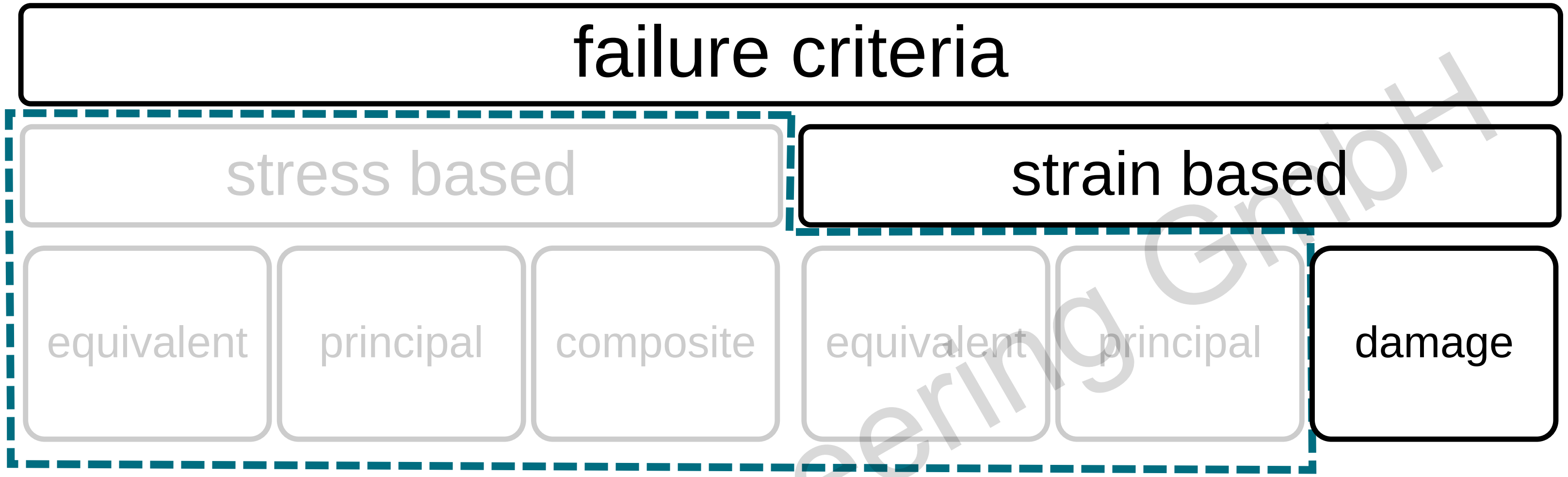
MAT_ADD_EROSION DIEM



From test to material card



Available failure models in LS-DYNA®



failure criteria

stress based

strain based

equivalent

principal

composite

equivalent

principal

damage

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 damage model in

****MAT_SAMP-1***

GISSMO like

****MAT_4A_MICROMEC***

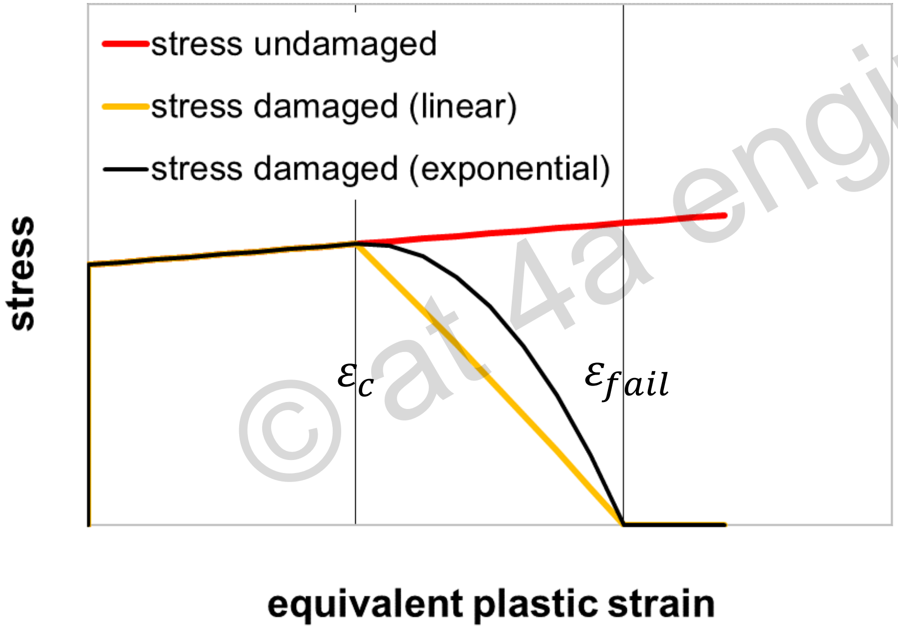
DIEM for matrix failure

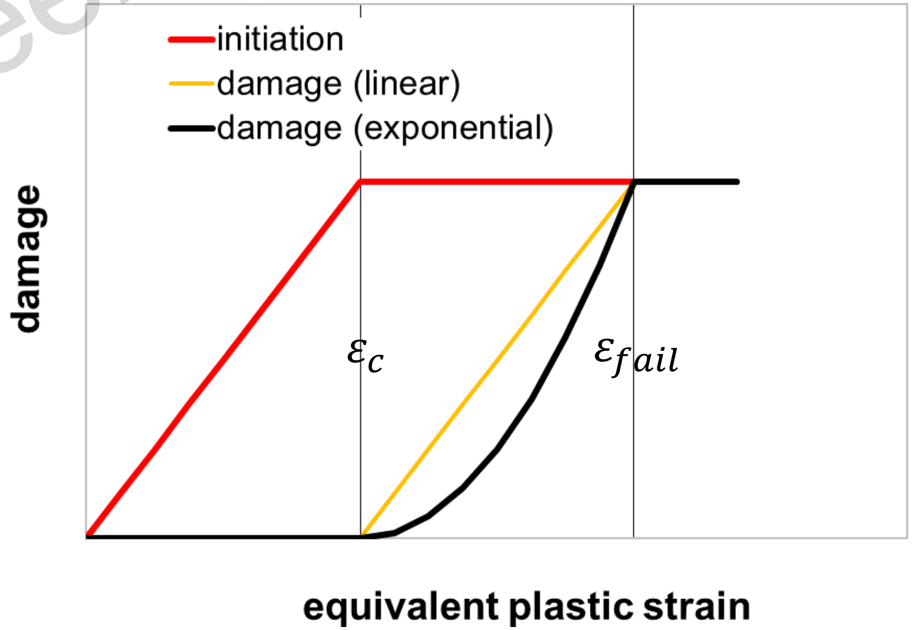
Available Failure Models – incremental damage formulation

failure criteria

stress based | strain based

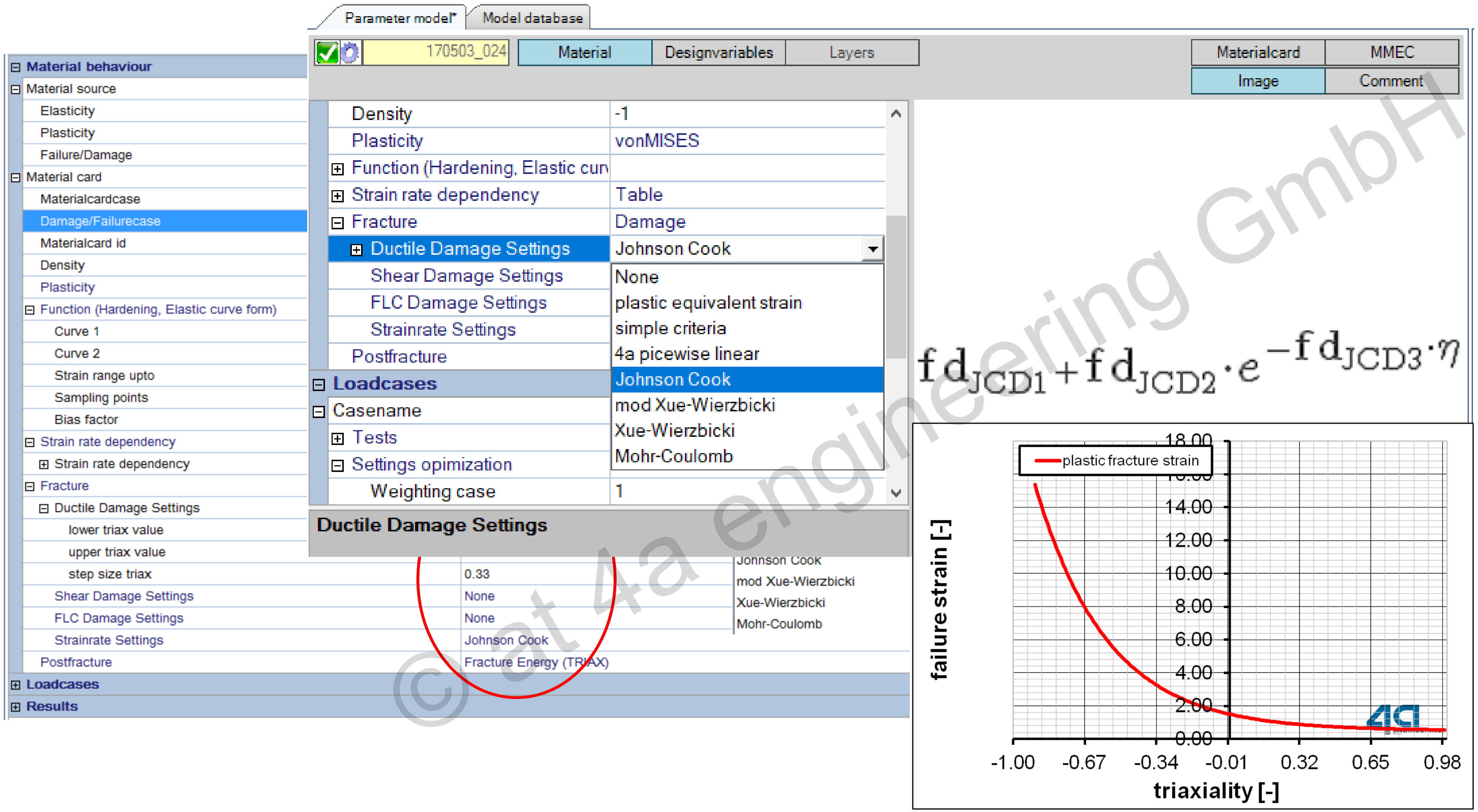
equivalent | principal | composite | equivalent | principal | **damage**





Fracture models → *MAT_ADD_EROSION

VALIMAT



Density	-1
Plasticity	vonMISES
⊞ Function (Hardening, Elastic curv	
⊞ Strain rate dependency	Table
⊟ Fracture	Damage
⊞ Ductile Damage Settings	Johnson Cook
Shear Damage Settings	
FLC Damage Settings	
Strainrate Settings	
Postfracture	
⊟ Loadcases	
⊟ Casename	
⊞ Tests	
⊟ Settings opimization	
Weighting case	1

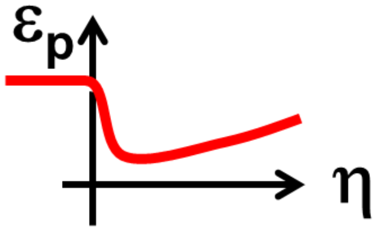
- None
- plastic equivalent strain
- simple criteria
- 4a picewise linear
- Johnson Cook
- mod Xue-Wierzbicki
- Xue-Wierzbicki
- Mohr-Coulomb

Ductile Damage Settings

⊟ 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	0.33
Shear Damage Settings	None
FLC Damage Settings	None
Strainrate Settings	Johnson Cook
Postfracture	Fracture Energy (TRIAX)
⊞ Loadcases	
⊞ Results	

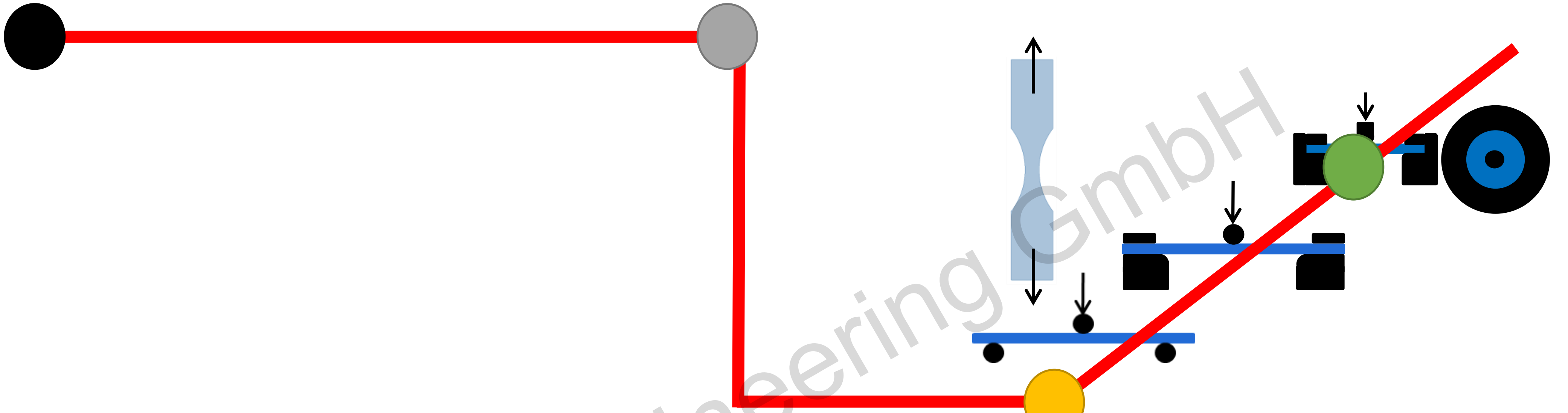
- Johnson Cook
- mod Xue-Wierzbicki
- Xue-Wierzbicki
- Mohr-Coulomb

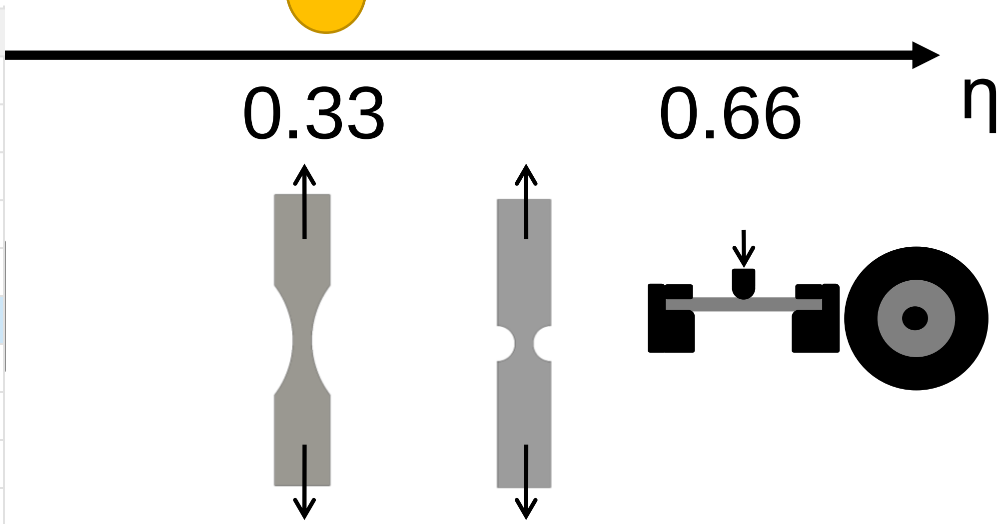
$$fd_{JCD1} + fd_{JCD2} \cdot e^{-fd_{JCD3} \cdot \eta}$$

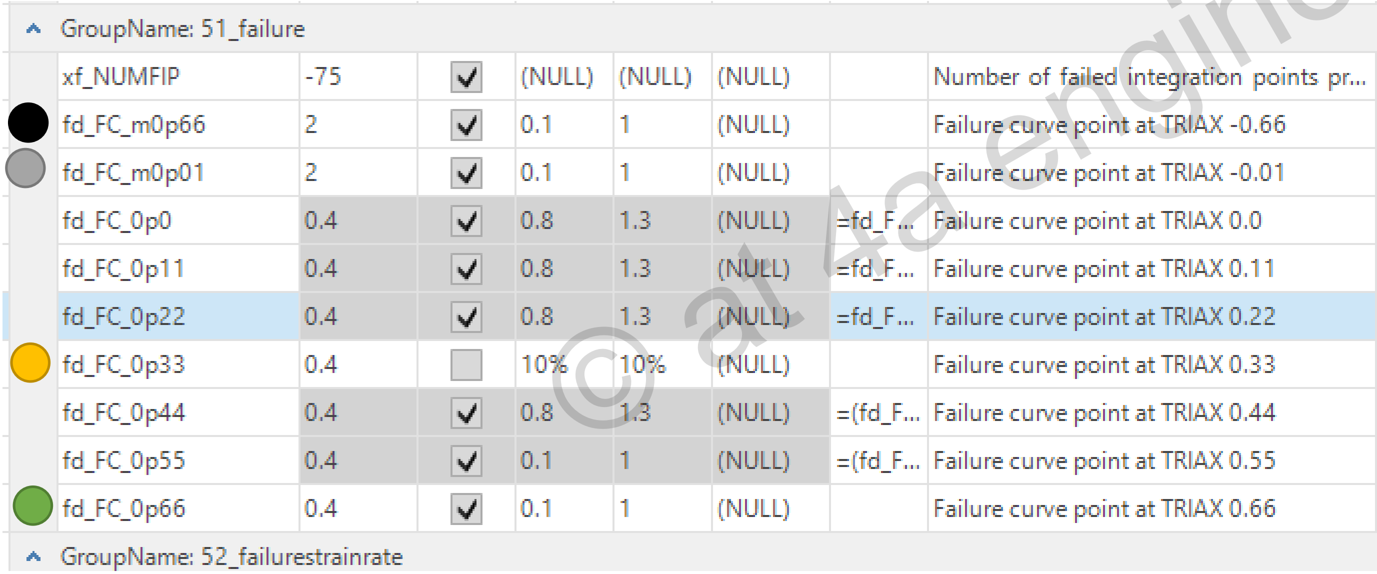


Damage/Failure

From test to material card







	GroupName: 51_failure							
	xf_NUMFIP	-75	☑	(NULL)	(NULL)	(NULL)		Number of failed integration points pr...
⚫	fd_FC_m0p66	2	☑	0.1	1	(NULL)		Failure curve point at TRIAX -0.66
⚪	fd_FC_m0p01	2	☑	0.1	1	(NULL)		Failure curve point at TRIAX -0.01
	fd_FC_0p0	0.4	☑	0.8	1.3	(NULL)	=fd_F...	Failure curve point at TRIAX 0.0
	fd_FC_0p11	0.4	☑	0.8	1.3	(NULL)	=fd_F...	Failure curve point at TRIAX 0.11
	fd_FC_0p22	0.4	☑	0.8	1.3	(NULL)	=fd_F...	Failure curve point at TRIAX 0.22
🟡	fd_FC_0p33	0.4	☐	10%	10%	(NULL)		Failure curve point at TRIAX 0.33
	fd_FC_0p44	0.4	☑	0.8	1.3	(NULL)	=(fd_F...	Failure curve point at TRIAX 0.44
	fd_FC_0p55	0.4	☑	0.1	1	(NULL)	=(fd_F...	Failure curve point at TRIAX 0.55
🟢	fd_FC_0p66	0.4	☑	0.1	1	(NULL)		Failure curve point at TRIAX 0.66
	GroupName: 52_failurestrainrate							

Available failure models – typical curves

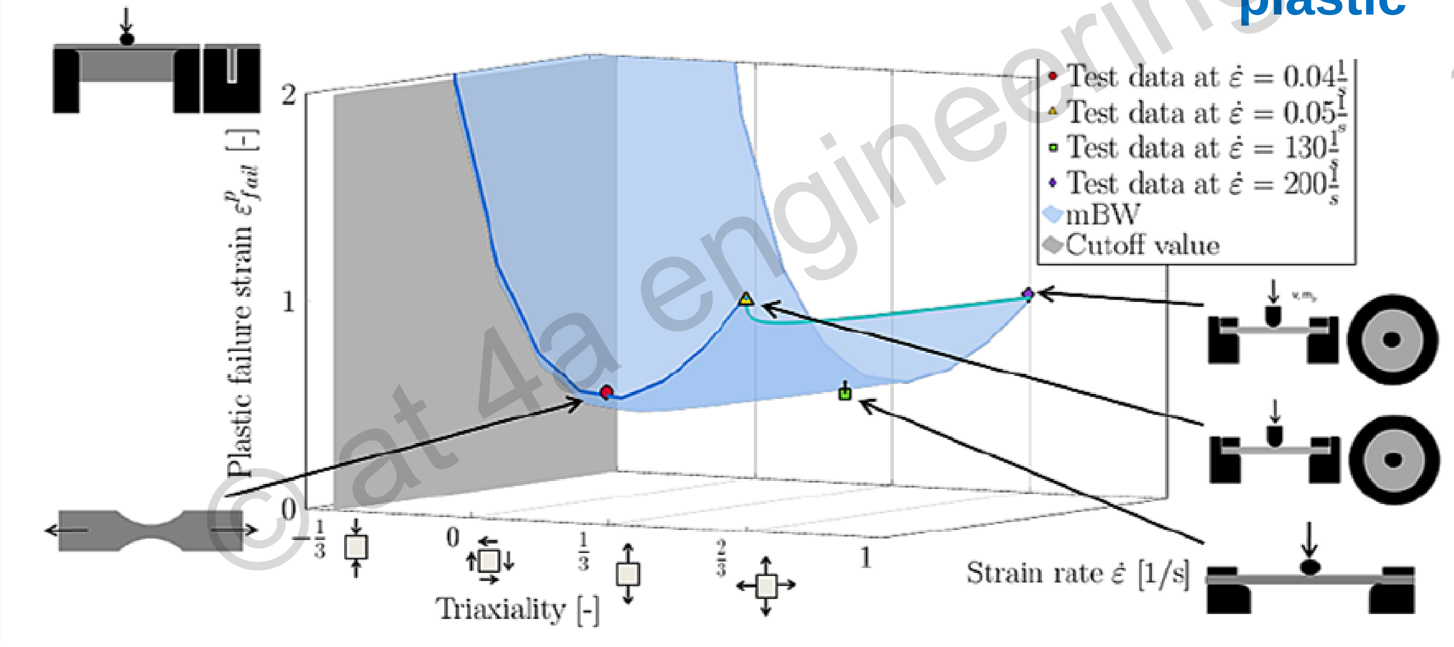
failure criteria

stress based

strain based

plastic

damage



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

Failure model

Incremental damage accumulation

- Rule for damage progression
  - damage history variable
    - undamaged d=0.0
    - criterion reached d=1.0
  - **driving force**: example equivalent plastic strain increments
  - **failure model** norms the damage history variable

$$d = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{f,init}} dt$$

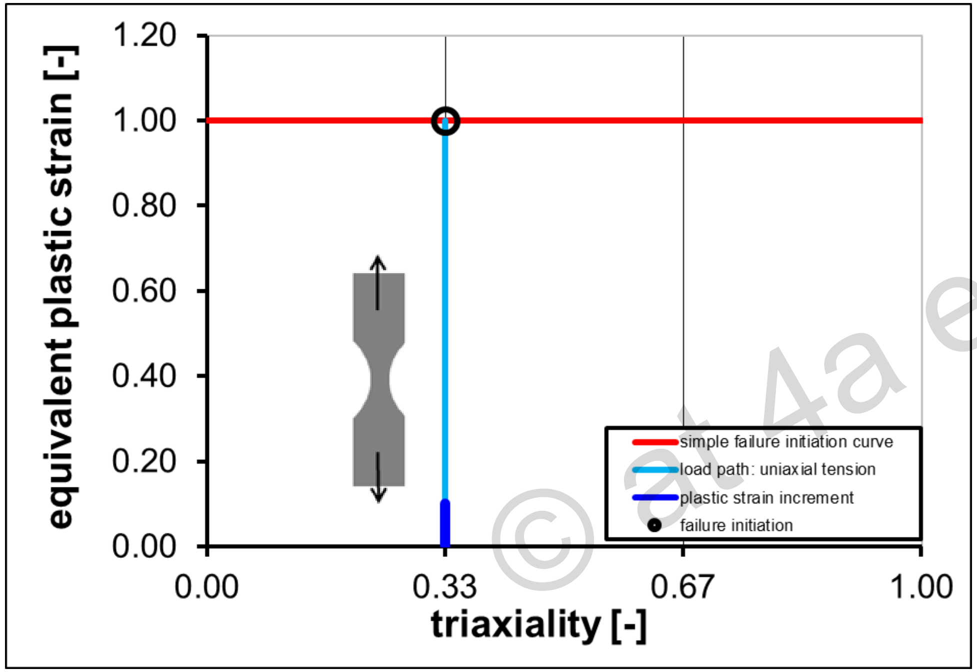
Failure model

Incremental damage accumulation – simplified case

- **driving force:** e.g. equivalent plastic strain increments $d\varepsilon_p$
- **failure model norm:** e.g. equivalent plastic strain=1.
- Load case: uniaxial tension

$$d = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{f,init}} dt$$

$$d = \frac{d\varepsilon_p}{\varepsilon_{f,init}}$$



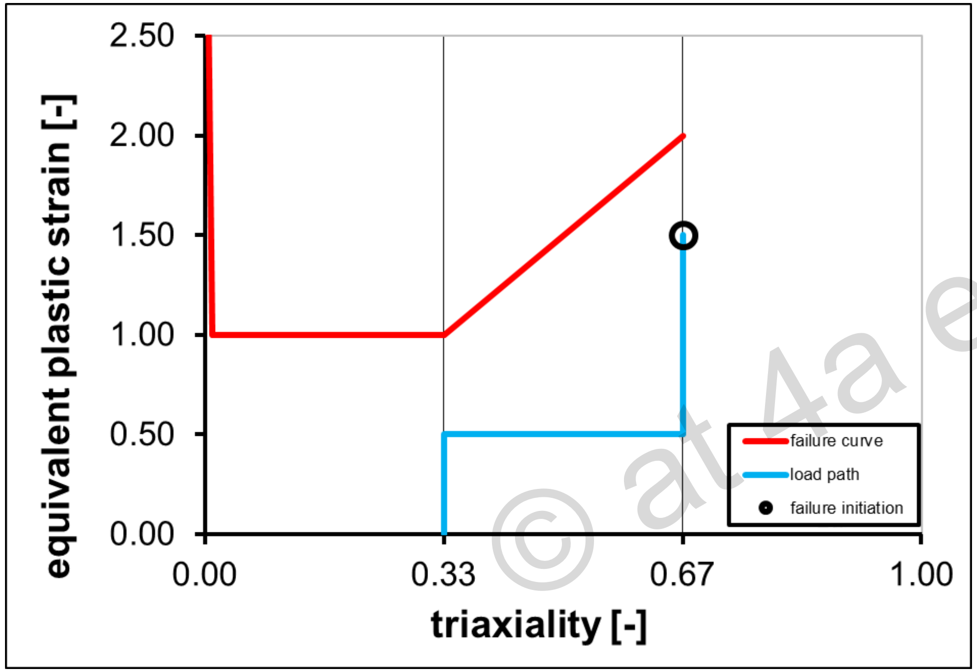
Failure model

Incremental damage accumulation – split uniaxial, biaxial tension

- **driving force:** e.g. equivalent plastic strain increments $d\varepsilon_p$
- **failure model norm:** e.g. equivalent plastic strain
- Load case: split uniaxial, biaxial tension

$$d = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{f,init}} dt$$

$$d = \frac{d\varepsilon_p}{\varepsilon_{f,init}}$$



Post failure model

Incremental damage accumulation

- Rule for damage progression
  - damage history variable
    - undamaged D=0.0
    - criterion reached D=1.0
    - this damage history variable is coupled to stress!
    - If damage history variable reaches 1:
      - Solid element deletion
      - Shell depends (number of integration points for element deletion)
  - **driving force**: e.g. equivalent plastic strain increments
  - **post failure model** norms the damage history variable

$$
\begin{aligned}
&if\ d \geq 1: \\
&\qquad D = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{rpt}} dt \\
&else: \\
&\qquad D = 0.
\end{aligned}
$$

$$\sigma^* = \sigma(1 - D)$$

Post failure model

Incremental damage accumulation – simple stress coupling example

- stress coupling
  - e.g. linear hardening curve
    - h_y=100
    - h_ET=10

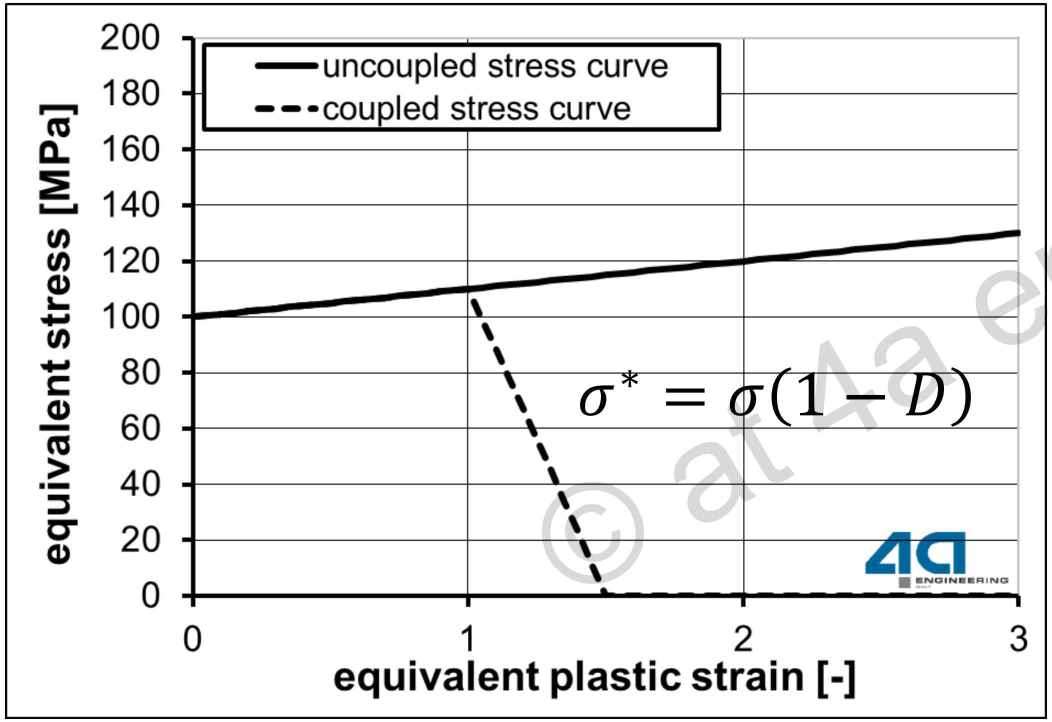
$$d = \frac{d\varepsilon_p}{\varepsilon_{f,init}}$$

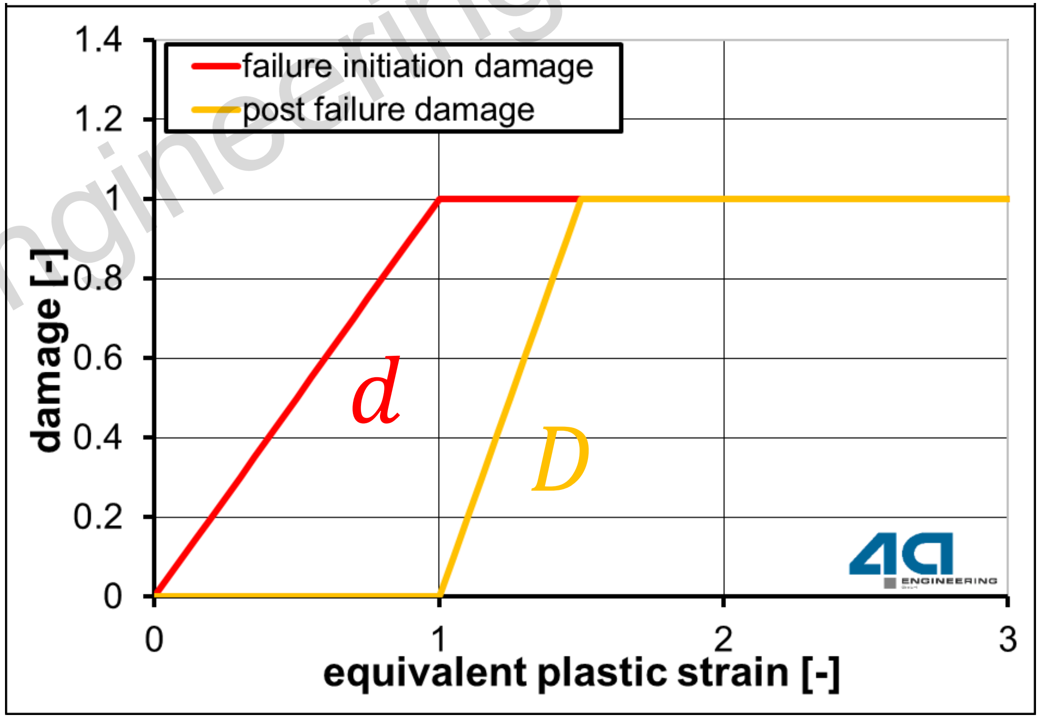
$$if\ d \geq 1:$$

$$D = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{rpt}} dt$$

$$else:$$

$$D = 0.$$





Post failure model

Incremental damage accumulation – simplified case

- **driving force:** e.g. equivalent plastic strain increments $d\varepsilon_p$
- **failure model norm:** e.g. equivalent plastic strain=1.
- **post failure model**: e.g. equivalent plastic strain=1.5
- Load case: split uniaxial Tension, biaxial Tension

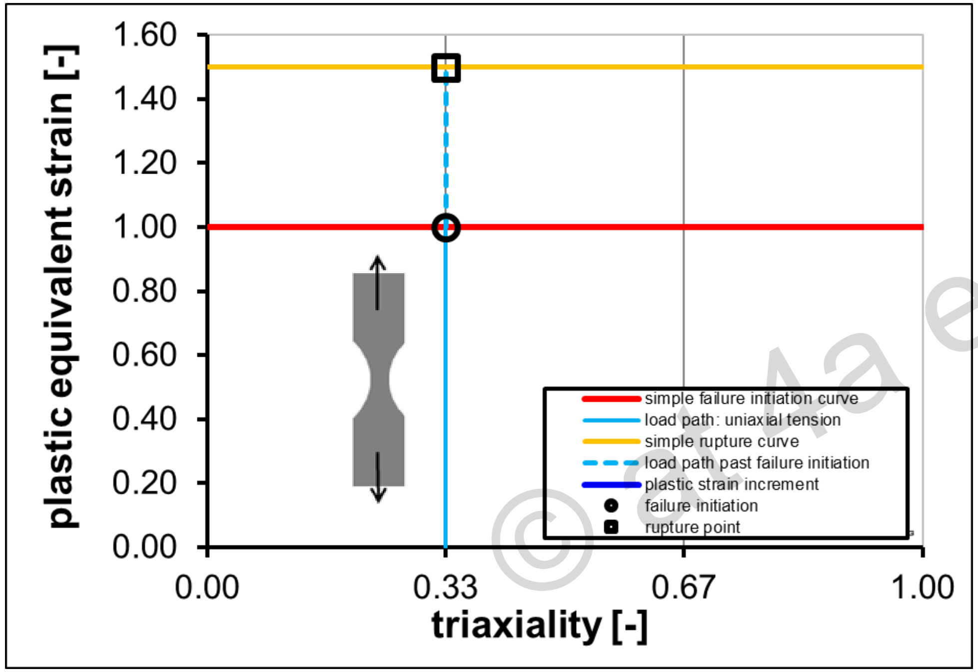
$$d = \frac{d\varepsilon_p}{\varepsilon_{f,init}}$$

$if\ d \geq 1$:

$$D = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{rpt}} dt$$

$else$:

$$D = 0.$$



Post failure model

Incremental damage accumulation – split uniaxial, biaxial tension

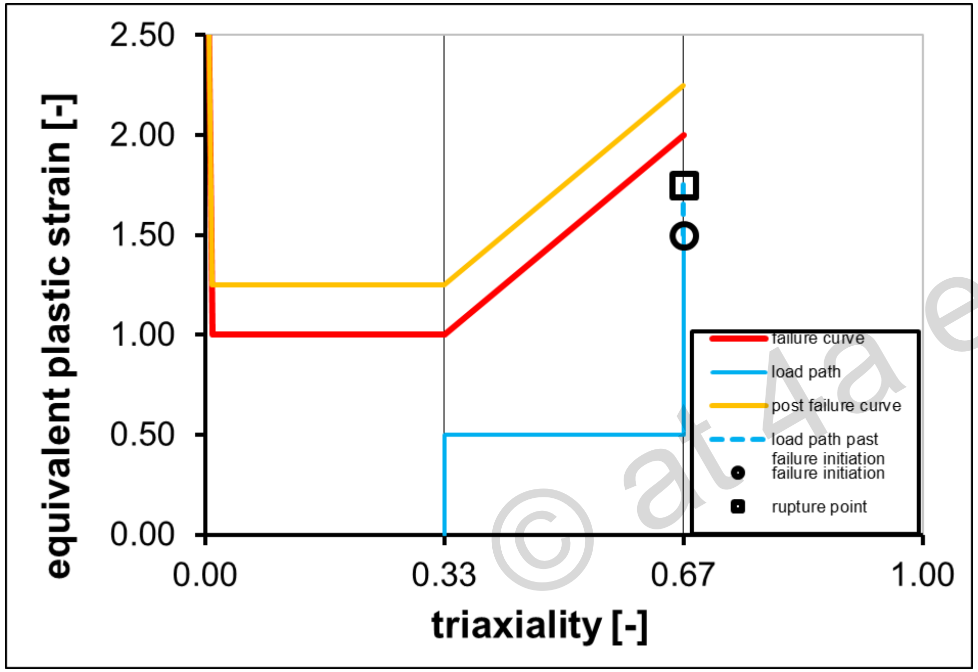
- **driving force:** e.g. equivalent plastic strain increments $d\varepsilon_p$
- **failure model norm:** e.g. equivalent plastic strain
- **post failure model**: e.g. equivalent plastic strain
- Load case: split uniaxial Tension, biaxial Tension

$$d = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{f,init}} dt$$

$$d = \frac{d\varepsilon_p}{\varepsilon_{f,init}}$$

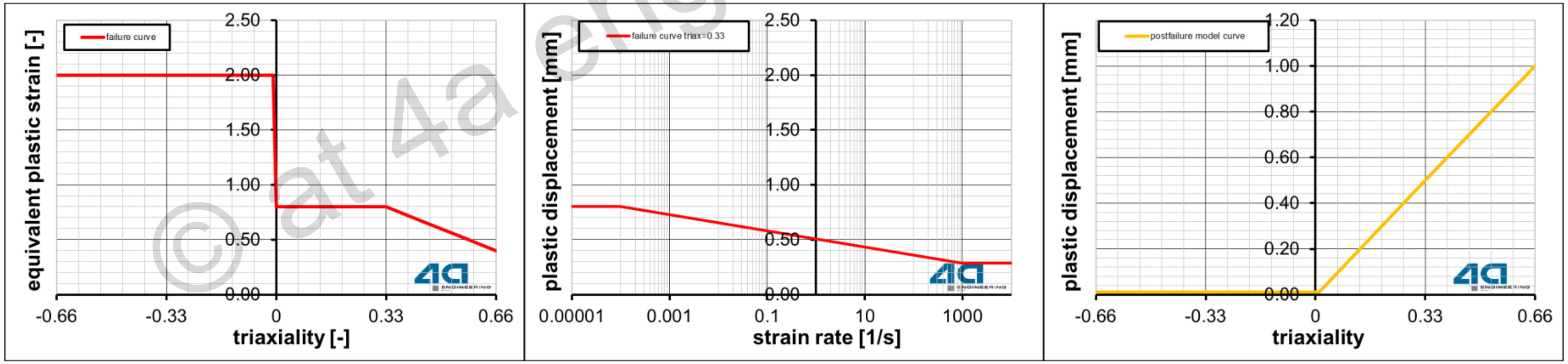
$$if\ d \geq 1: \quad D = \int \frac{\dot{\varepsilon}_p}{\varepsilon_{rpt}} dt$$

$$else: \quad D = 0.$$



Failure and post failure model

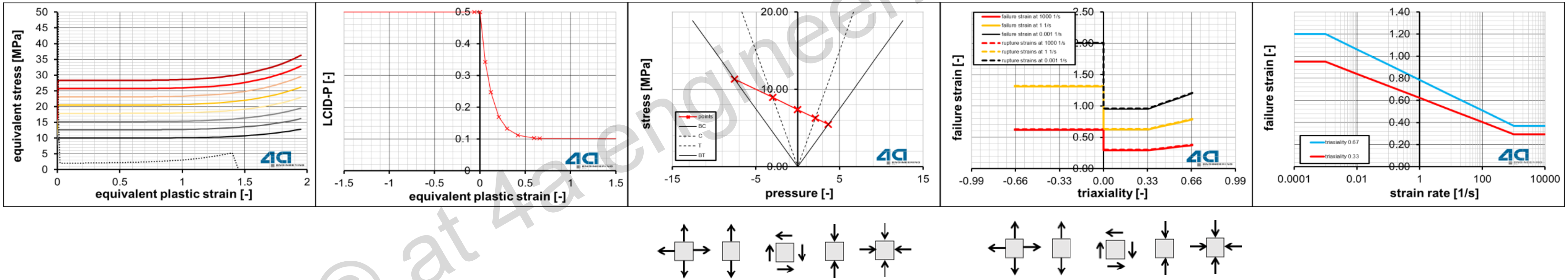
- **DIEM** (**D**amage **I**nitiation and **E**volution **M**odel)
  - failure model: from several options selected:
    - driving force: equivalent plastic strain
    - model: equivalent plastic failure strain function of triaxiality and strain rate
  - post failure model: from several options selected:
    - driving force: plastic displacement (regularization)
    - model: plastic displacement function over triaxiality



Simulation results, PP ED113AE - 9502, 23°C

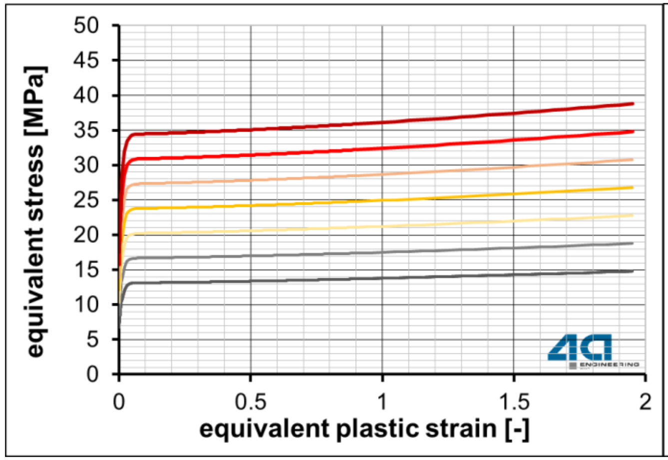
Material card overview

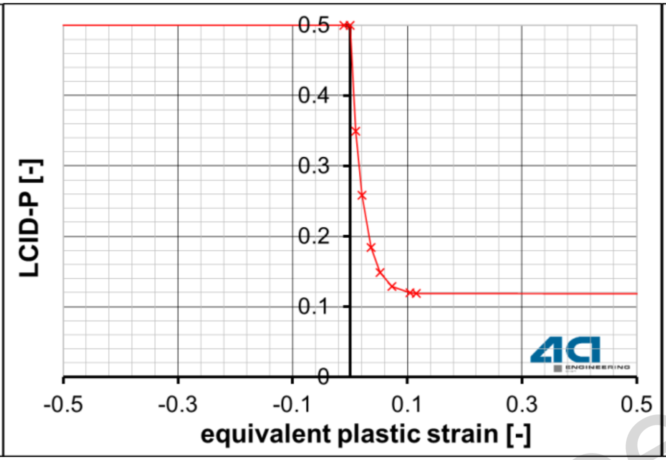
- ****MAT_SAMP-1*** material card:
  - Deformation: elastic, viscoplastic with tension/compression asymmetry
  - Plastic Poisson‘s ratio: exponential law fitted for static tensile tests
  - failure: piecewise linear, strain rate dependent MAT_ADD_EROSION (DIEM)

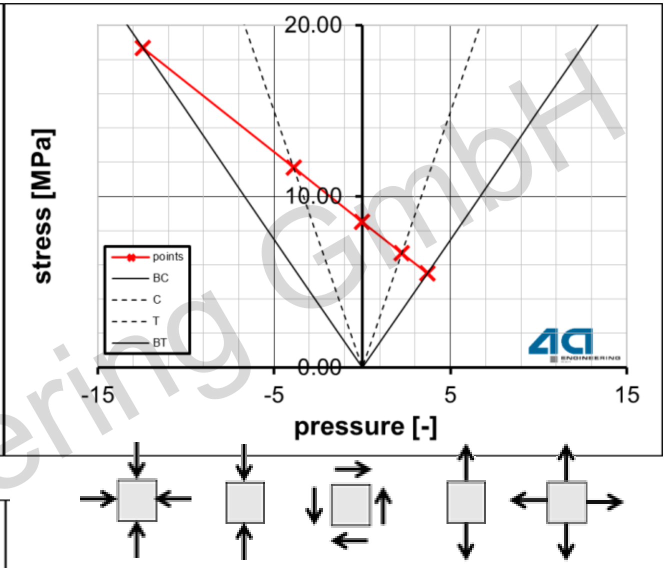


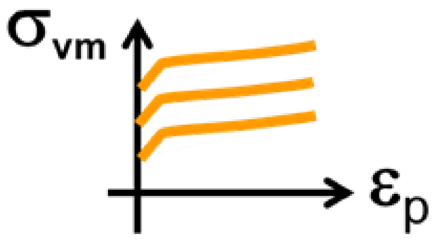
*MAT-SAMP 1 with internal FM – result AUTOFIT

VALIMAT

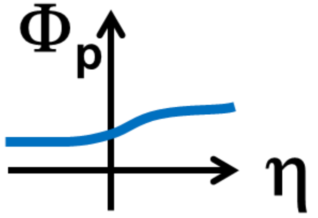




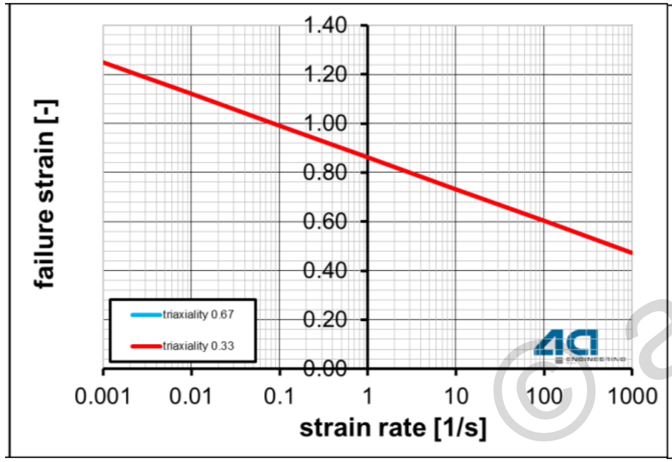


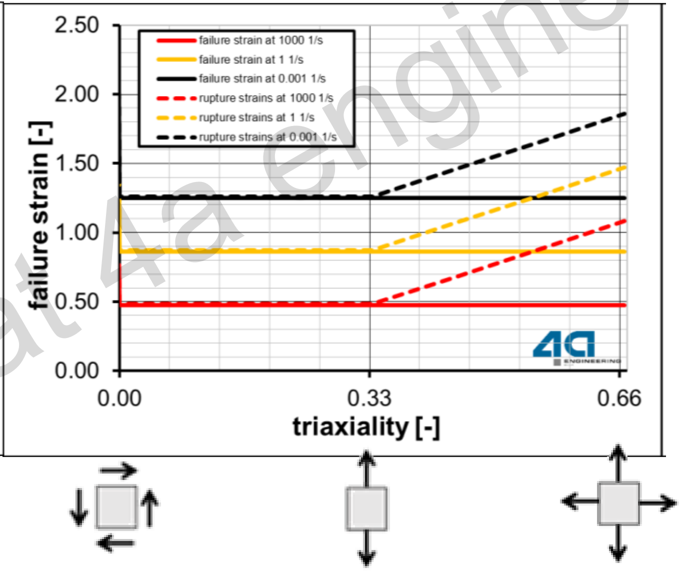


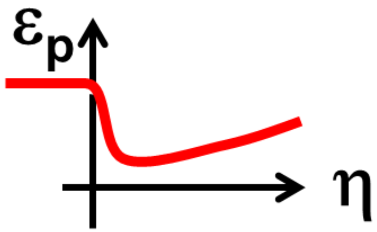
Hardening



Triaxiality





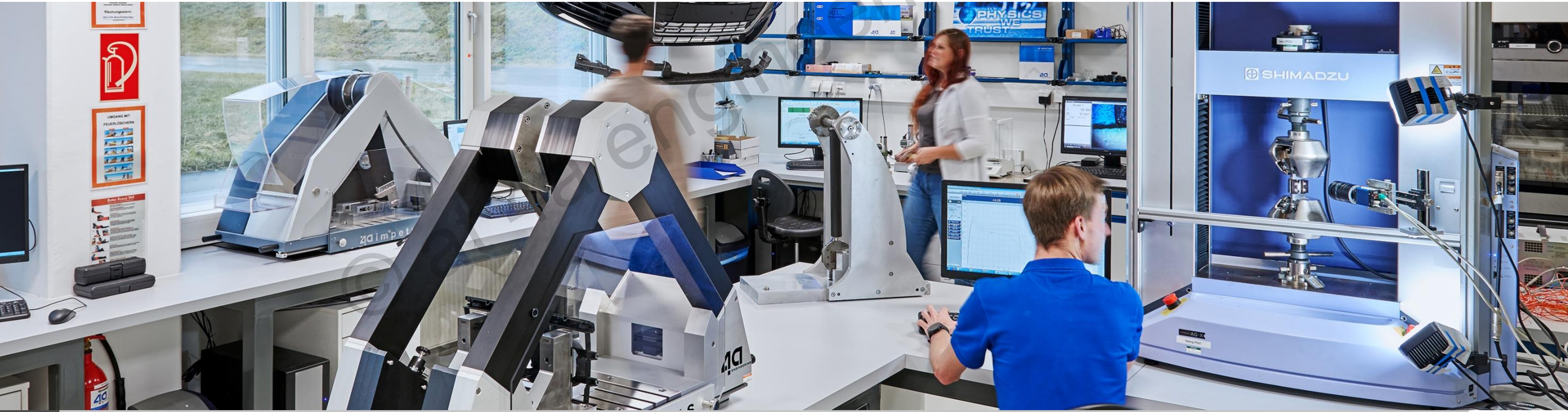


Damage/Failure

source: Benjamin Hirschmann, master thesis

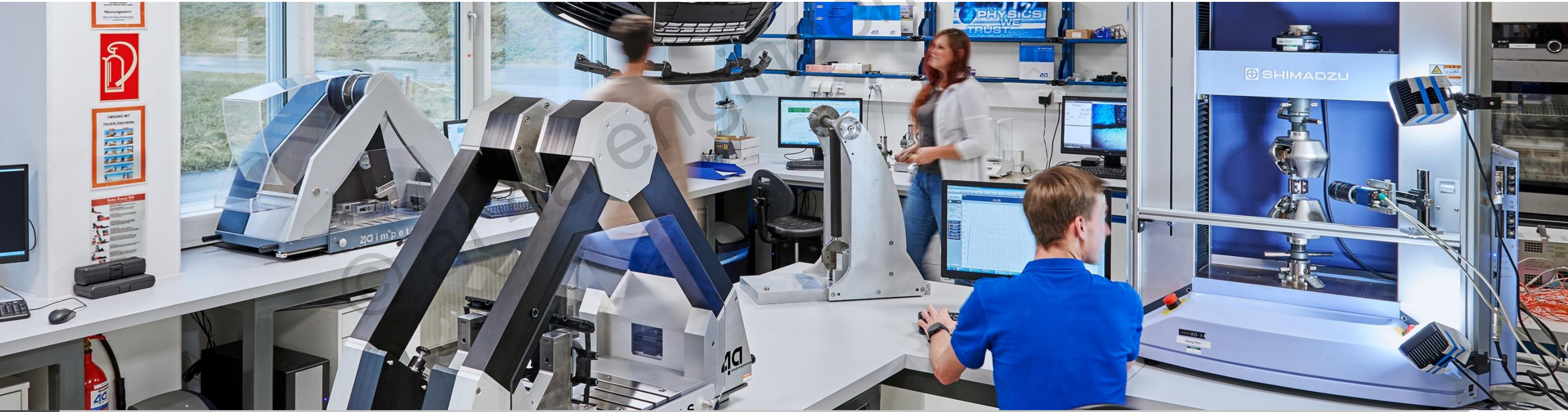
VALIMAT

UPCOMING MATERIAL MODELS



UPCOMING MATERIAL MODELS

*MAT_187L



Upcoming material models
*MAT_187L

- ***MAT_SAMP_LIGHT (187L)*** material card:
  - Slimmed down version of the *MAT_SAMP-1
  - Plastic Poisson‘s ratio: constant or variable plastic Poissons ratio
  - failure: strain rate dependent MAT_ADD_EROSION or *MAT_ADD_DAMAGE
  - Computationally cheaper when compared to the *MAT_SAMP-1 material model

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`	parabolic; piecewise linear	✓ Table	✓	✓	✓
`*MAT_187L`	linear	✗	✓	✓	✓

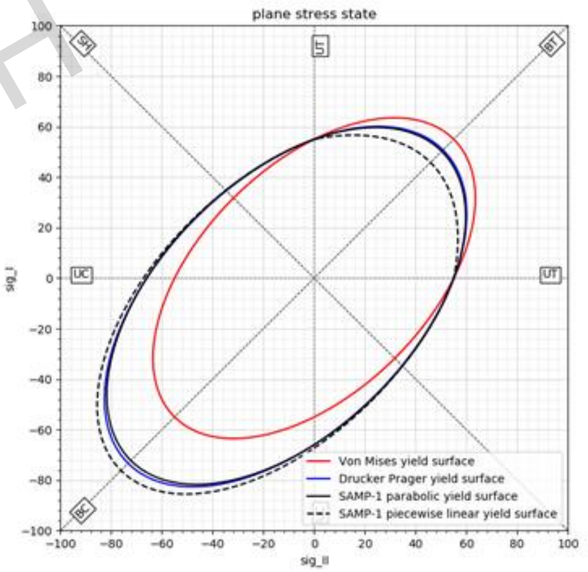
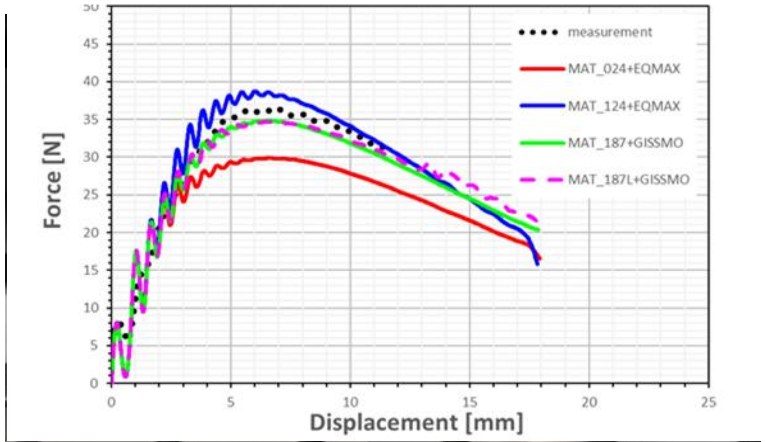
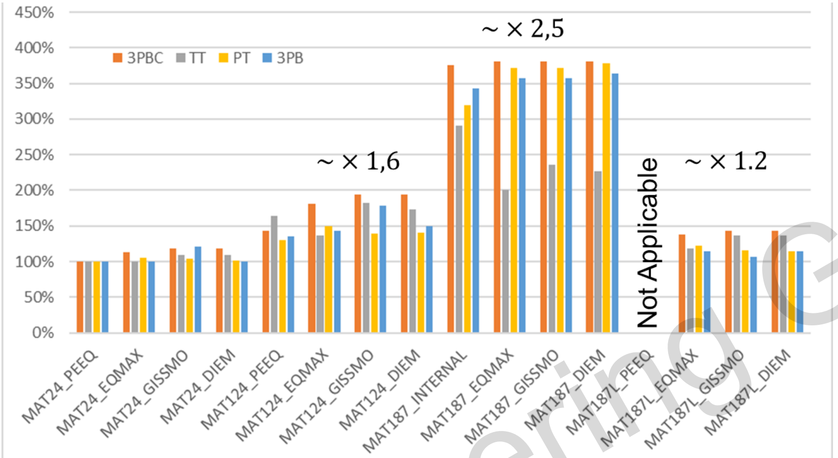


Figure: exemplary yield surfaces in MAT_SAMP depicted in the plane stress state
BT: Biaxial Tension
UT: Uniaxial Tension
SH: Shear
UC: Uniaxial Compression
BC: Biaxial Compression

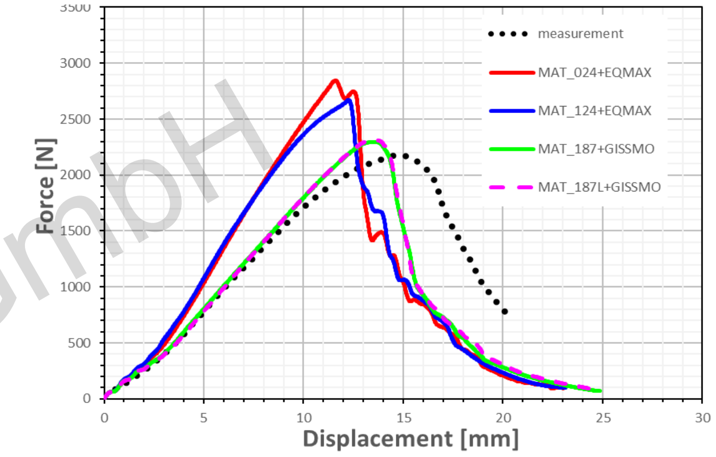
Upcoming material models
comparison of different material models



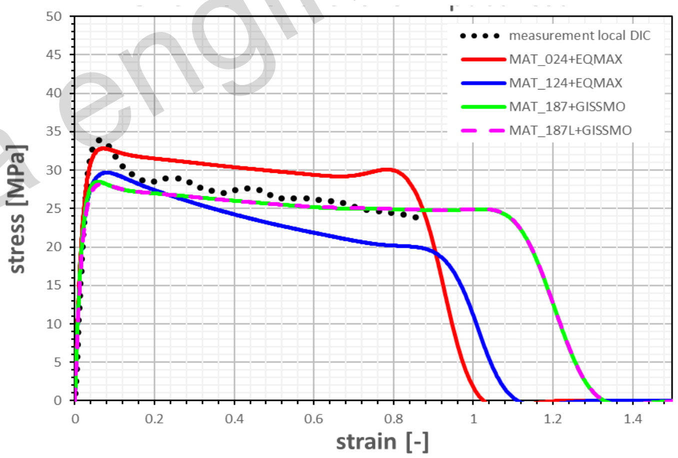
3 POINT BENDING

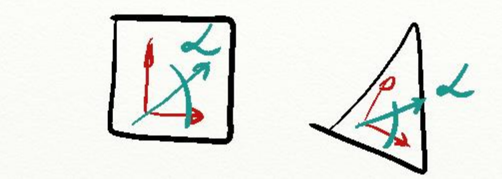


CPU Time comparisons



PUNCTURE TEST





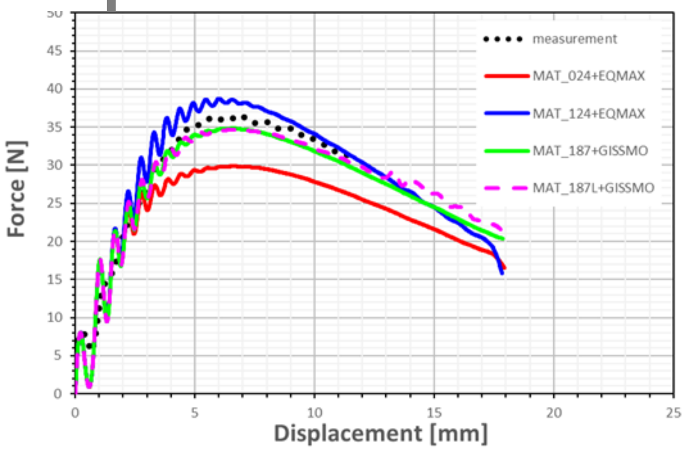
IMPETUS™ ~ 3 m/s

source: Benjamin Hirschmann, master thesis

TENSION TEST

Upcoming material models
comparison of different material models

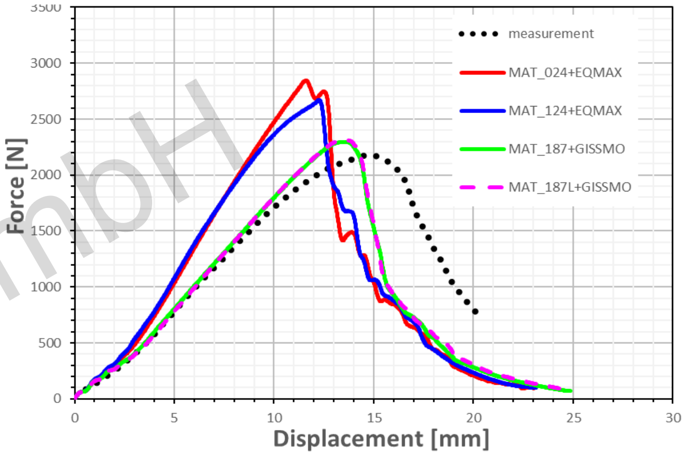
VALIMAT



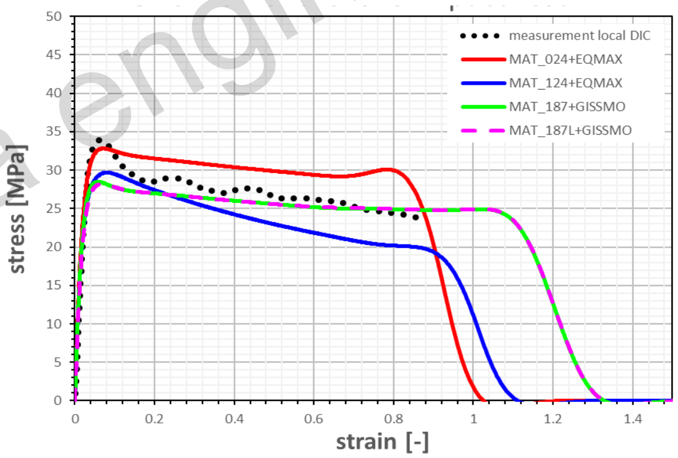
3 POINT BENDING

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

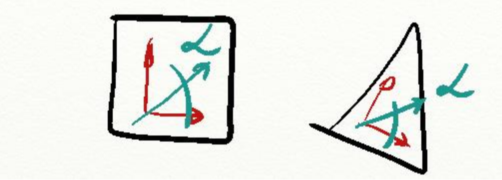
CPU Time comparisons



PUNCTURE TEST



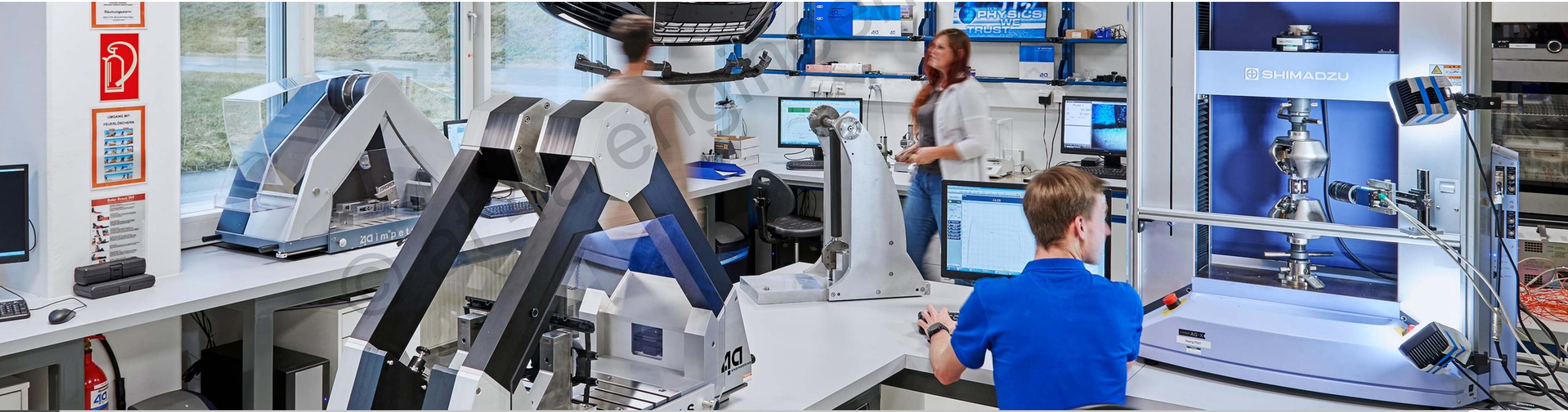
TENSION TEST



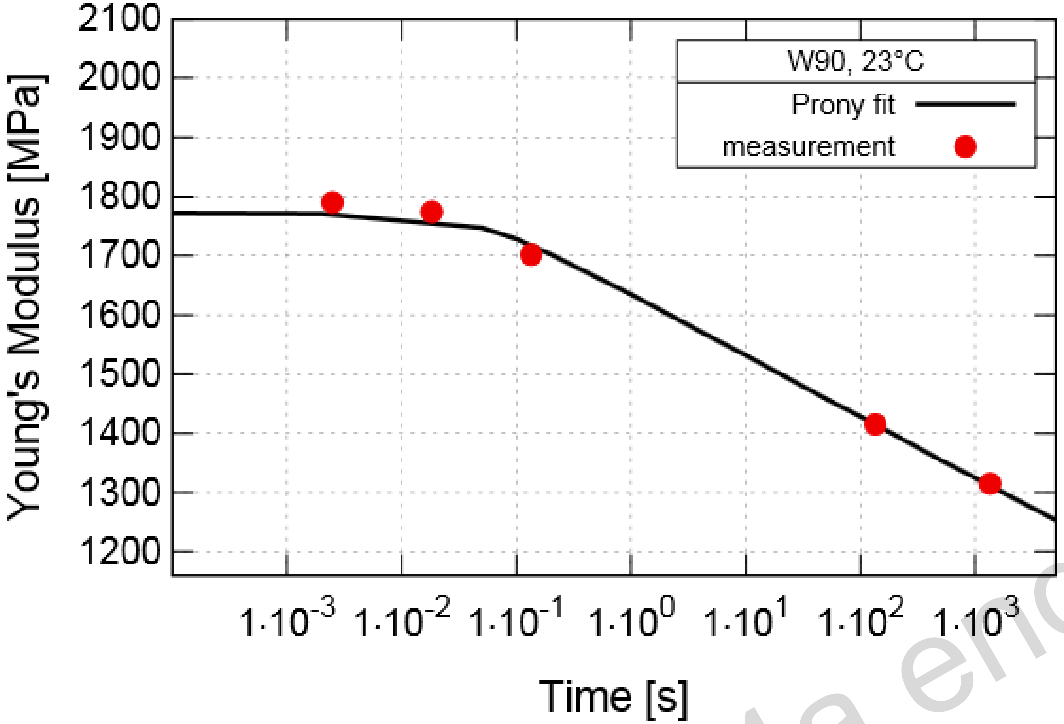
IMPETUS™ ~ 3 m/s

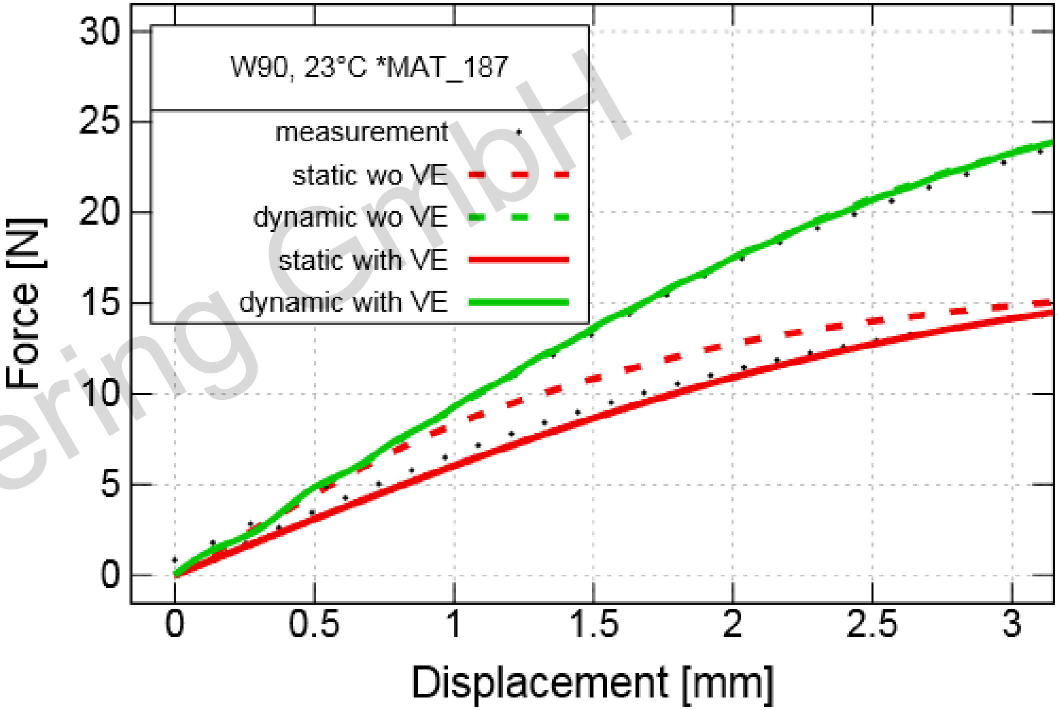
source: Benjamin Hirschmann, master thesis

UPCOMING MATERIAL MODELS *MAT_ADD_INELASTICITY



Upcoming material models
visco-elasticity





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

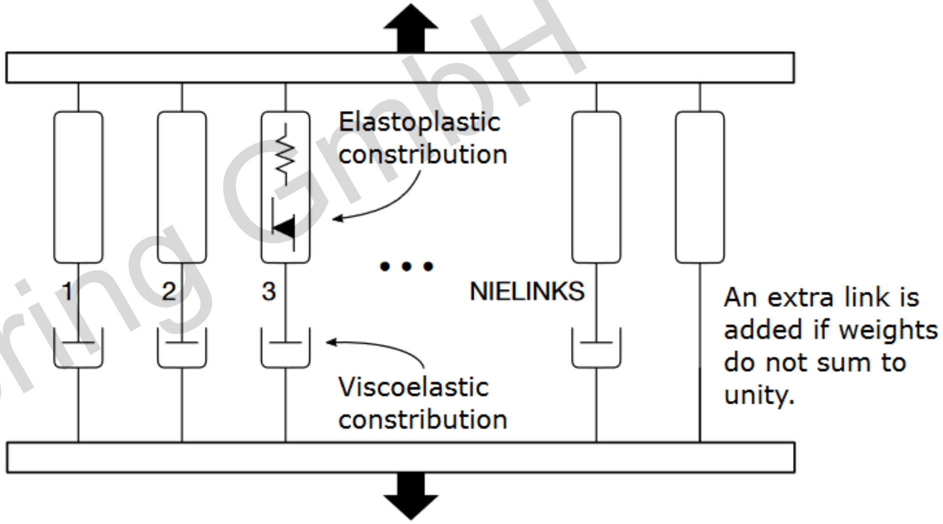
→implementing visco-elasticity:
strain-rate dependent Young's Moduli
to use in ***MAT_187**

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

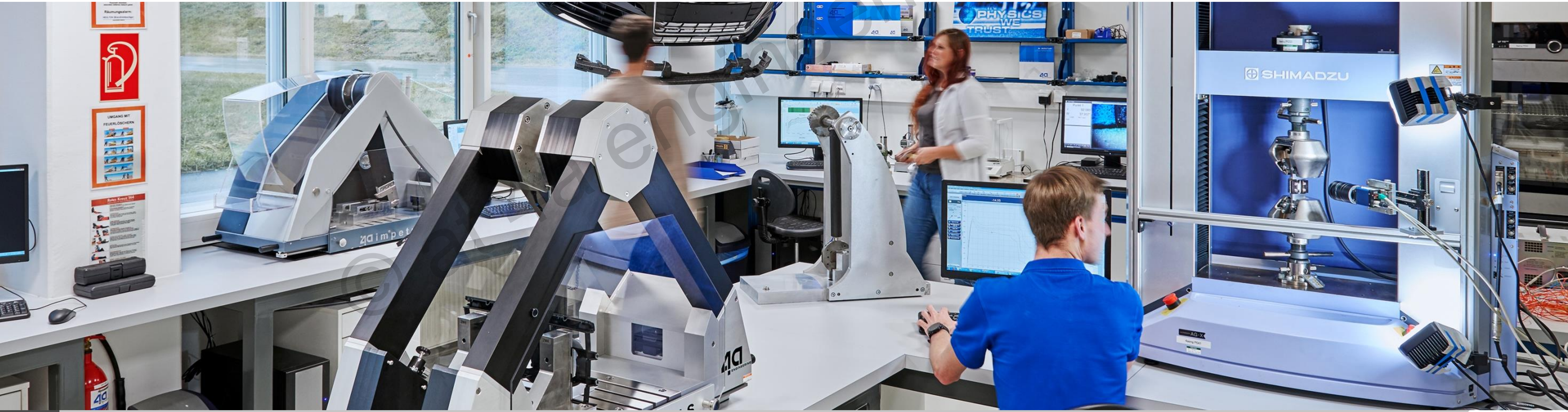
- inelastic features
  - isotropic hardening plasticity
  - creep
  - Visco-elasticity



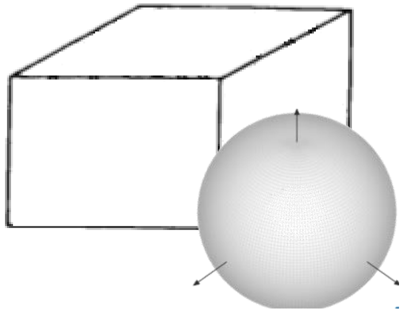
LS-DYNA_Manual_Volume_II_Dev (r:11680)

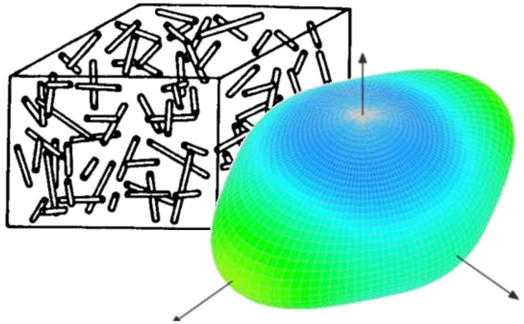
UPCOMING MATERIAL MODELS

*MAT_215

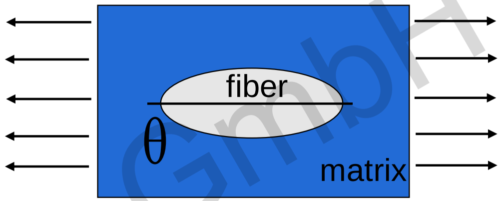


Upcoming material models composites - actual approaches





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



Eshelby Tensor

macro scale

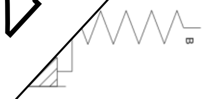
constitutive law → composi

micro scale

homogenizat

Mises plasticity

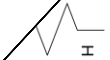
- quick & di



- criti g
  t l
  orientation

*MAT_024

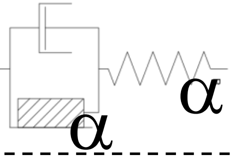
elastic



- orthotro
- aniso

elastic stic

- city



*MAT_157

M… matrix

- isotropic elas
  viscoplasti

F… fiber

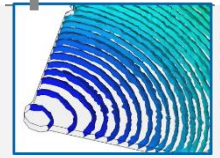
- iso stic

*MAT_215

α − orientation dependent

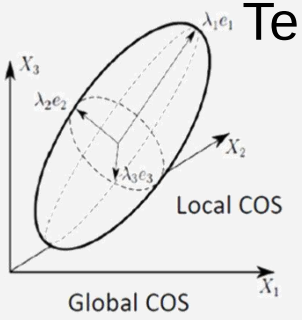
Upcoming material models composites – actual approaches

Process simulation



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

Tensor 2nd order



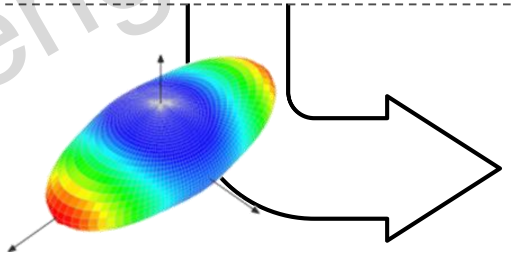
CADMOULD 3D-F SIMULATION

Moldex3D MOLDING INNOVATION

MOLDFLOW

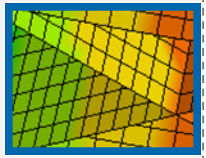
FIBERMAP

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



MICROMEC

Structural simulation



Homogenization (Micro Scale)

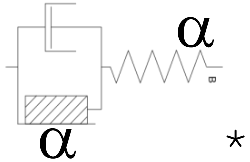
Mean Field Theory

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

`*MAT_215`

Composite (Macro Scale)

Hill Plasticity



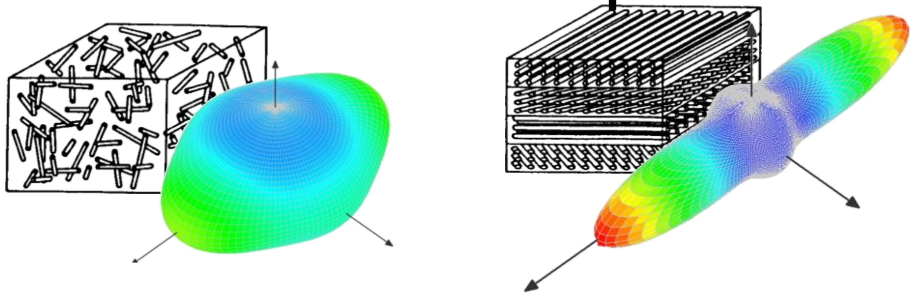
`*MAT_157`

LSTC Livermore Software Technology Corp.

LS-DYNA®

MICROMEC

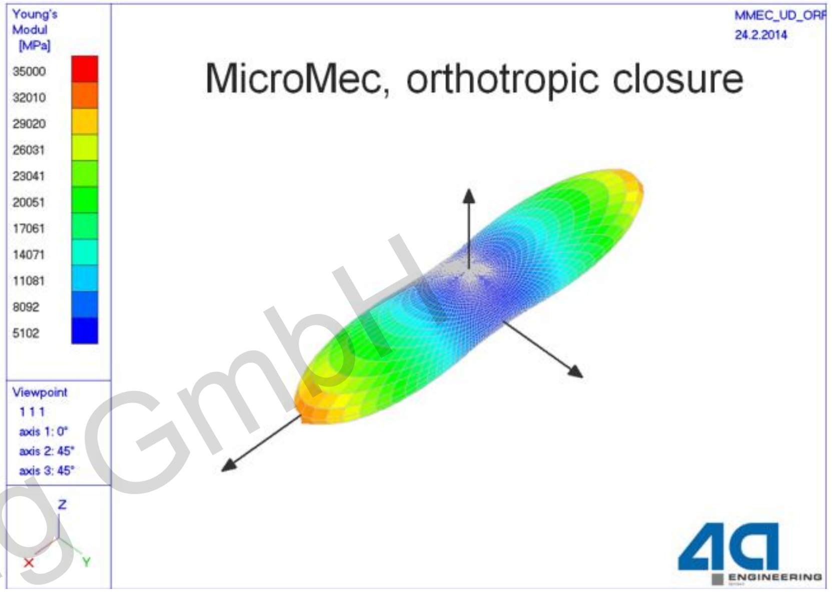
SFRT / LFRT **Composite**

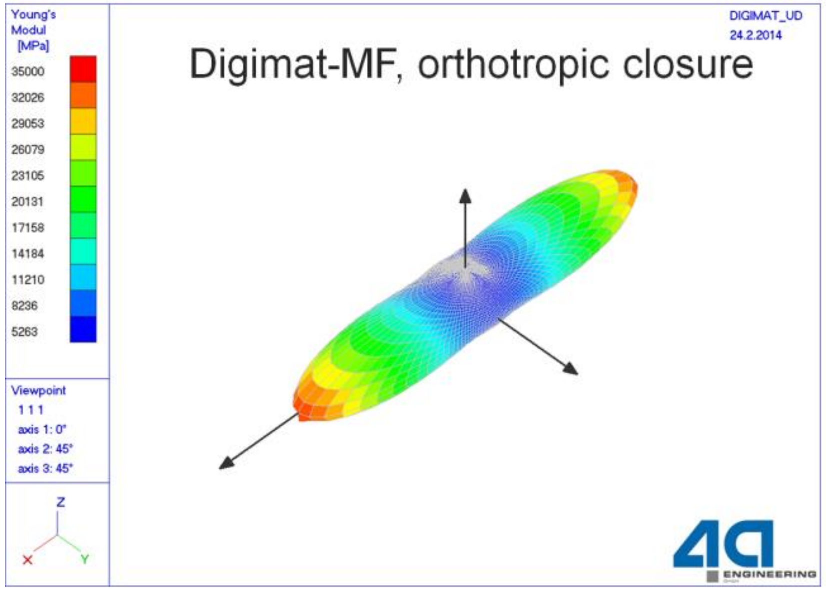


$$\overline{\sigma}^{C} = \varphi\overline{\sigma}^{F} + (1-\varphi)\overline{\sigma}^{M}$$

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

- **Standalone product (2001)**
- **Usermaterial (2007)**
- **Library→4a impetus (2015)**
- **in LSDYNA R10.1 (2018)**
  `*MAT_4A_MICROMEC`



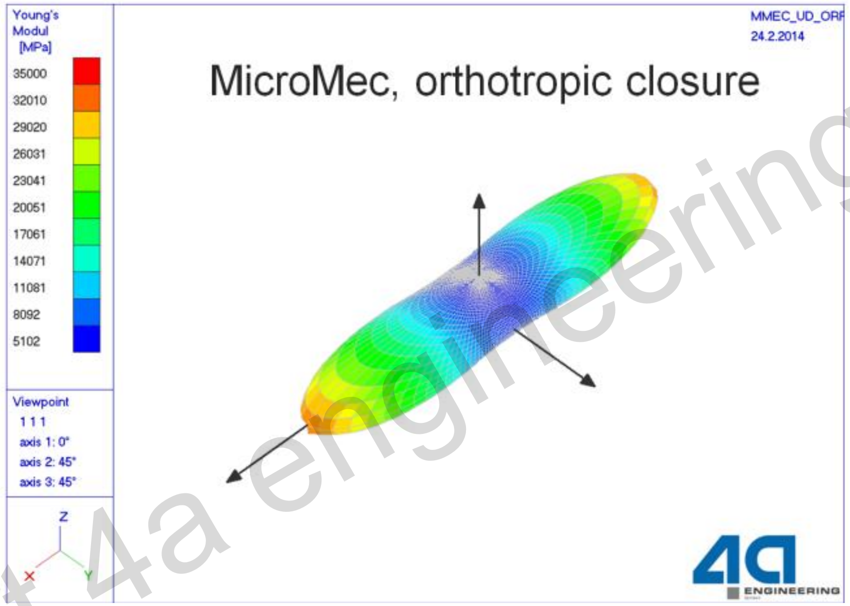


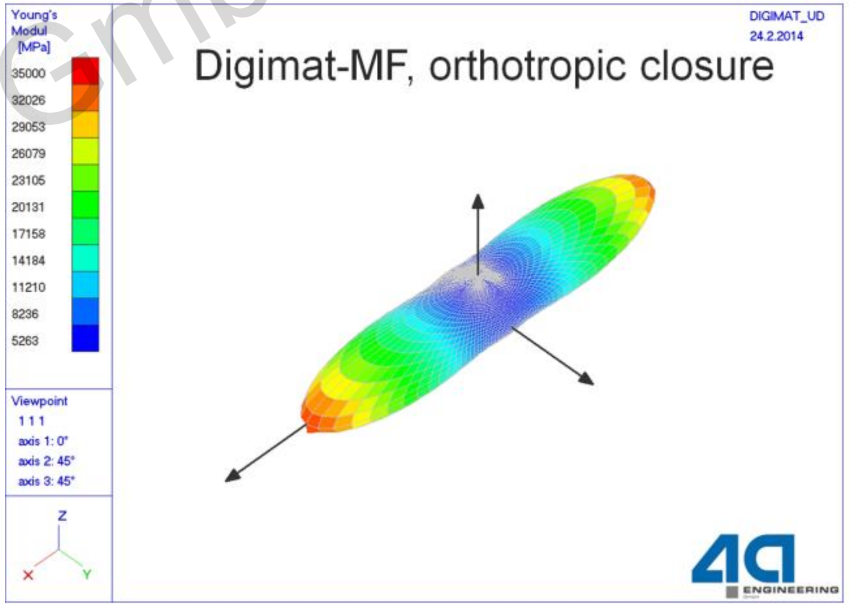
Comparison by University of Leoben [Bodor2014]

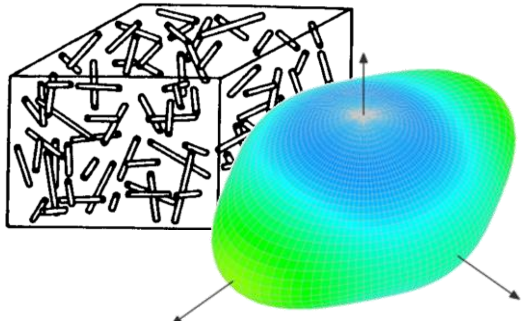
Upcoming material models
micro mechanical motivated material models

MICROMEC

Standalone product







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

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

Comparison by University of Leoben [Bodor2014]

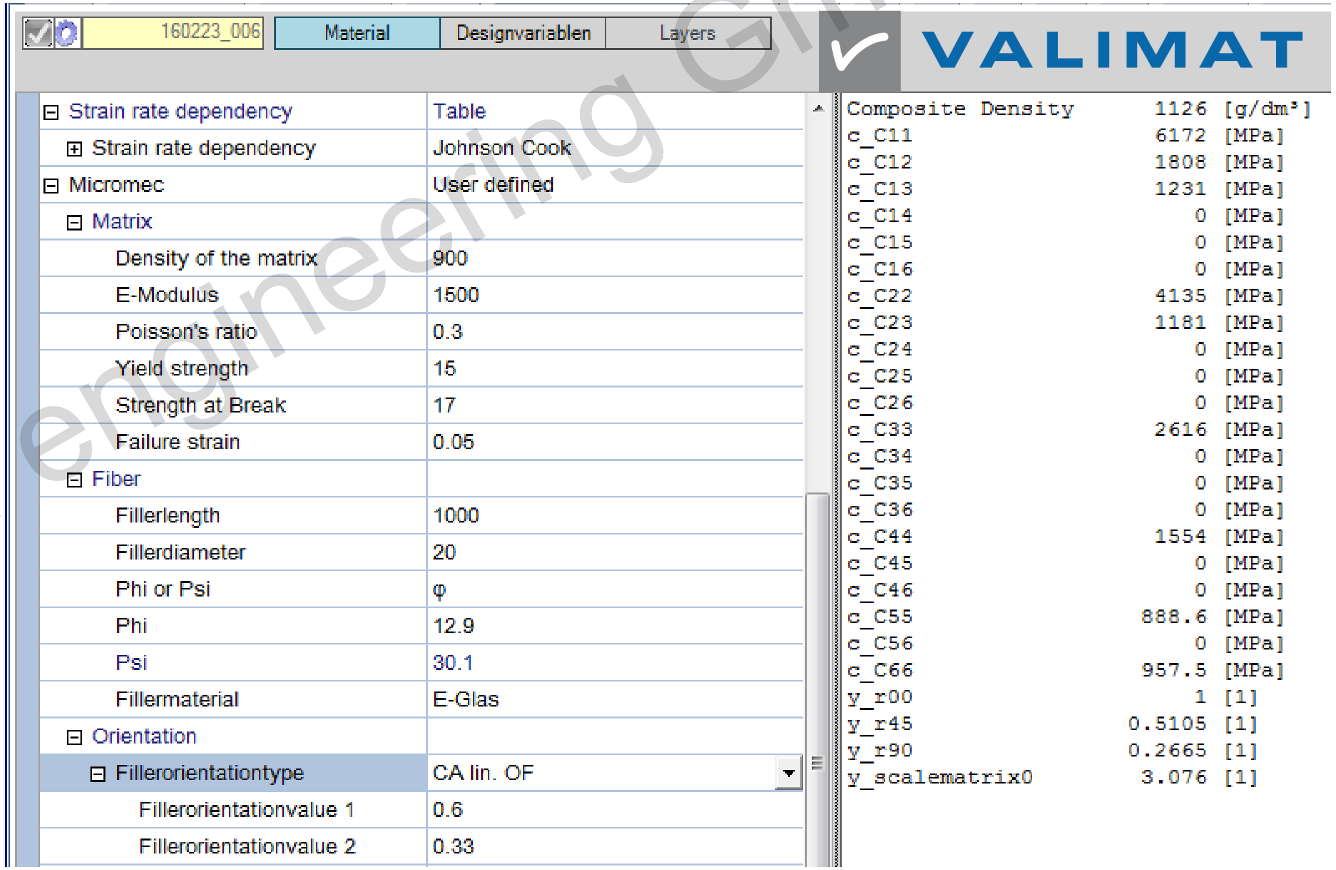
Upcoming material models
micro mechanical motivated material models

MICROMEC

Standalone product

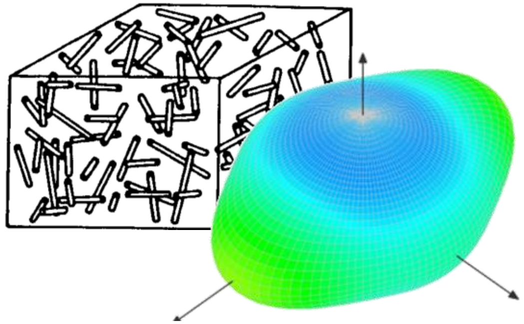
Library → VALIMAT™

calculate parameter for constitutive law → ***MAT_157**



⊟ Strain rate dependency	Table
⊞ Strain rate dependency	Johnson Cook
⊟ Micromec	User defined
⊟ Matrix	
Density of the matrix	900
E-Modulus	1500
Poisson's ratio	0.3
Yield strength	15
Strength at Break	17
Failure strain	0.05
⊟ Fiber	
Fillerlength	1000
Fillerdiameter	20
Phi or Psi	φ
Phi	12.9
Psi	30.1
Fillermaterial	E-Glas
⊟ Orientation	
⊟ Fillerorientationtype	CA lin. OF
Fillerorientationvalue 1	0.6
Fillerorientationvalue 2	0.33

```
Composite Density     1126 [g/dm³]
c_C11                 6172 [MPa]
c_C12                 1808 [MPa]
c_C13                 1231 [MPa]
c_C14                    0 [MPa]
c_C15                    0 [MPa]
c_C16                    0 [MPa]
c_C22                 4135 [MPa]
c_C23                 1181 [MPa]
c_C24                    0 [MPa]
c_C25                    0 [MPa]
c_C26                    0 [MPa]
c_C33                 2616 [MPa]
c_C34                    0 [MPa]
c_C35                    0 [MPa]
c_C36                    0 [MPa]
c_C44                 1554 [MPa]
c_C45                    0 [MPa]
c_C46                    0 [MPa]
c_C55                888.6 [MPa]
c_C56                    0 [MPa]
c_C66                957.5 [MPa]
y_r00                    1 [1]
y_r45               0.5105 [1]
y_r90               0.2665 [1]
y_scalematrix0       3.076 [1]
```



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

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

Upcoming material models
micro mechanical motivated material models

MICROMEC

Standalone product

Library → VALIMAT™

usermaterial

$$\Delta\varepsilon^C \Rightarrow \Delta\varepsilon^M, \left(\Delta\varepsilon^F\right)$$

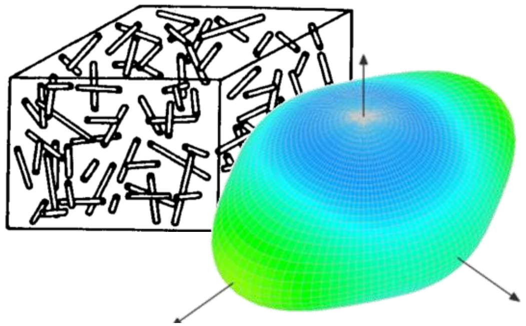
$$\Delta\varepsilon^M = \frac{1}{\varphi\overline{B}_i + (1-\varphi)I}\Delta\varepsilon^C$$

$$\Delta\varepsilon^M \Rightarrow E_M^T, \Delta\varepsilon^M{}_{pl}, \Delta\sigma^M$$

$$\overline{B}_{i+1} = f\left(fo^{(4)}, E_M^T, {}^{l}\!/_{d}\right)$$

$$\overline{A} = S^F \overline{B}_{i+1} C^M$$

$$\Delta\sigma^C = \left[\varphi\overline{A} + (1-\varphi)I\right]\Delta\sigma^M$$



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

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

Main Framework
Mori Tanaka Mean Field Theory

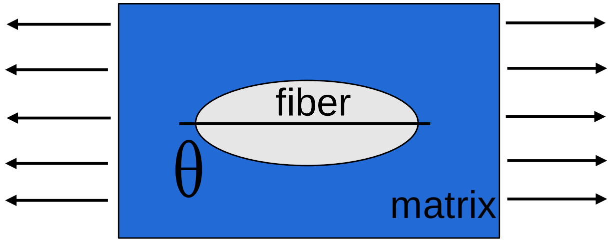
Composite stresses, strains (i)
↓
Matrix stresses, strains
↓
Fiber stresses, strains
↓
Failure, Damage Criteria
↓
Composite stresses, strains (i+1)

→ Yield condition

plug able
possible extensions
other plasticity
formulations, ...

→ J2 Plasticity
Isotropic Harding

Table Lookup or
Parameter Setup



assumption elliptical inclusion (Eshelby Tensor)

Upcoming material models
micro mechanical motivated material models

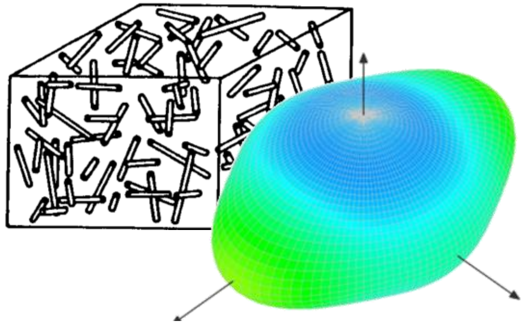
MICROMEC

Standalone product

Library → VALIMAT™

usermaterial

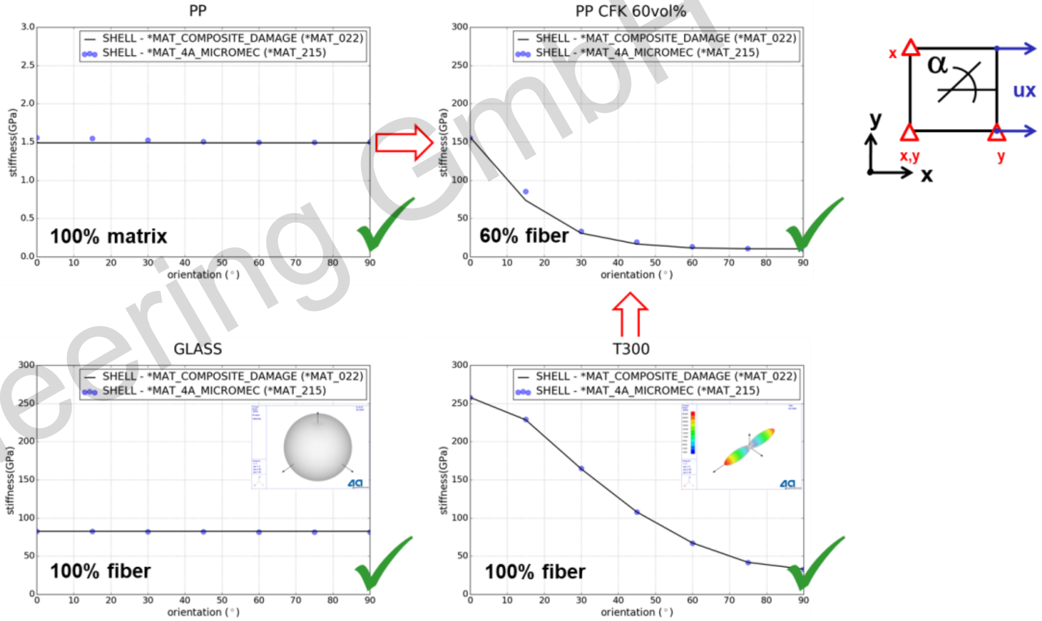
*MAT_4A_MICROMEC → **LS-DYNA R10**



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

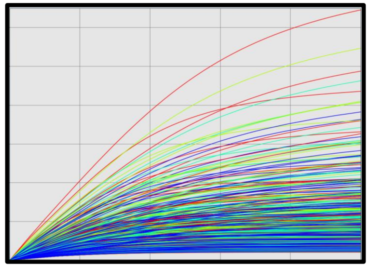
C...composite, F...fiber, M...matrix

Verifications

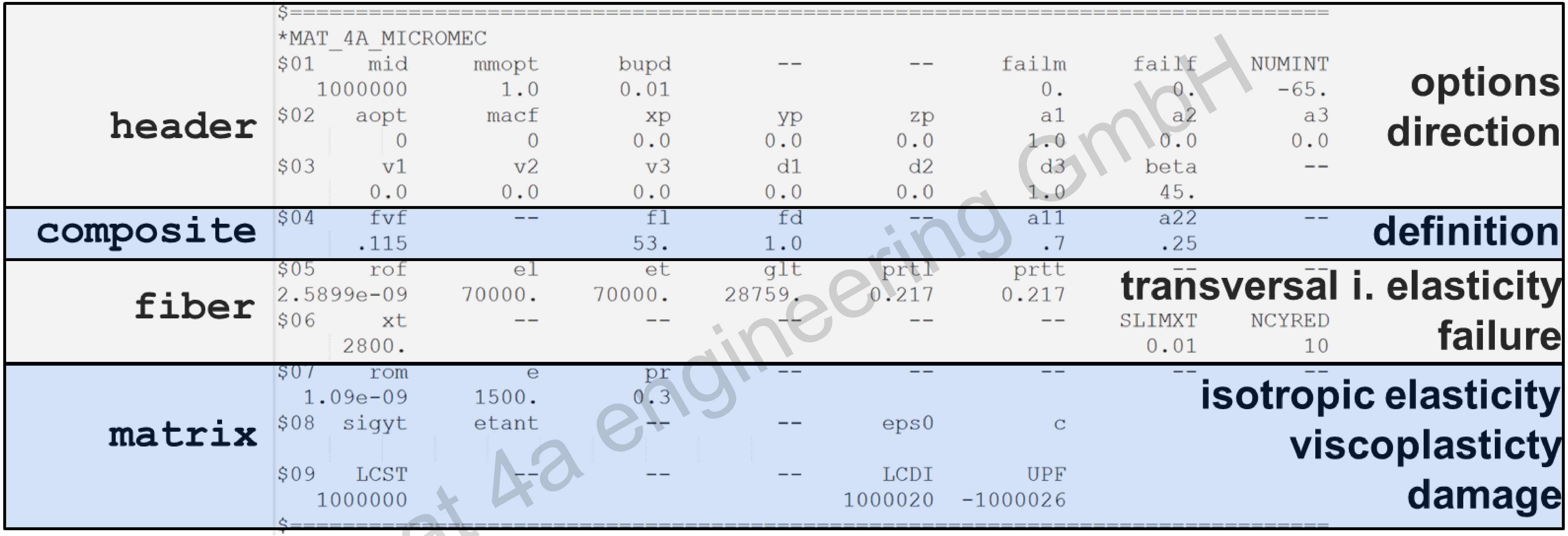


Robustness

DOE - RUNS
without an error



Upcoming material models
*MAT_215 KEYWORD



```
$===============================================================================
*MAT_4A_MICROMEC
$01    mid     mmopt      bupd        --        --     failm     failf    NUMINT
   1000000       1.0      0.01                           0.        0.      -65.
$02   aopt      macf        xp        yp        zp        a1        a2        a3
         0         0       0.0       0.0       0.0       1.0       0.0       0.0
$03     v1        v2        v3        d1        d2        d3      beta        --
       0.0       0.0       0.0       0.0       0.0       1.0       45.
$04    fvf        --        fl        fd        --       a11       a22        --
      .115                 53.       1.0                  .7       .25
$05    rof        el        et       glt      prtl      prtt        --        --
2.5899e-09    70000.    70000.    28759.     0.217     0.217
$06     xt        --        --        --        --        --    SLIMXT    NCYRED
     2800.                                                      0.01        10
$07    rom         e        pr        --        --        --        --        --
  1.09e-09     1500.       0.3
$08  sigyt     etant        --        --      eps0         c

$09   LCST        --        --        --      LCDI       UPF
   1000000                                 1000020  -1000026
$===============================================================================
```

header — options, direction

composite — definition

fiber — transversal i. elasticity, failure

matrix — isotropic elasticity, viscoplasticty, damage

Upcoming material models
*MAT_215 KEYWORD

CARD 1: General Options / Parameter

Card 1	1	2	3	4	5	6	7	8
Variable	MID	MMOPT	BUPD			FAILM	FAILF	NUMINT
Type	A8	F	F			F	F	F
Default	**none**	**0.0**	**0.01**			**0.0**	**0.0**	**1.0**

`FAILM:` Matrix failure – ductile DIEM-Model

- **LT.0:** |FAILM| - matrix **equivalent** plastic strain
- **EQ.1:** active DIEM (triaxiality of **matrix** stresses)
- **EQ.11:** active DIEM (triaxiality of **composite** stresses)

`FAILF:` Fiber failure

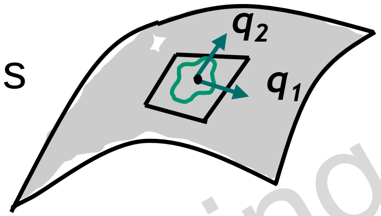
- EQ.0: off
- **EQ.1:** active (Reserve factor **Fiber tensile strength**)

Upcoming material models
*MAT_215 KEYWORD

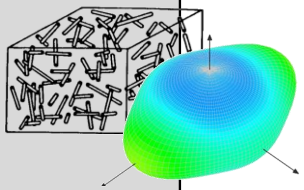
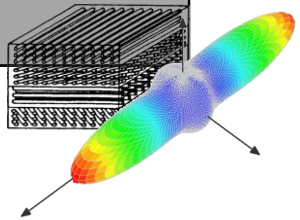
CARD 1: General Options / Parameter

CARD 2-3: Element orientation*

analog to LSDYNA standard anisotropic material cards



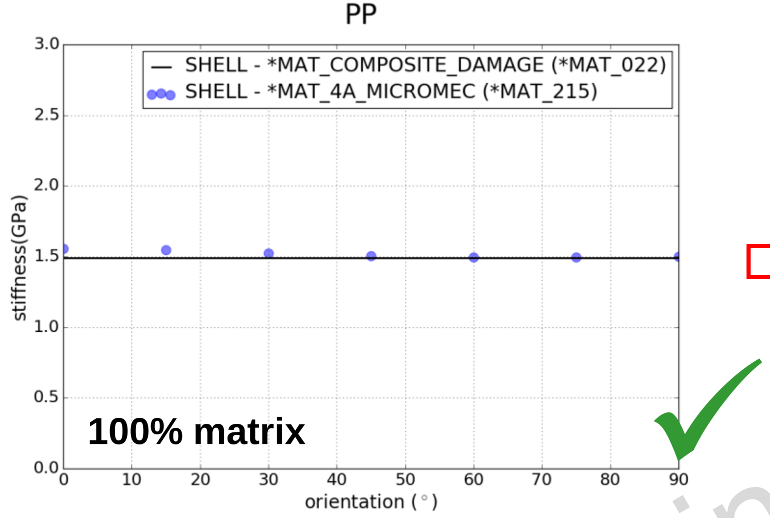
CARD 4: Composite Buildup*

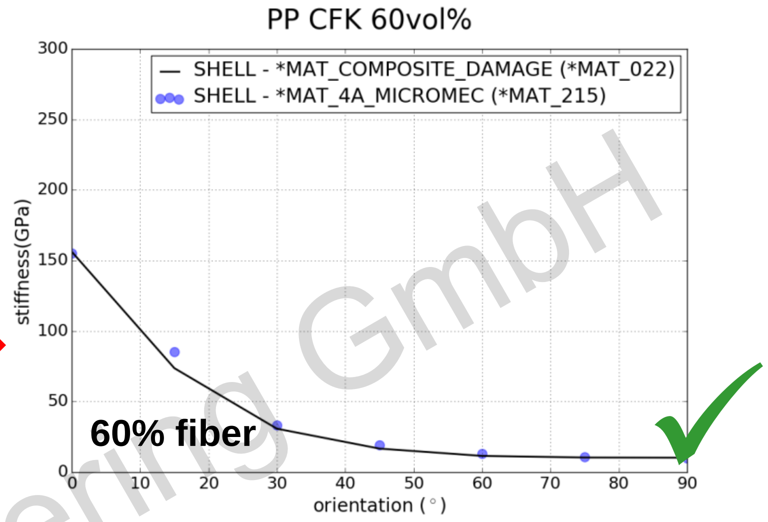
Card 4	1	2	3	4	5	6	7	8
	FVF		FL	FD		A11	A22	
PP GF30	**-0.3**		**200.0**	**10.0**		**0.7**	**0.25**	
PP LGF50	**-0.5**		**1000.0**	**20.0**		**0.65**	**0.30**	
PA6 GF45	**-0.45**		**250.0**	**10.0**		**0.8**	**0.15**	
Carbon UD	**0.6**		**10000.0**	**10.0**		**1.0**	**0.0**	

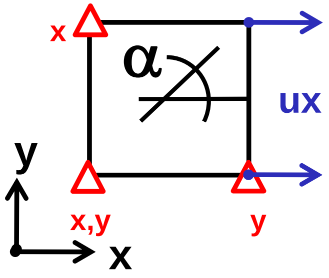
FVF > 0: fiber volume fraction → Composite
FVF < 0: fiber mass fraction → SFRT/LFRT

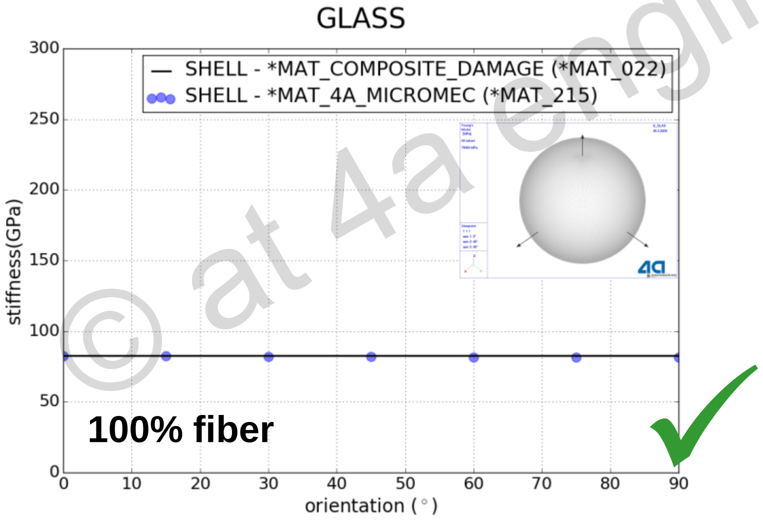
*may be overwritten by
`*INITIAL_STRESS_SHELL/SOLID`

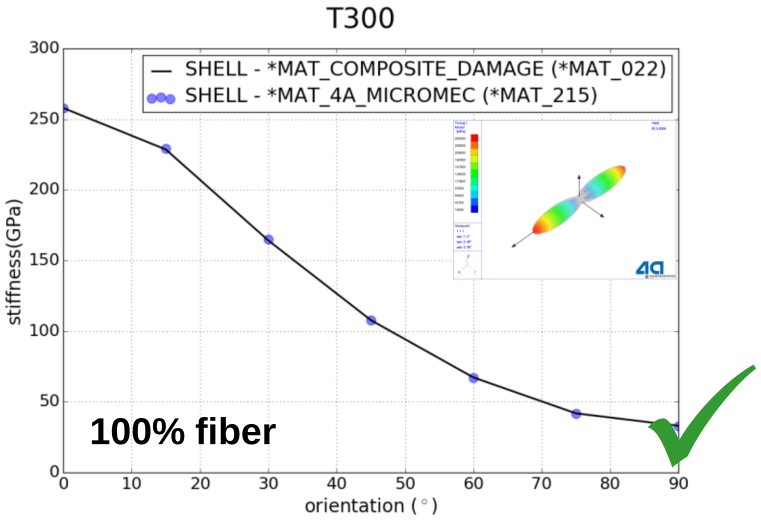
Upcoming material models
*MAT_215 - Verification


PP

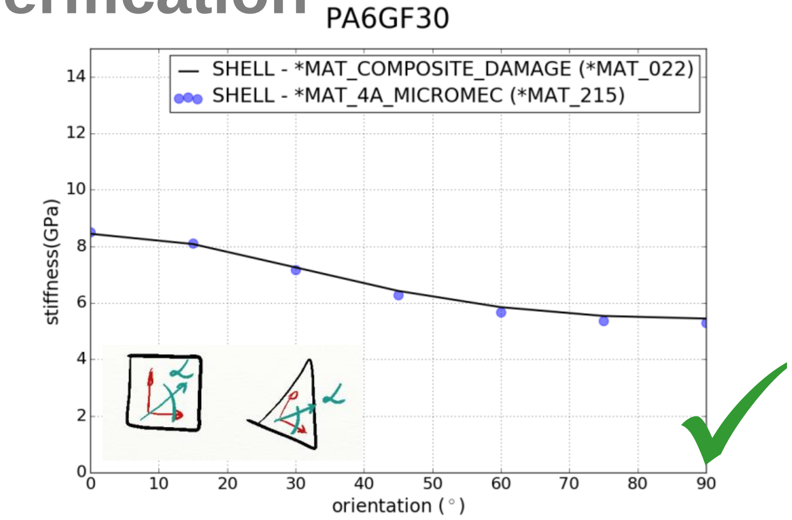

PP CFK 60vol%

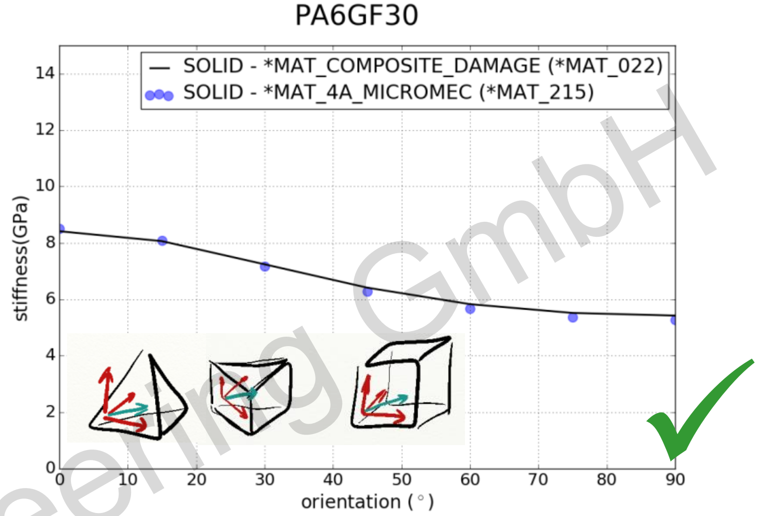


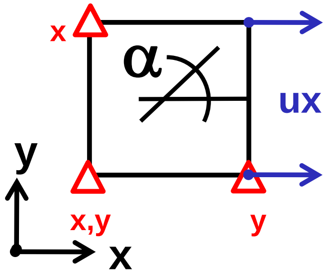

GLASS

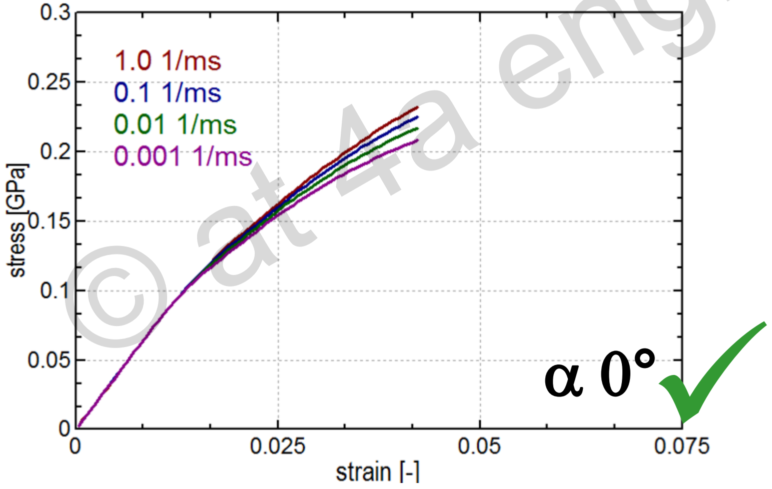

T300

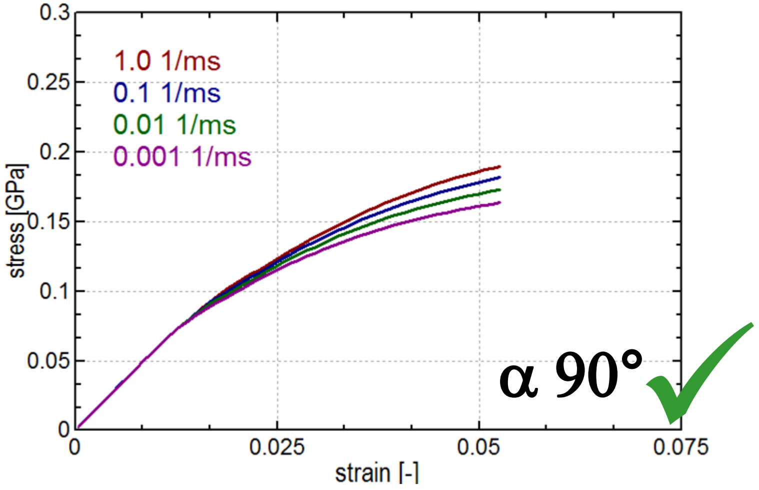
Upcoming material models
*MAT_215 - Verification



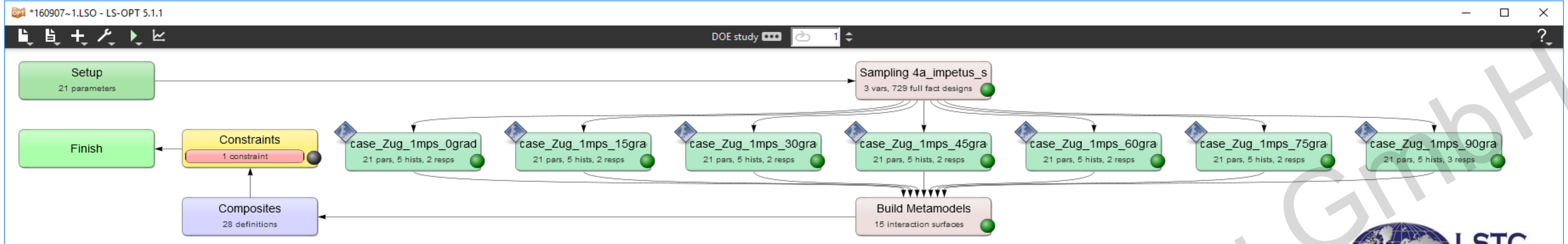


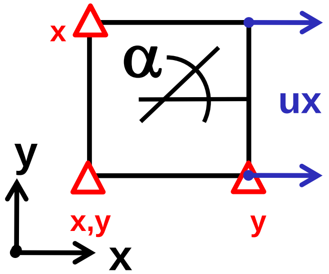






Upcoming material models
*MAT_215 - Verification





LSTC Livermore Software Technology Corp.
LS-OPT ®

DOE with LS-OPT:

MATRIX: PP

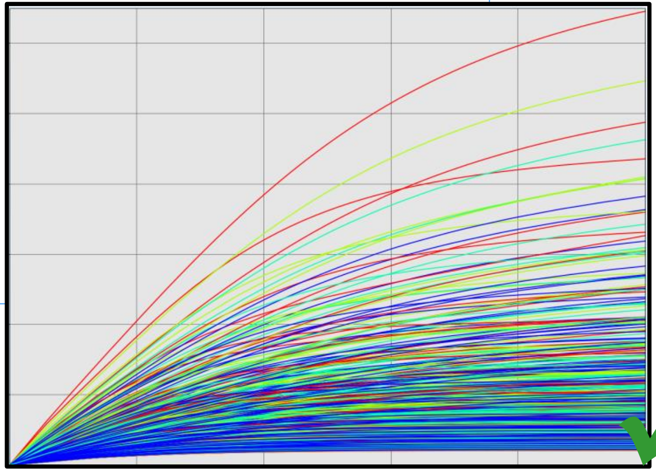
FIBER: GLASS

FVF: -0.05;-0.15;-0.20;-0.25;-0.30;-0.35;-0.40;-0.50;-0.60

FL: 100;200;500;1000

A11: 0.6;0.7;0.8;0.9

α: 0°;15°;30°;45°;60°;75°;90°



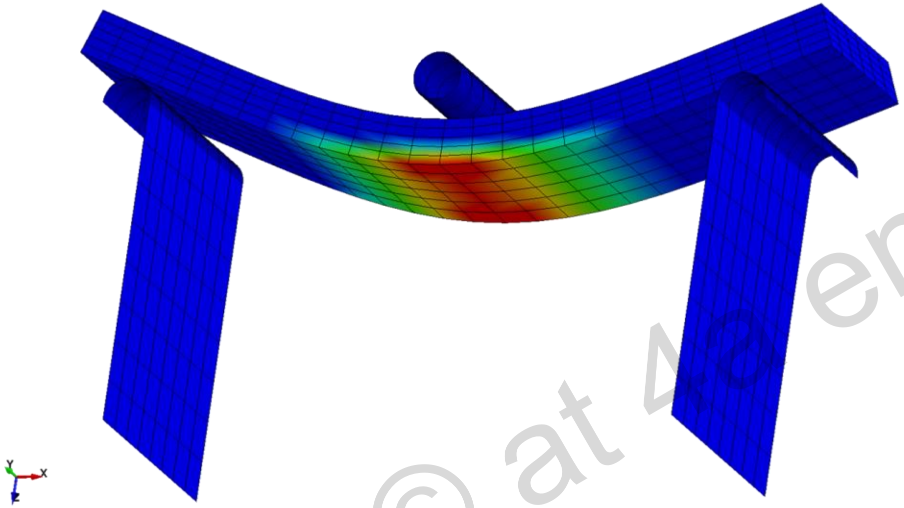
✓

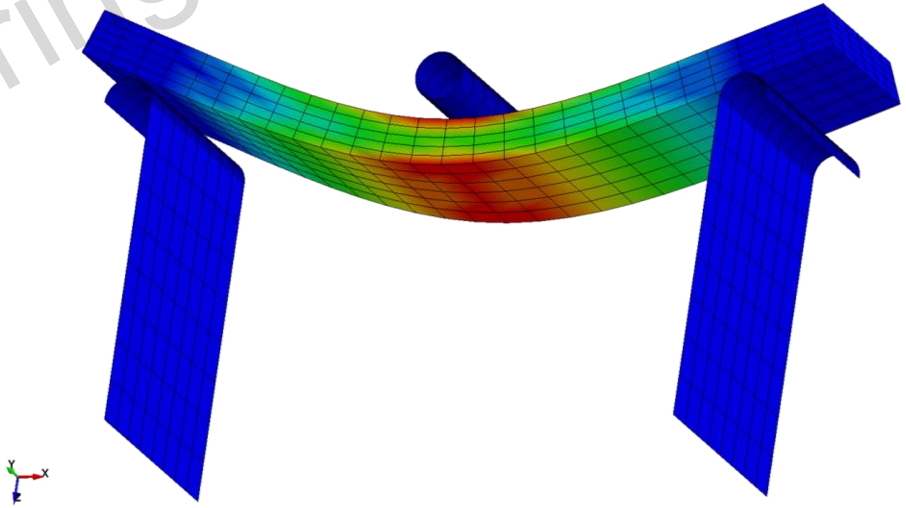
RUNS without an error

Upcoming material models
*MAT_215 KEYWORD

CARD 1: General Options / Parameter

Card 1	1	2	3	4	5	6	7	8
Variable	MID	MMOPT	BUPD			FAILM	FAILF	NUMINT
Type	A8	F	F			F	F	F
Default	**none**	**0.0**	**0.01**			**0.0**	**0.0**	**1.0**





History#4 (step8: 0-0.81):

dm - matrix damage init.

History#6 (step8: 0-0.13):

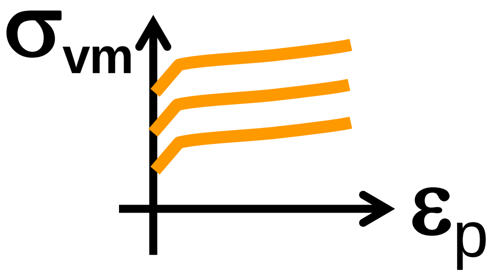
Fiber damage init.

Upcoming material models
*MAT_215 KEYWORD

CARD 9: matrix material tables

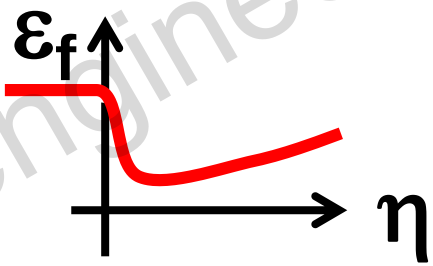
Card 9	1	2	3	4	5	6	7	8
Variable	LCIDT				LCDI	UPF		
Type	F				F	F		
Default	0				0	0.0		

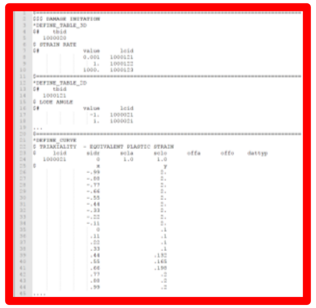
Hardening



LCIDT	Effective stress (Table)
LCDI	Damage initiation (Table)
UPF	Damage evolution parameter

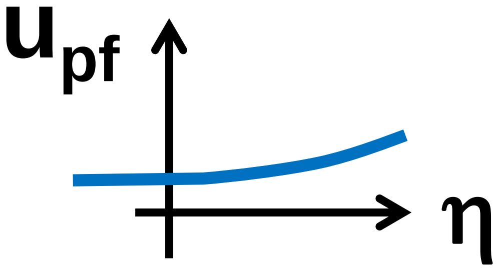
Damage Initiation

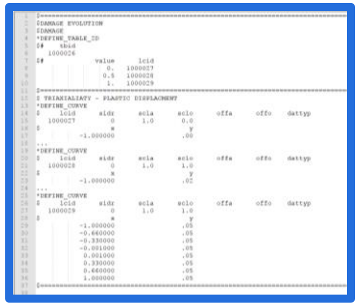




```
$==============================================================================
$$$ DAMAGE INITATION
*DEFINE_TABLE_3D
$#    tbid
   1000020
$ STRAIN RATE
$#              value      lcid
                0.001   1000121
                   1.   1000122
                1000.   1000123
$==============================================================================
*DEFINE_TABLE_2D
$#    tbid
   1000121
$ LODE ANGLE
$#              value      lcid
                  -1.   1000021
                   1.   1000021
...
$==============================================================================
*DEFINE_CURVE
$ TRIAXIALITY  - EQUIVALENT PLASTIC STRAIN
$     lcid      sidr      scla      sclo      offa      offo    dattyp
   1000021         0       1.0       1.0
$                  x                   y
                -.99                  2.
                -.88                  2.
                -.77                  2.
                -.66                  2.
                -.55                  2.
                -.44                  2.
                -.33                  2.
                -.22                  2.
                -.11                  2.
                   0                  .1
                 .11                  .1
                 .22                  .1
                 .33                  .1
                 .44                .132
                 .55                .165
                 .66                .198
                 .77                  .2
                 .88                  .2
                 .99                  .2
....
```

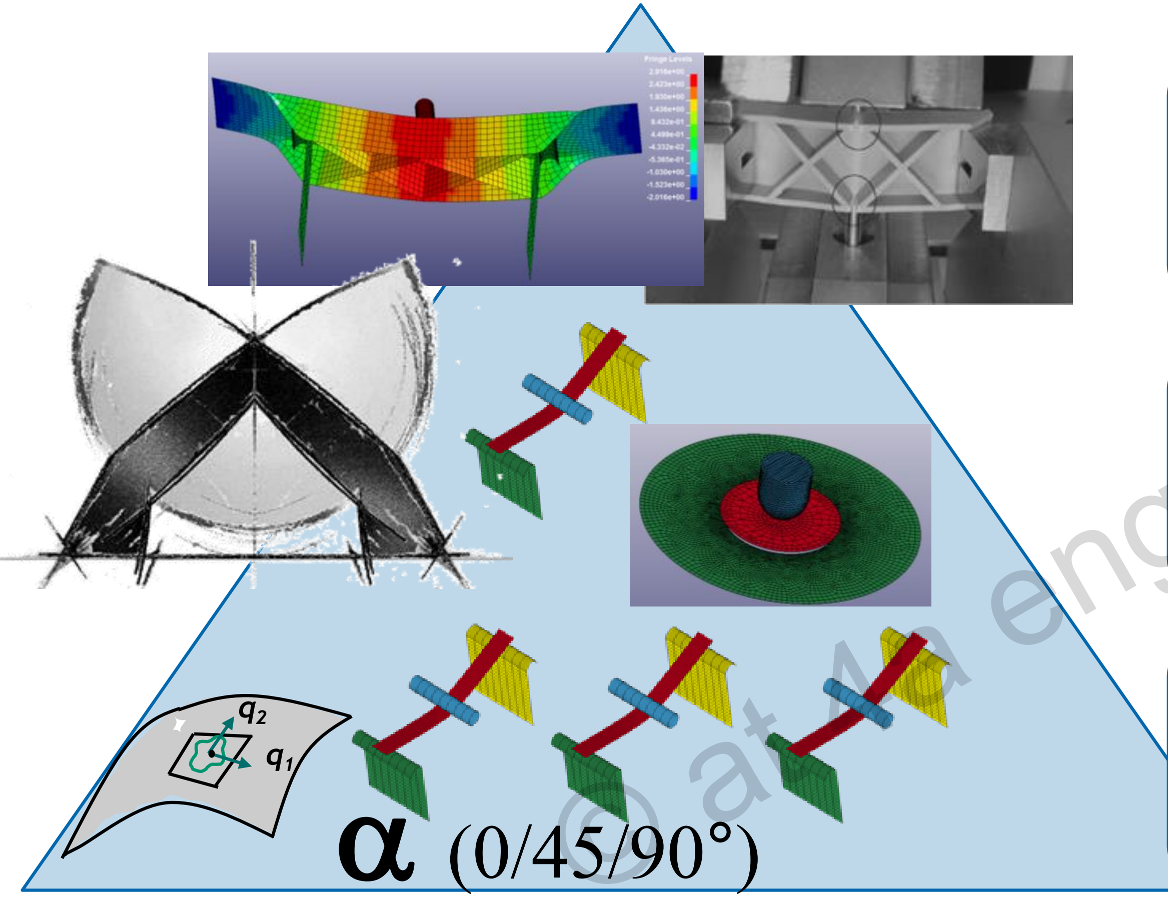
Damage Evolution



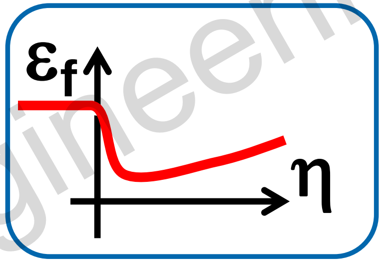


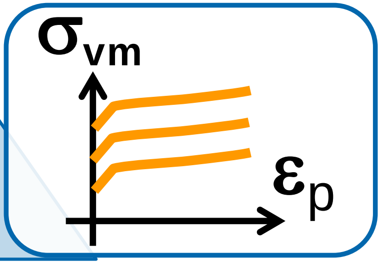
```
$==============================================================================
$DAMAGE EVOLUTION
$DAMAGE
*DEFINE_TABLE_2D
$#    tbid
   1000026
$#              value      lcid
                   0.   1000027
                  0.5   1000028
                   1.   1000029
$==============================================================================
$ TRIAXIALIATY - PLASTIC DISPLACMENT
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo    dattyp
   1000027         0       1.0       0.0
$                  x                   y
           -1.000000                 .00
...
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo    dattyp
   1000028         0       1.0       1.0
$                  x                   y
           -1.000000                 .02
...
*DEFINE_CURVE
$     lcid      sidr      scla      sclo      offa      offo    dattyp
   1000029         0       1.0       1.0
$                  x                   y
           -1.000000                 .05
           -0.660000                 .05
           -0.330000                 .05
           -0.001000                 .05
            0.001000                 .05
            0.330000                 .05
            0.660000                 .05
            1.000000                 .05
$==============================================================================
```

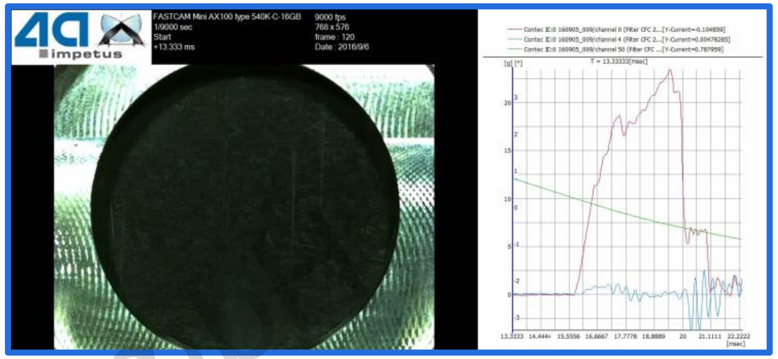
From test to material card

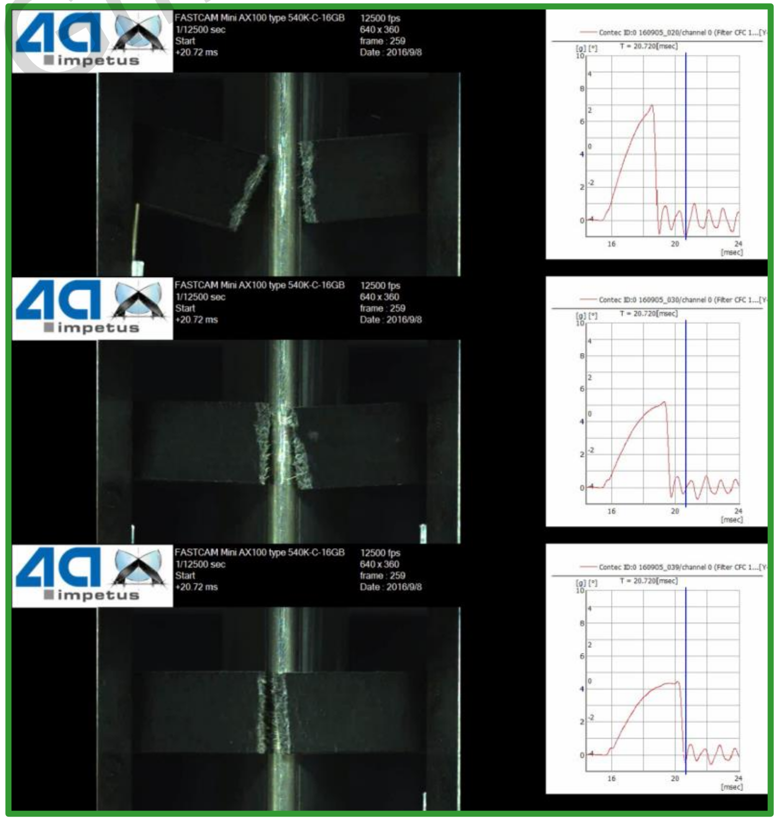


component validation



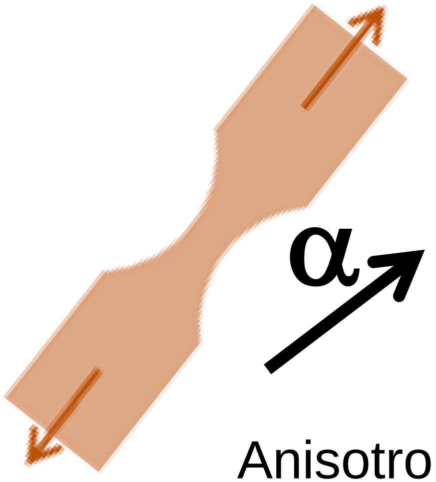






See more: P Reithofer, et.al., Versagen von faserverstärkten Kunststoffen bei dynamischer Beanspruchung, 4a Technologietag -2017

From test to material card

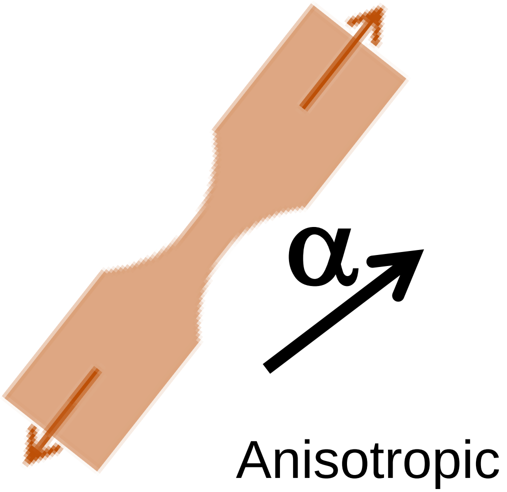


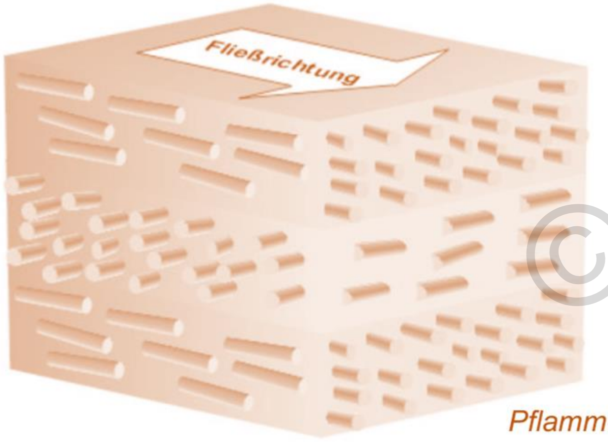
Anisotropic

Why not tension (only)?

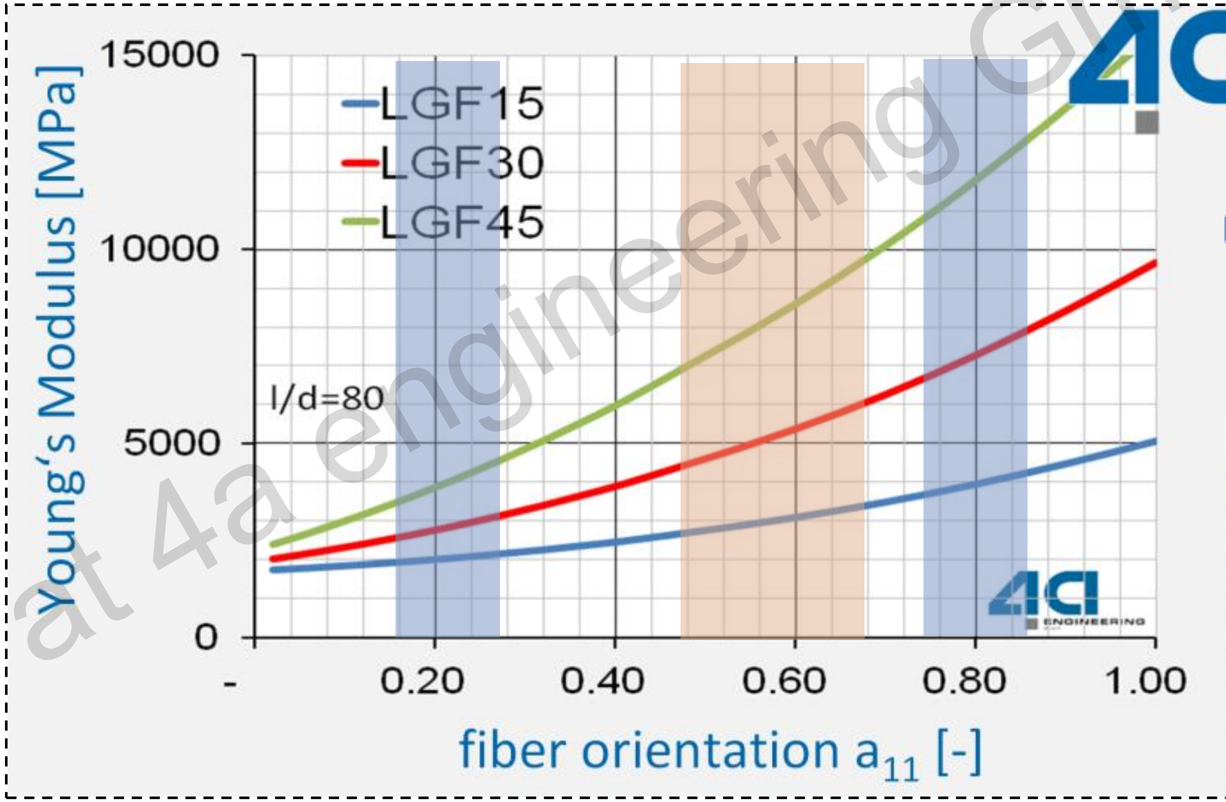
From test to material card

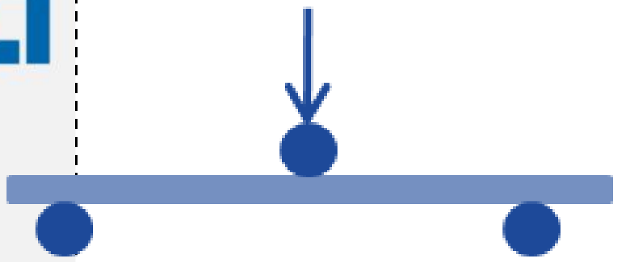
Why not tension (only)?

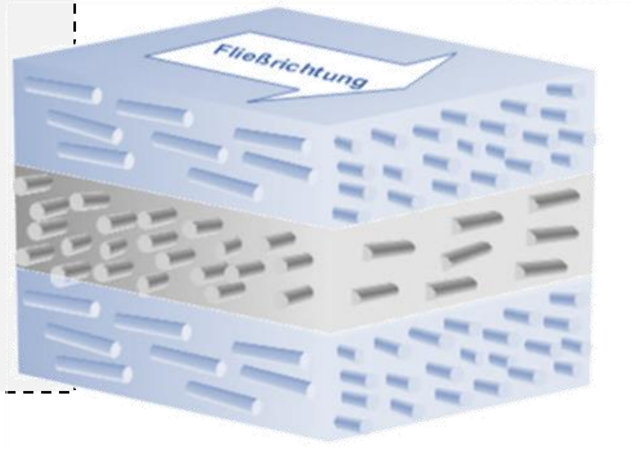




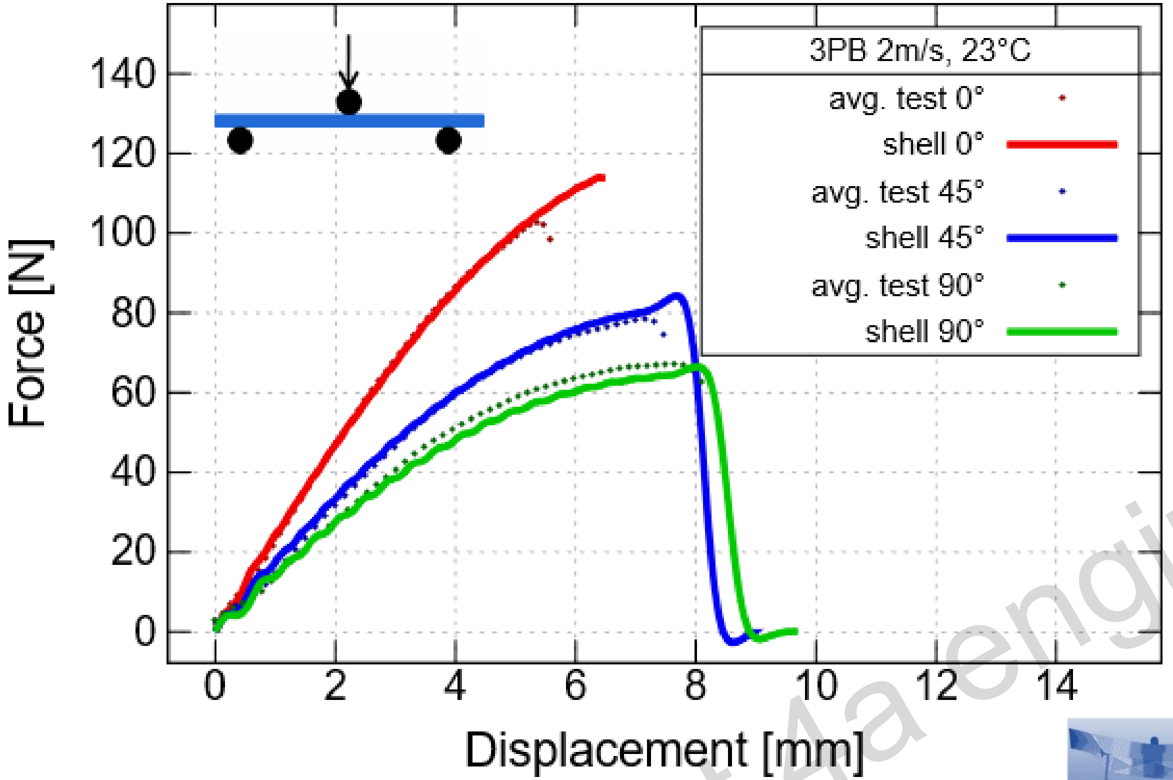
Pflamm-Jonas 2001

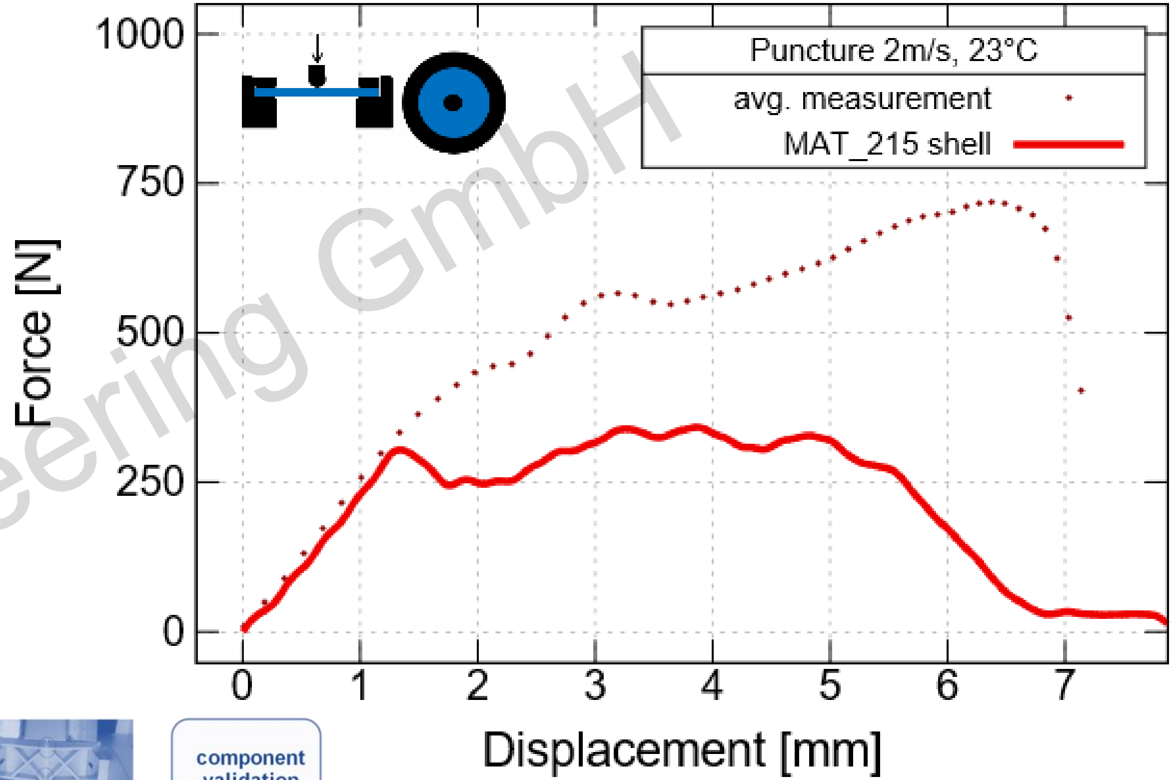


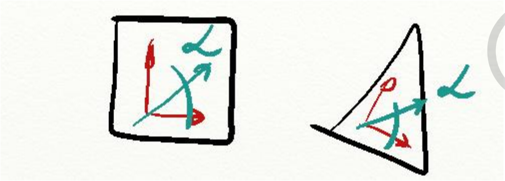


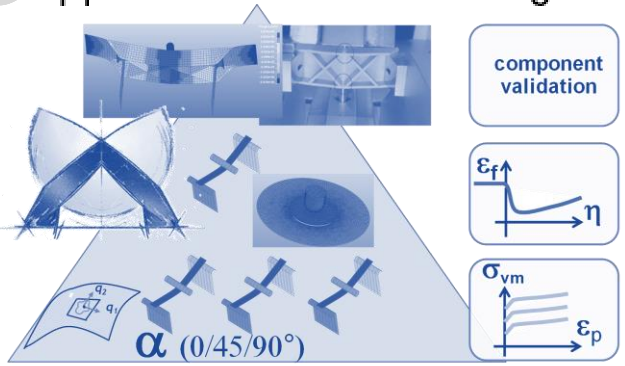


From test to material card – **PP LGF30** ***MAT_215**





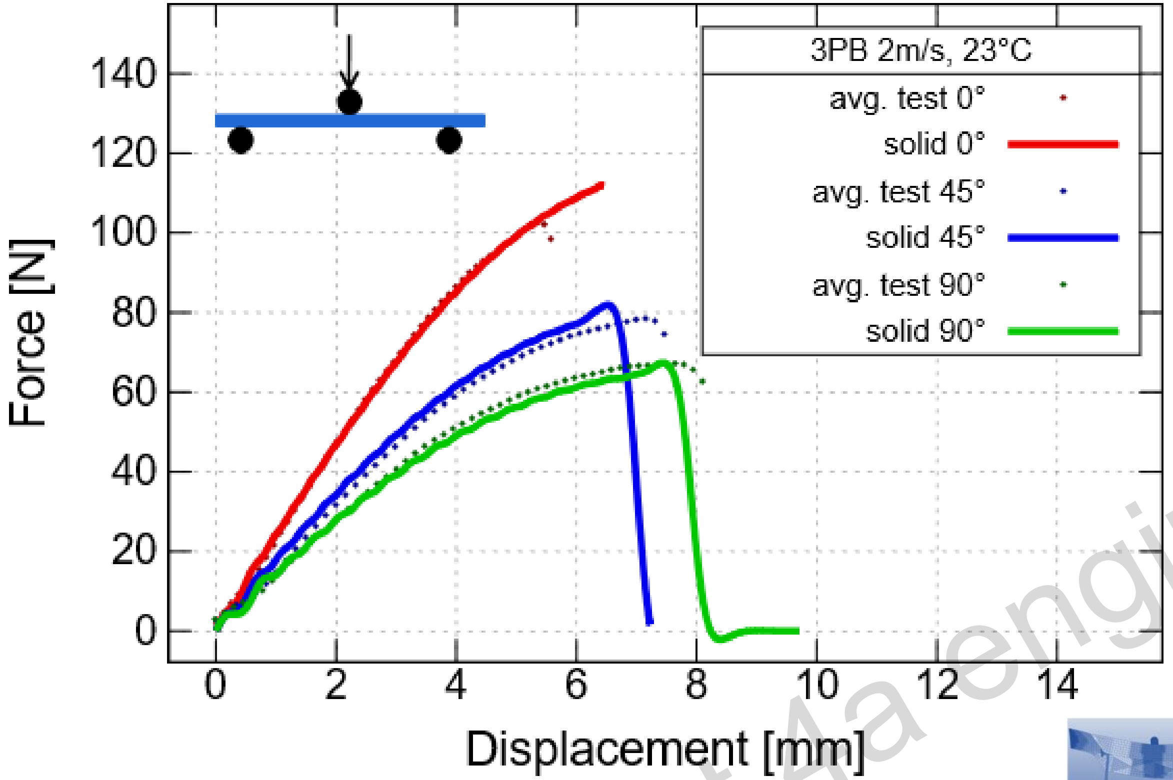


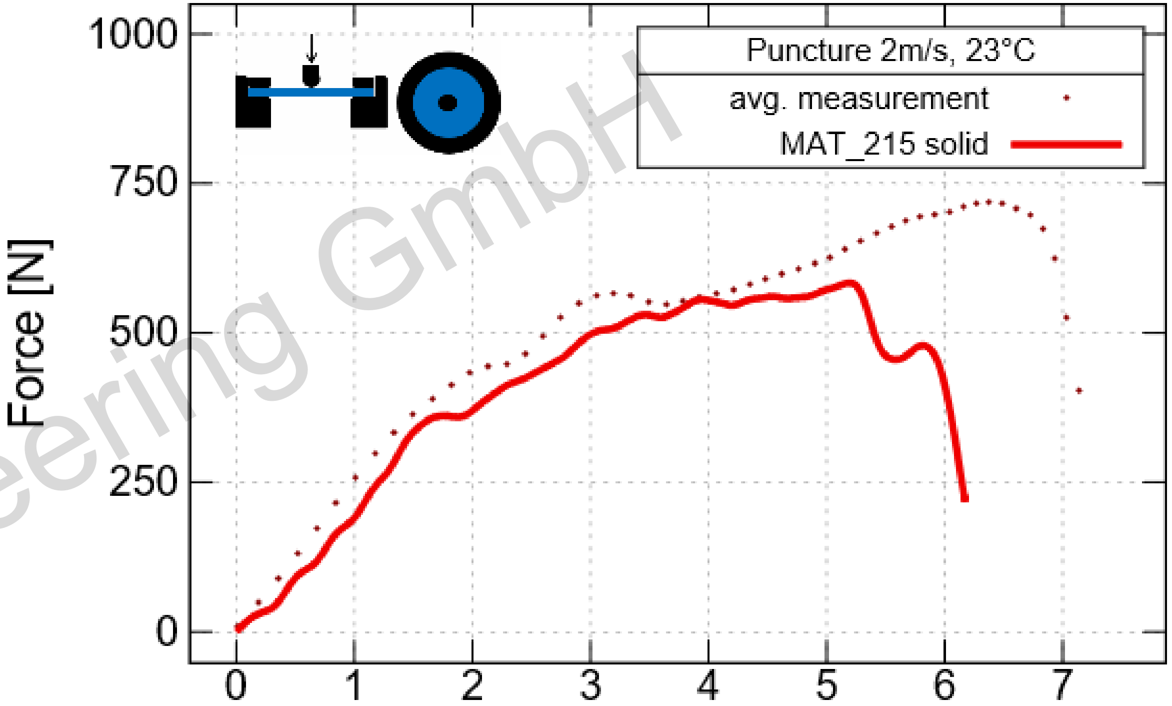


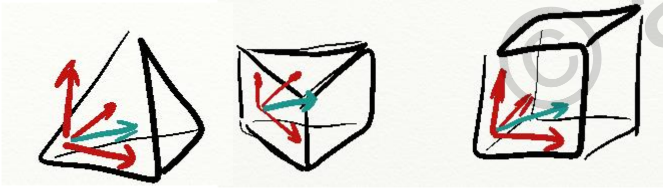
···· averaged test curves

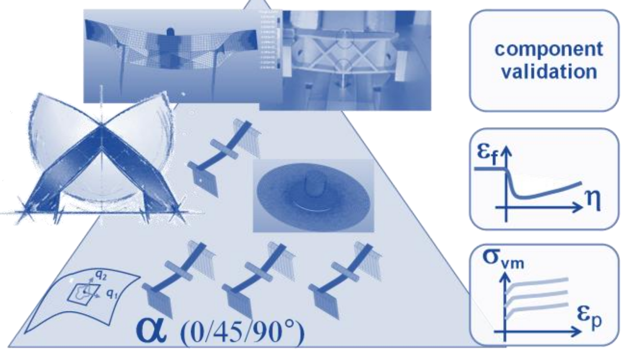
— result of simulation

From test to material card – **PP LGF30** ***MAT_215**





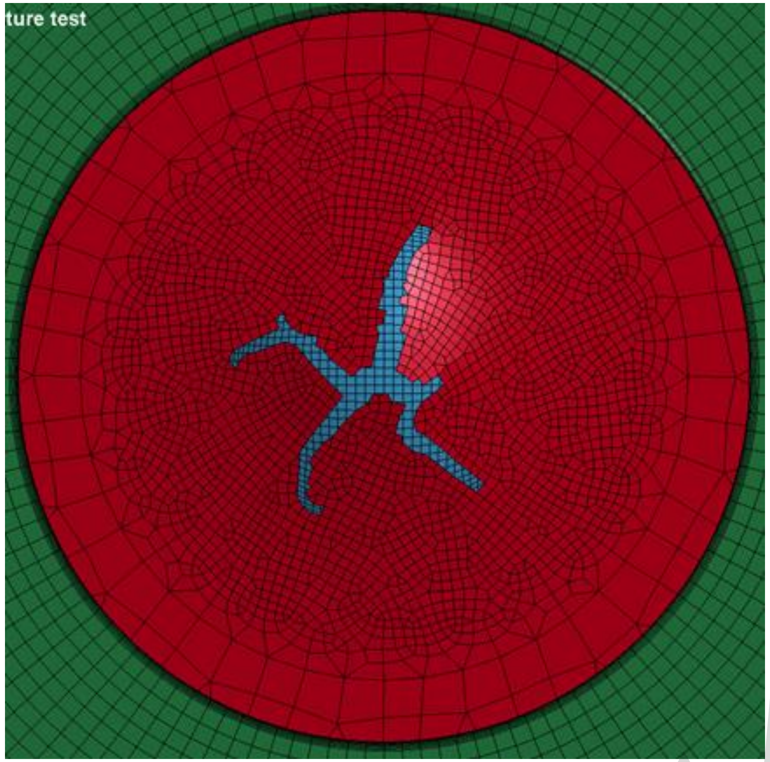


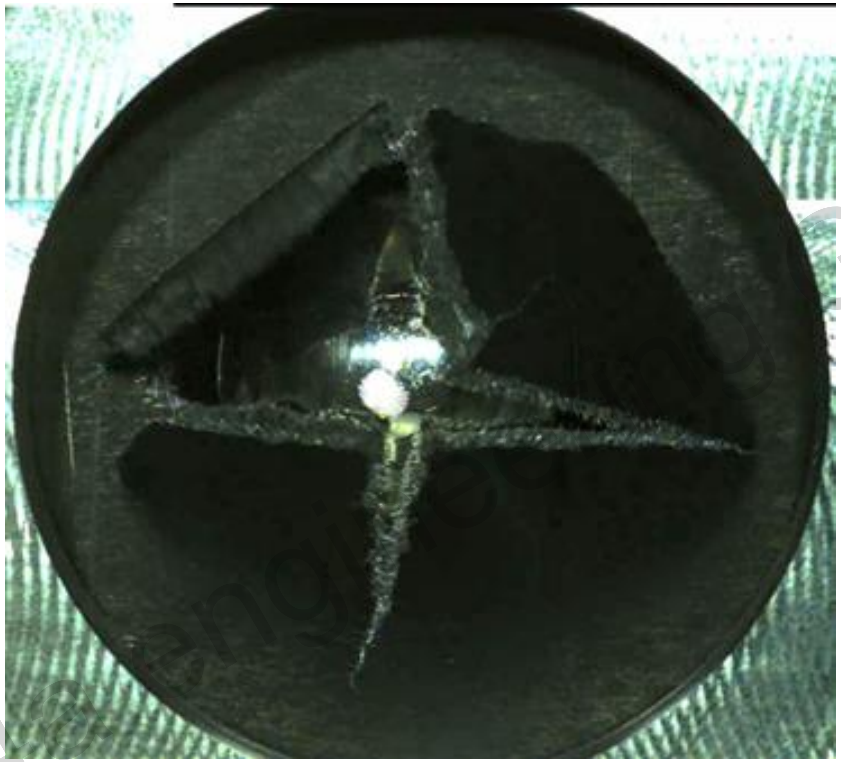


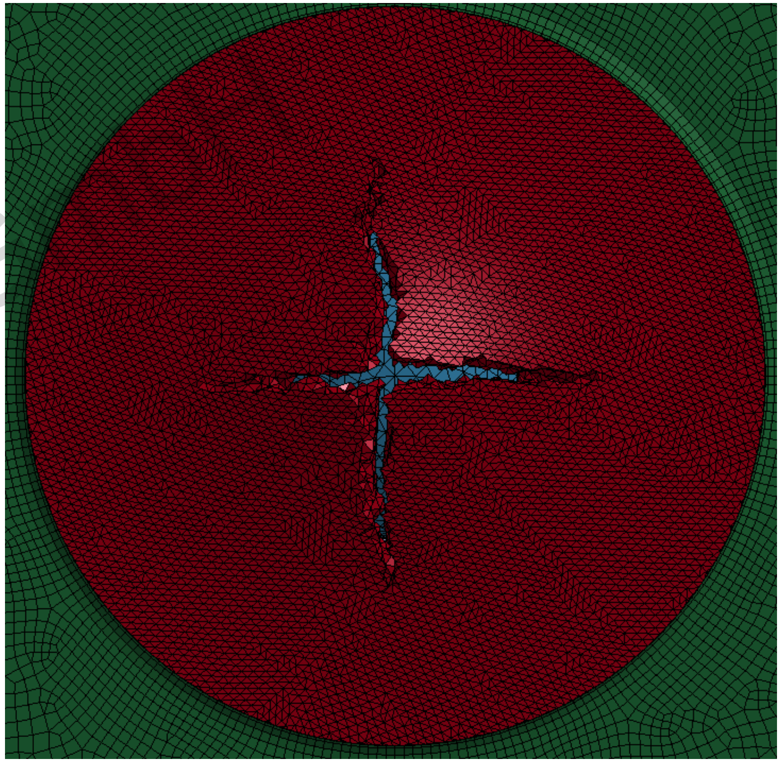
···· averaged test curves

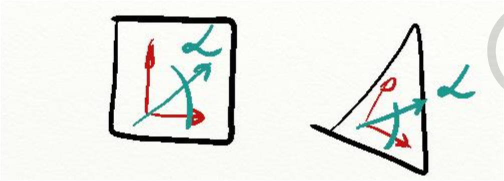
— result of simulation

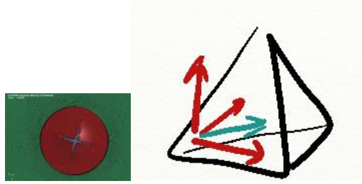
From test to material card – **PP LGF30** ***MAT_215**



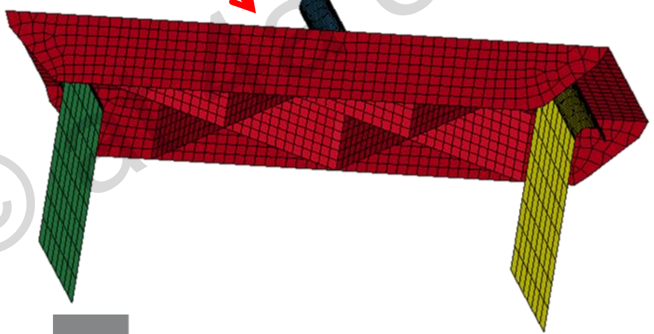


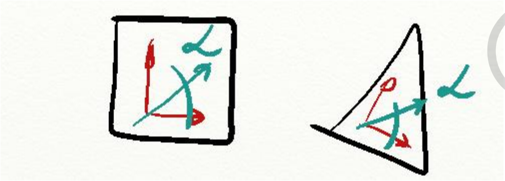




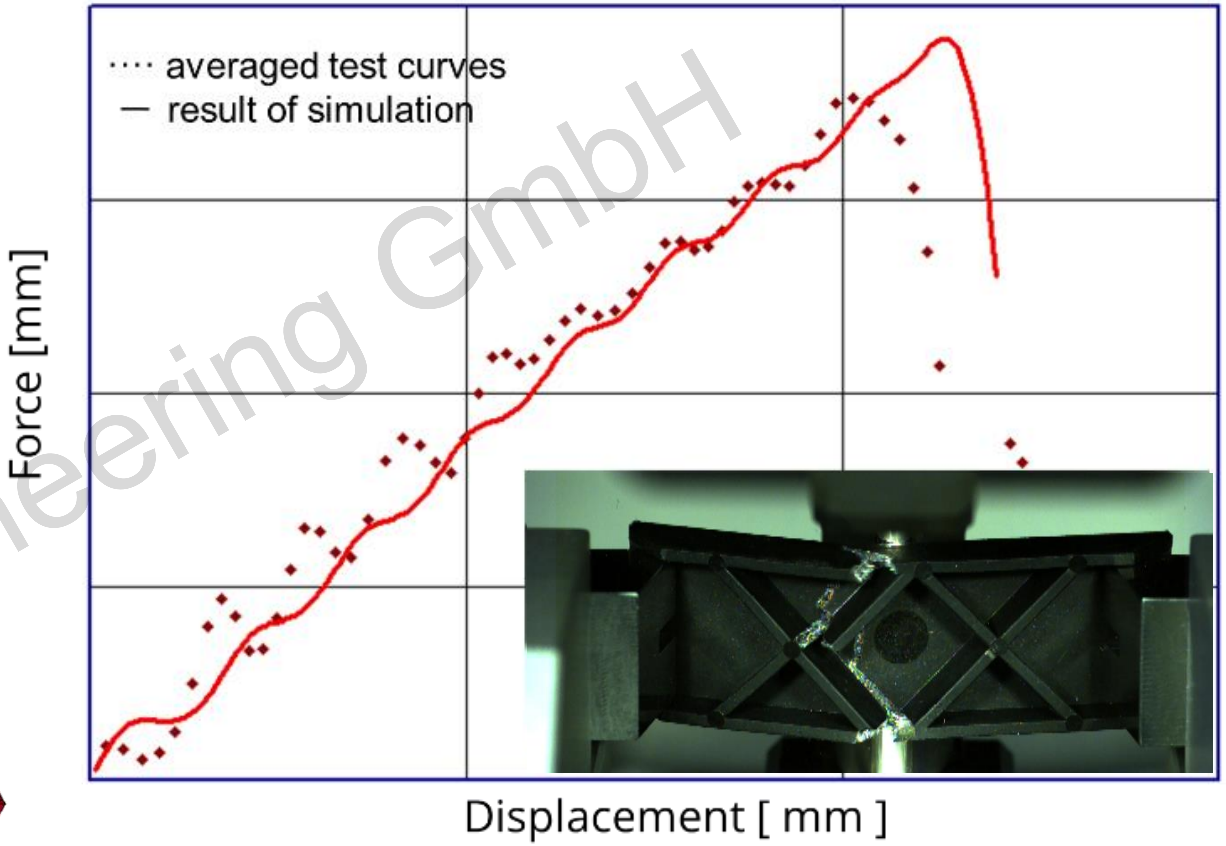


From test to material card – **PP LGF30** ***MAT_215**

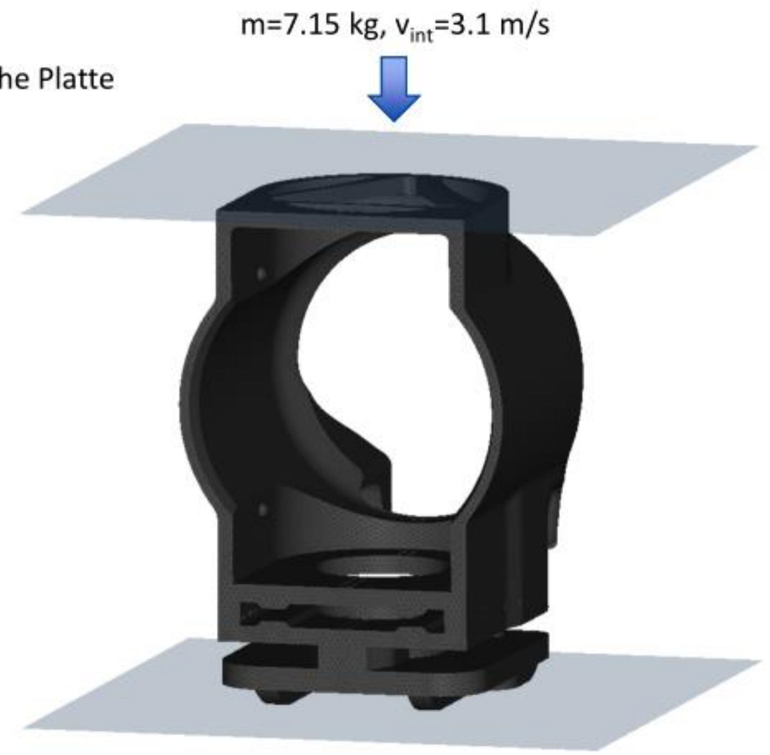


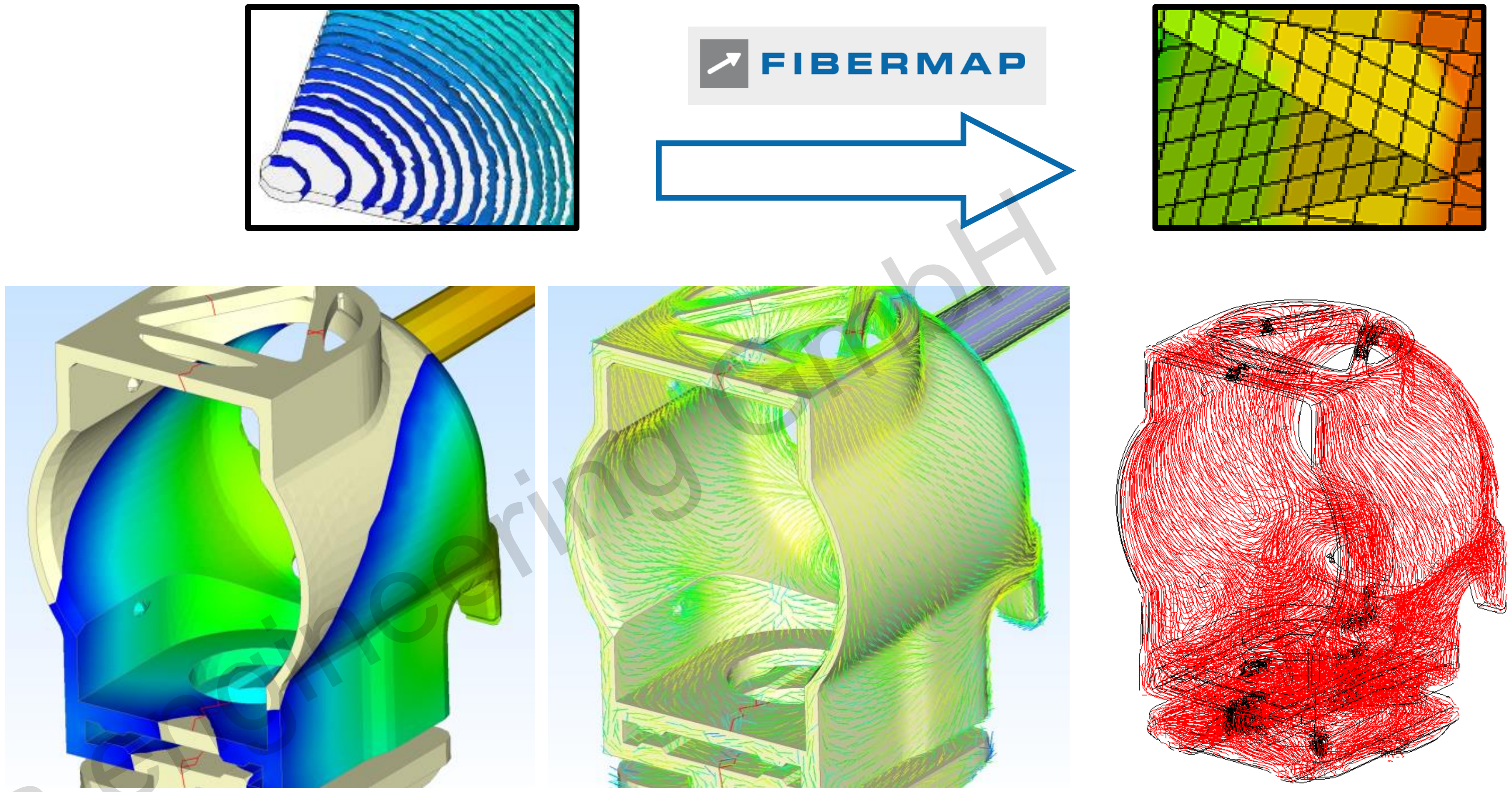


FIBERMAP



Case study - sleeve



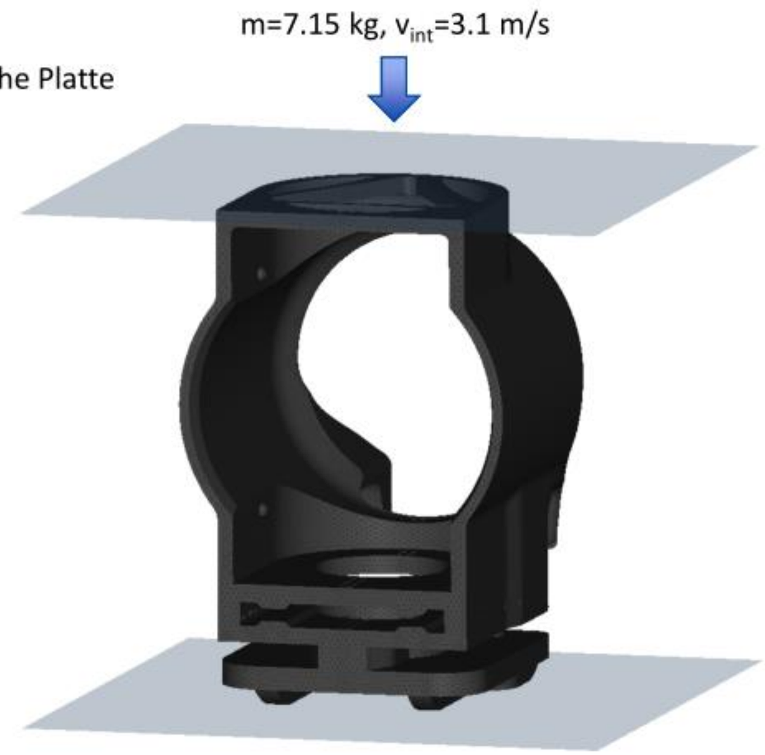


Typische Elementgröße: 0.25mm
Elementtyp: Tetrahedron Type 10
Elementanzahl: 469 470

hirtenberger
Automotive Safety

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

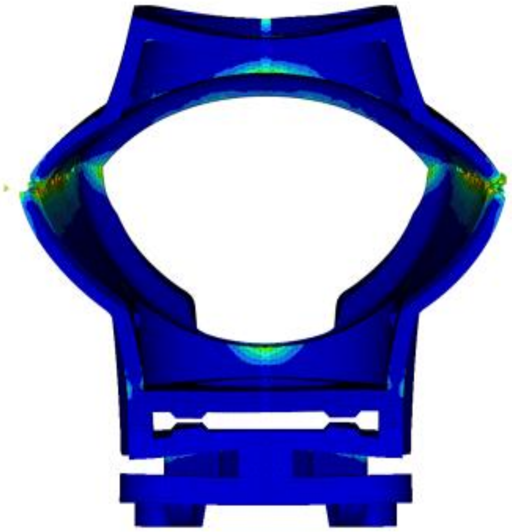
Case study - sleeve



test

***MAT_157/215**
local anisotropy

***MAT_24**
isotropic



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hirtenberger
Automotive Safety

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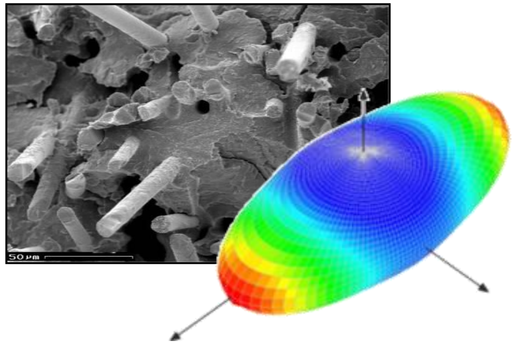
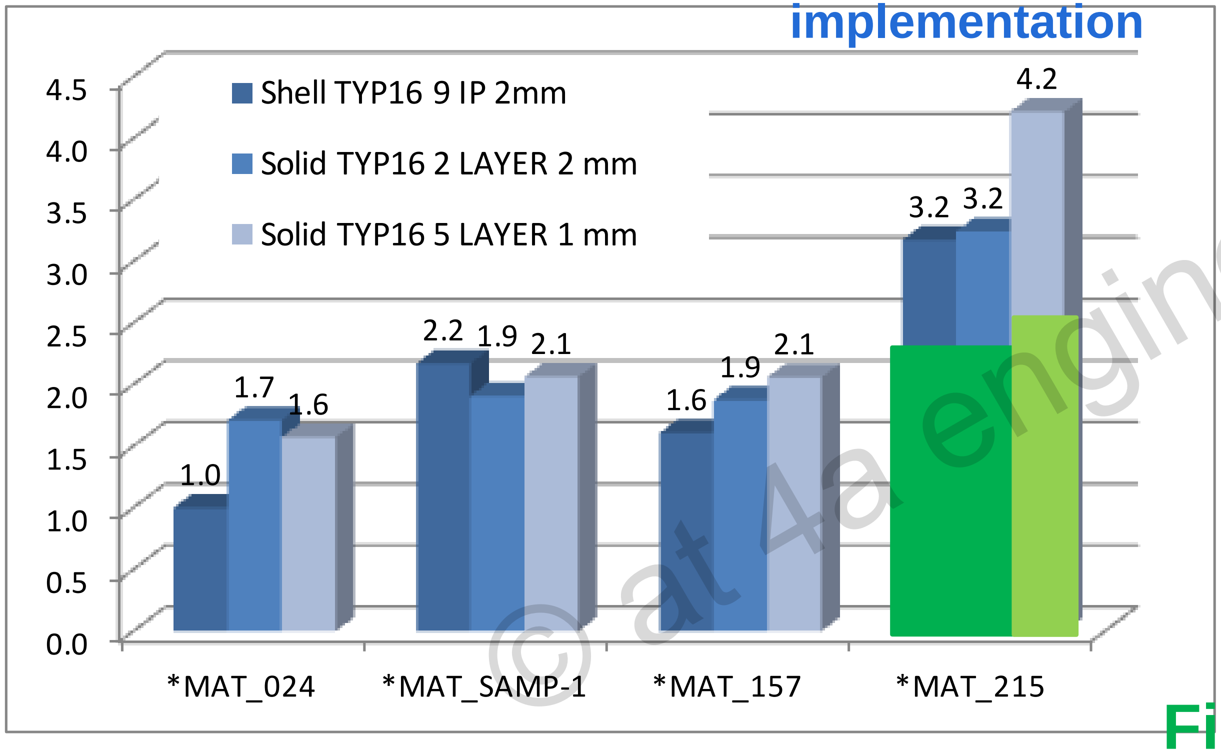




Current implementation

First improvements

Summary & Outlook

- advantages `*MAT_215`
  - micro mechanical approach model understands → fiber orientation, aspect ratio
  - simulation process chain considering local anisotropy process → structural
- ongoing improvement/development
  - CPU-time consumption
  - failure/damage model → further research
- LS-DYNA community
  - benchmark → feedback

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

[redacted]

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

IMPETUS

VALIMAT

SEMINAR AGENDA

10:00 - 10:45 INTRODUCTION

Material behavior for plastics

Introduction to VALIMAT™ - workflow for generating material cards

10:45 - 12:15 IMPETUS™ HANDS ON

Hardware introduction and hands on testing

13:15 - 14:45 VALIMAT™ HANDS ON

Evaluation of test data and organizing databases

AUTOFIT: *MAT_024 parameter identification using the new feature

14:45 - 15:30 ADVANCED TOPICS

Parameter identification:

- for yield surface and flow rule i.e. *MAT_187
- for damage and failure i.e. *MAT_ADD_EROSION

Outlook on upcoming material models

15:30 - 16:30 Q&A

4a ENGINEERING

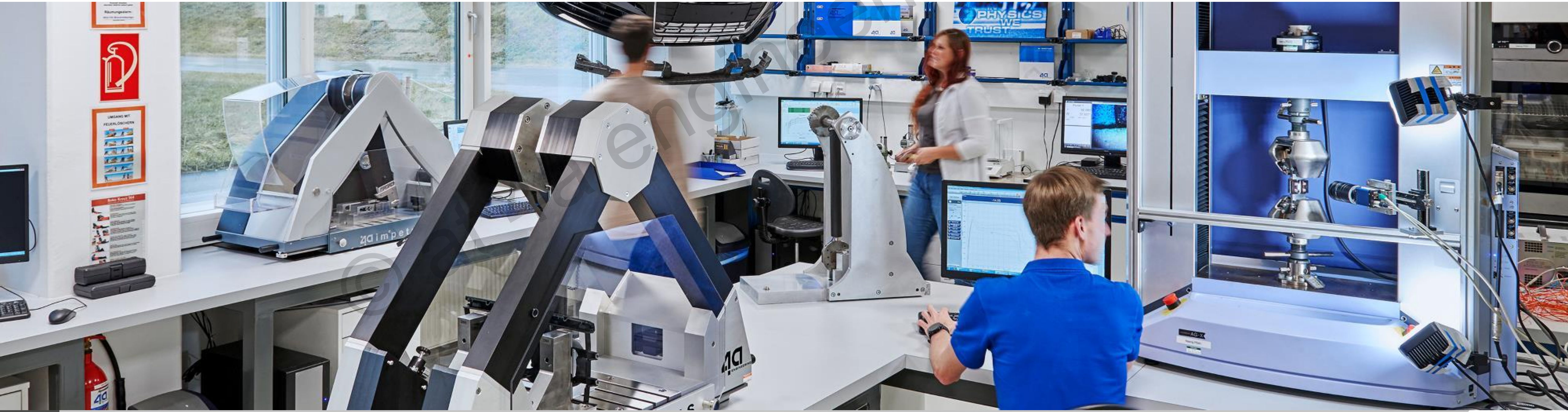
In cooperation with

JSOL CORPORATION   AR BROWN Think Quality & Create Value

IMPETUS http://impetus.4a.at

VALIMAT http://valimat.4a.at

YOUTUBE CHANNEL



Thank you for your attention

interested for more…

join us in Werfenweng, Austria from 3-4 March 2020