Investigations on different material models for a thermoplastic polymer in LS-Dyna

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03.03.2020

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Content

- Use Case of the Material Card
- Laboratory Measurements
- Material Model Selection and Calibration
- Material Card quality
- Relative Numerical Cost of the Material Model
- Outlook and Conclusion

Use Case of the Material Card

Crash simulation: Finite Element Analysis (FEA) of a car crash scenario

- Crash simulation objectives
  - economical design and front loading
  - pedestrian/occupant safety compliance
- Simulation characteristics
  - short time period, time dependent response necessary ➔ explicit simulation
  - high deformations, undefined local stress states ➔ wide range of strain rates, material models for larger strains
  - impact ➔ deformation most of the time in one direction
- Economically viable models must introduce simplifications like:
  - using **Shell elements**
  - setting lower limits for the **element sizes** (full crash model about **3-4mm**)
- Relevant materials are mostly metals or reinforced plastics

ELEMENT TYPE	NUMBERS OF ELEMENTS (without the Barrier Model)
SHELL	3,679,226
SOLID	1,533,452
MASS	39
DISCRETE	26
BEAM	1,762
SEAT BELT	126
Total	5,214,631

"Vehicle Interior and Restraints Modeling Development of Full Vehicle Finite Element Model Including Vehicle Interior and Occupant Restraints Systems For Occupant Safety Analysis Using THOR Dummies"; NHTSA (2018)

Use Case of the Material Card

Pedestrian safety simulation:

- **Ductile thermoplastics** are used in the bumper and lower absorber as they absorb impact energy the expected severity of the injuries in the pedestrian decreases
- Load cases and general guidelines defined by EURO NCAP

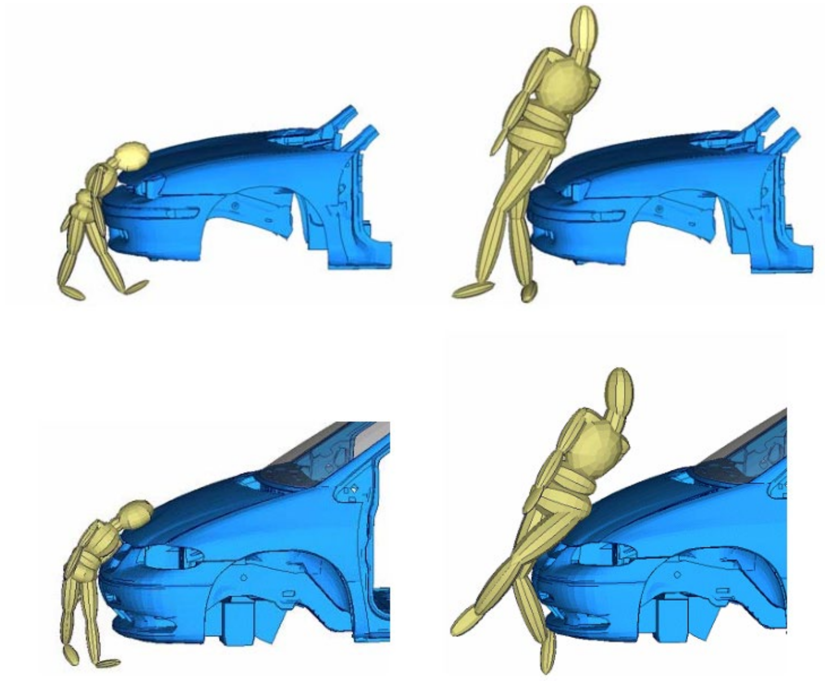
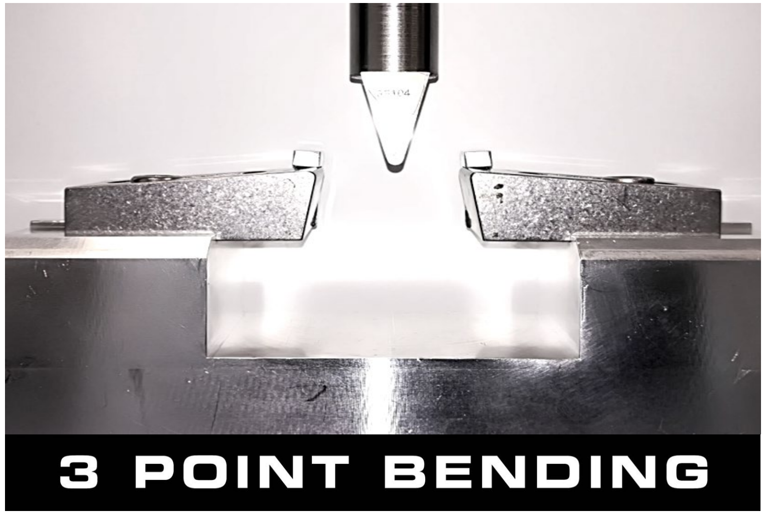


Figure 1 Impact of a 6 year old child and a 50 percentile male on a sport car and on a van

"Crash Simulation in Pedestrian Protection"; S. Dörr, H. Chladek, A. Huß; (2003); 4th european LS-DYNA Users Conference

Let‘s take a closer look on the plastic!

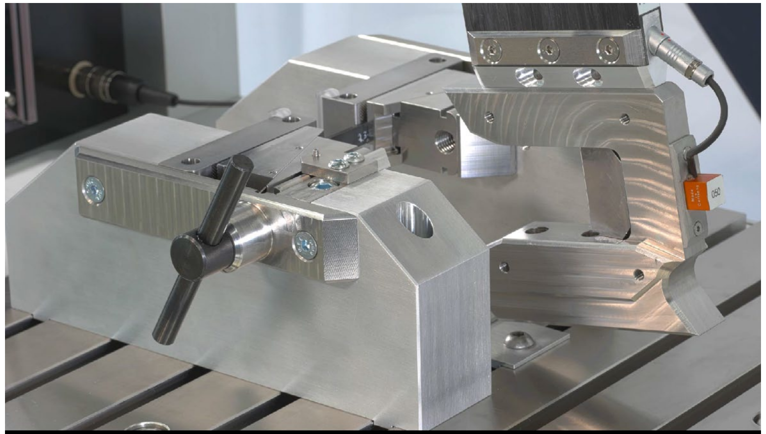
Static Testing



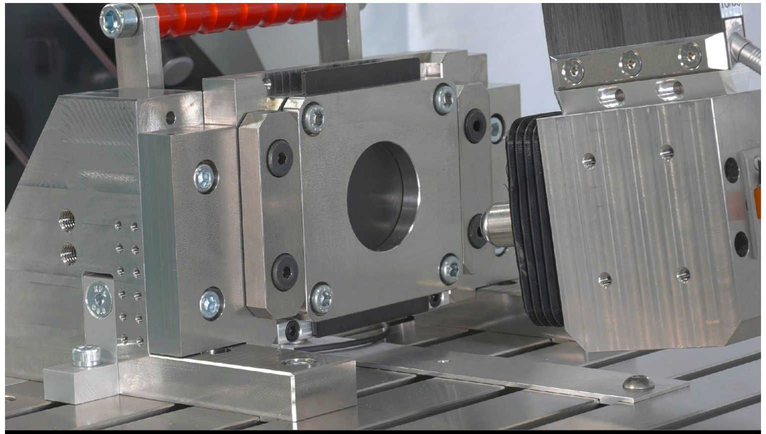
static ~ 1mm/s

IMPETUS® - efficient dynamic testing

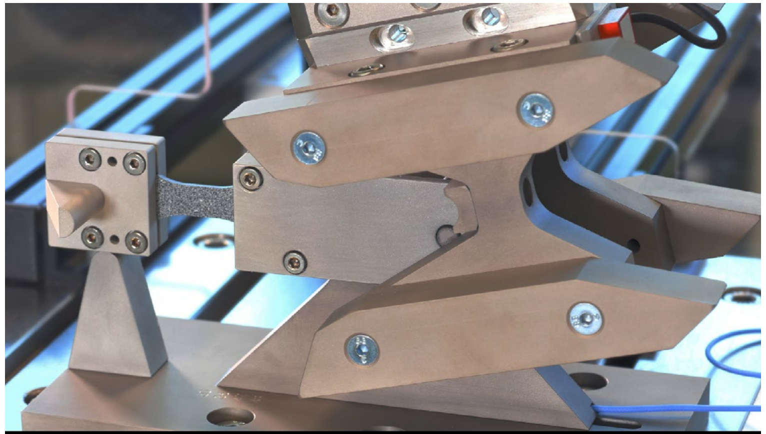
3 POINT BENDING



TENSION BENDING



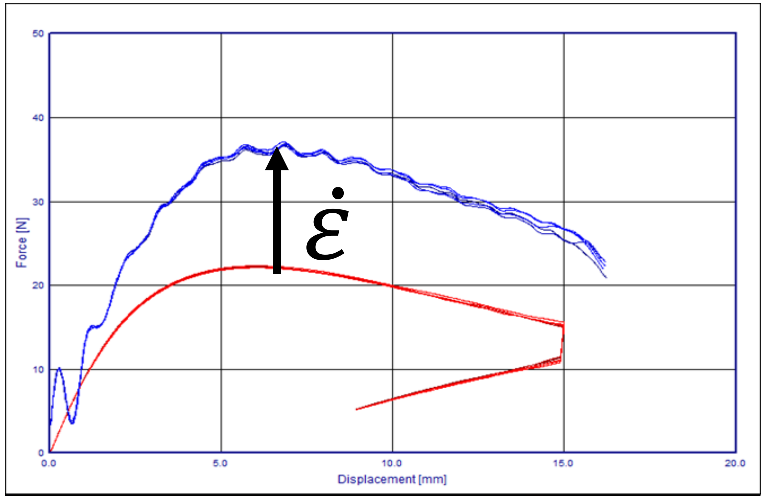
PUNCTURE TEST



TENSION TEST

IMPETUS® ~ 3 m/s

Measurement Results



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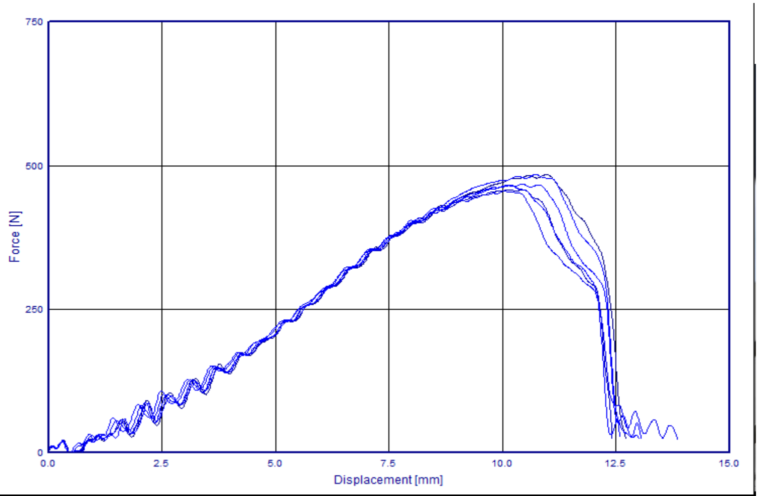

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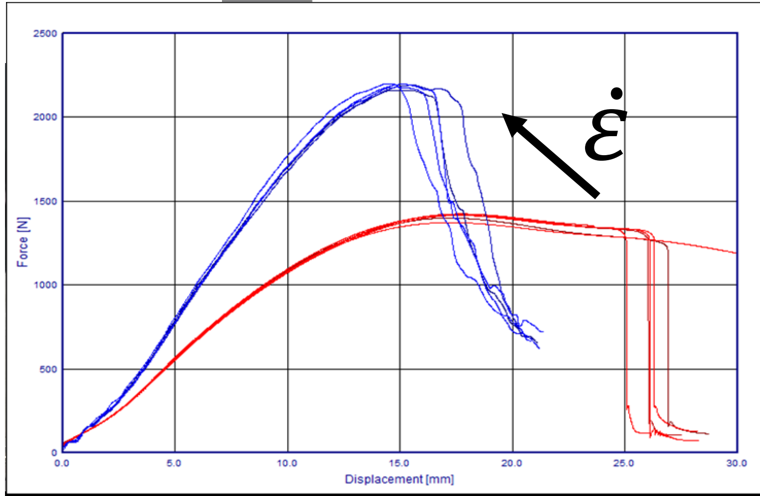

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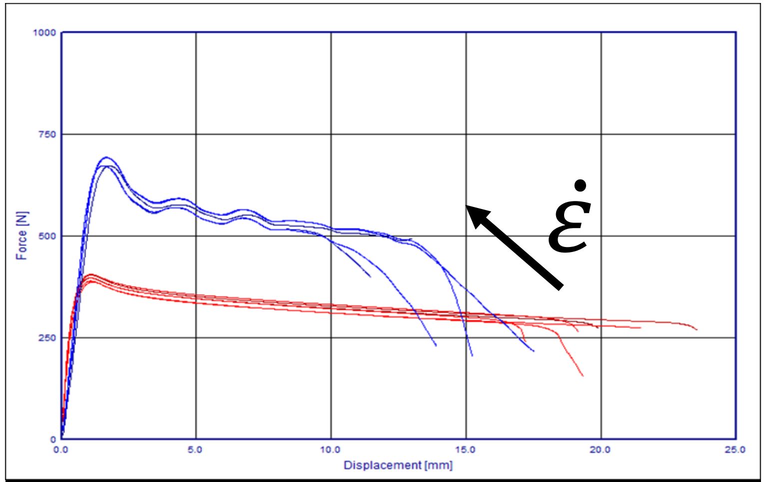
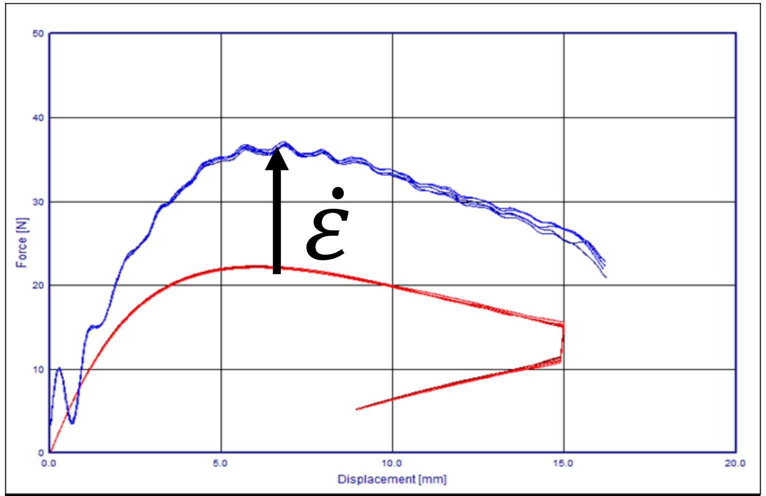


TENSION TEST

IMPETUS® ~ 3 m/s

static ~ 1mm/s

Measurement Results ➔ Material Model



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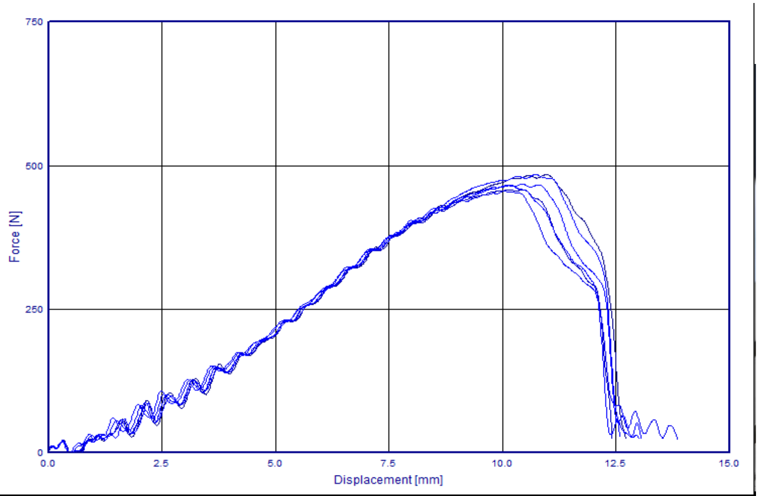

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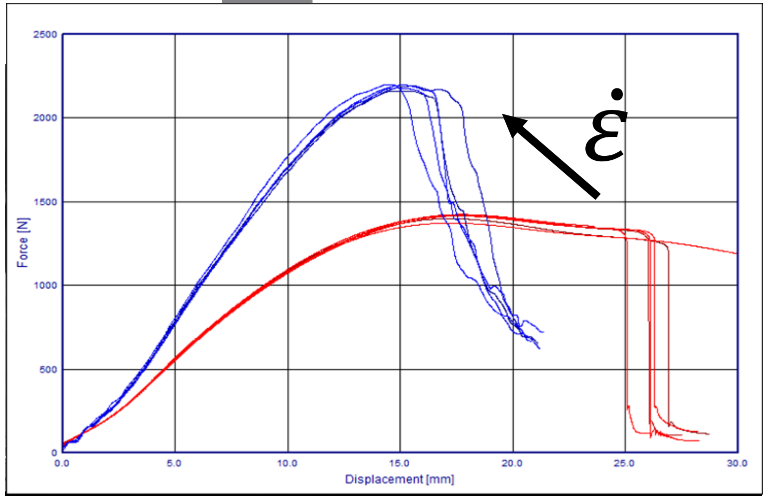

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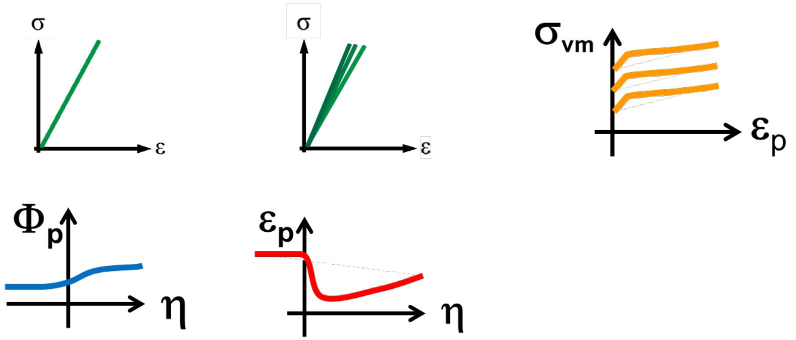
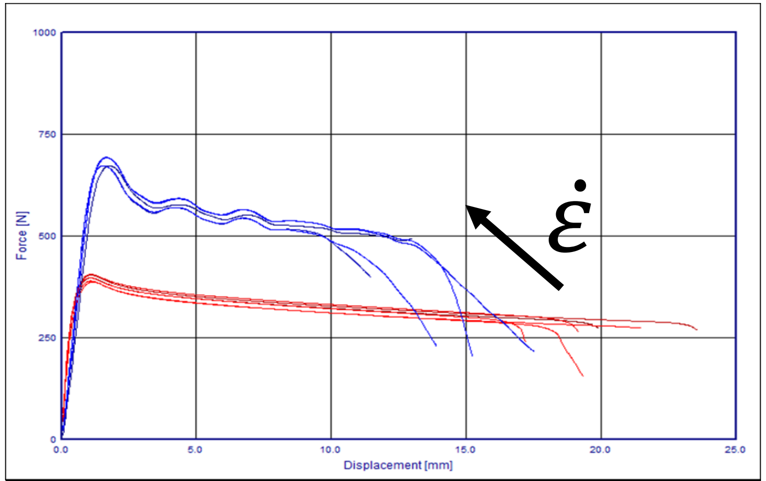
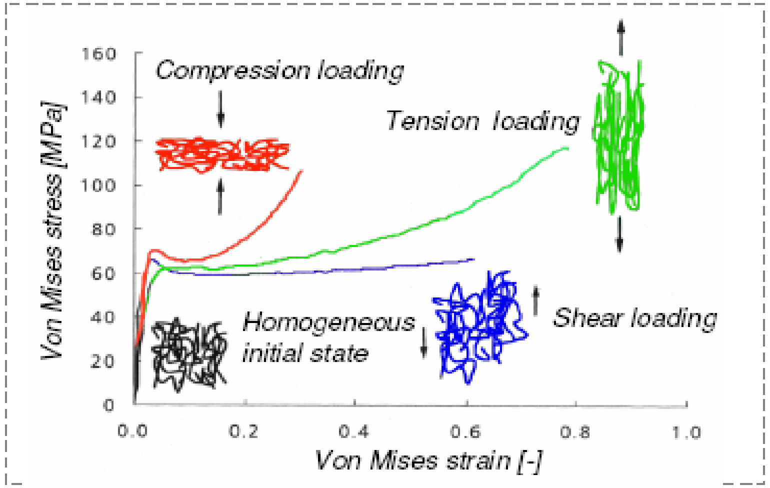




TENSION TEST



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

Material Model Selection

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

Of those the most used material model is **`*MAT_024`**.

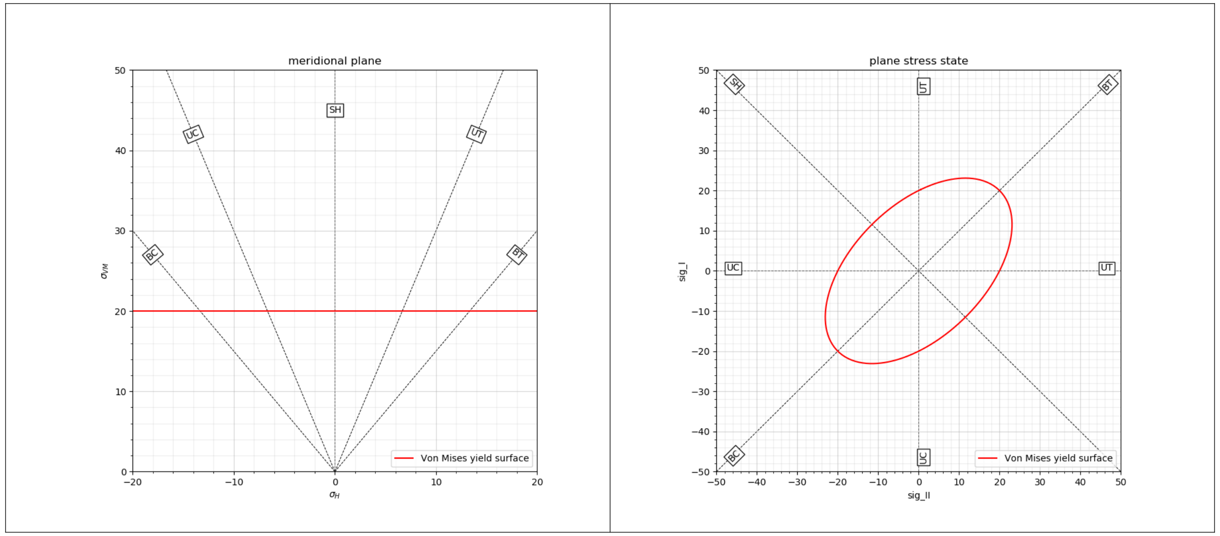
Other interesting material models for thermoplastic polymers are **`*MAT_124`** and **`*MAT_187`**.

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

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

Commonly Used Material Models For Plastics

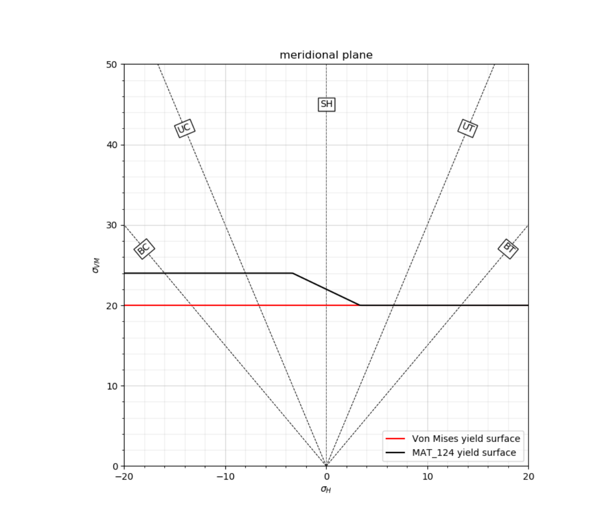
- ***MAT_024* - The workhorse**
  (***MAT_081**, ***MAT_089**, ***MAT_123**, …)

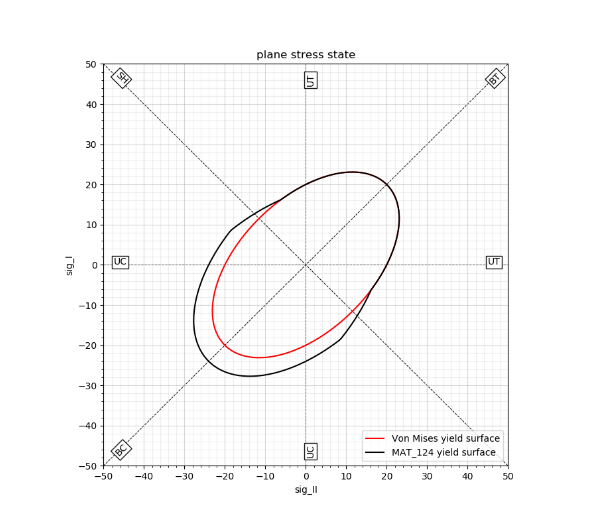


Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
*MAT_024	von Mises	✗	✓	✗	0.5

Commonly Used Material Models For Plastics

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





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

Commonly Used Material Models For Plastics

- ***MAT_024* - The workhorse**
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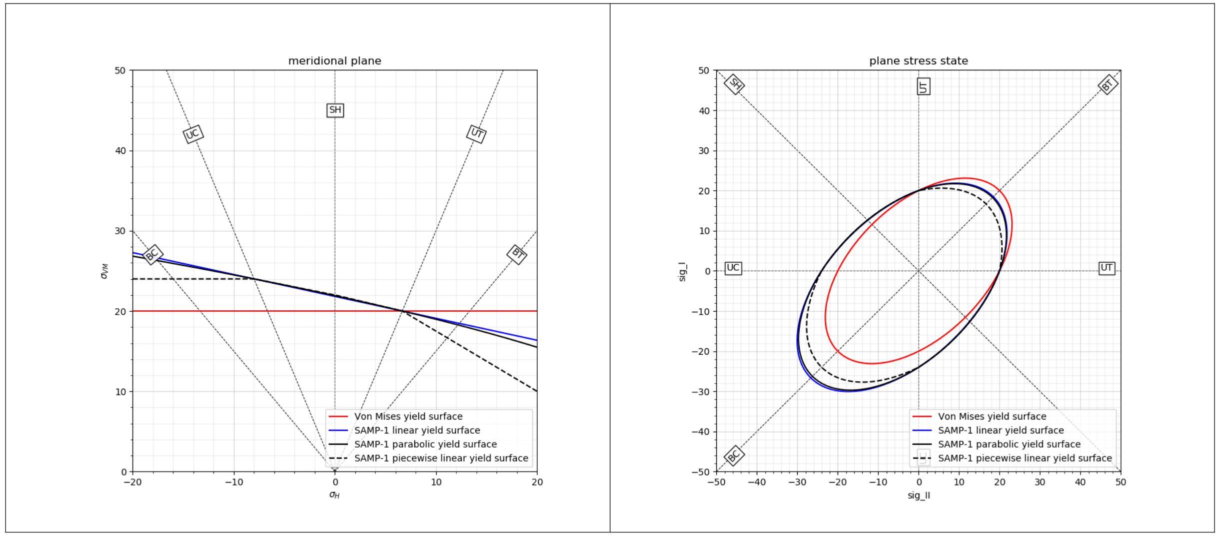
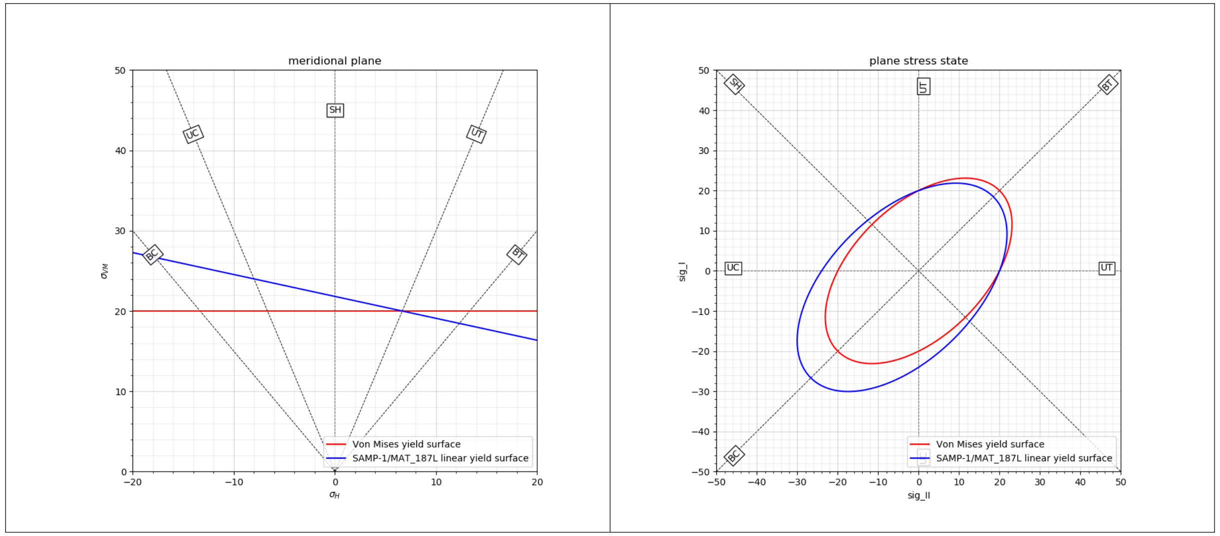
- ***MAT_124* - The hidden**
- ***MAT_187* - The plastic expert**



Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
*MAT_024	von Mises	✗	✓	✗	0.5
*MAT_124	2x von Mises	✓ Pronyseries	✓	✓	0.5
*MAT_187	linear; parabolic; piecewise linear	✓ Table	✓	✓	✓

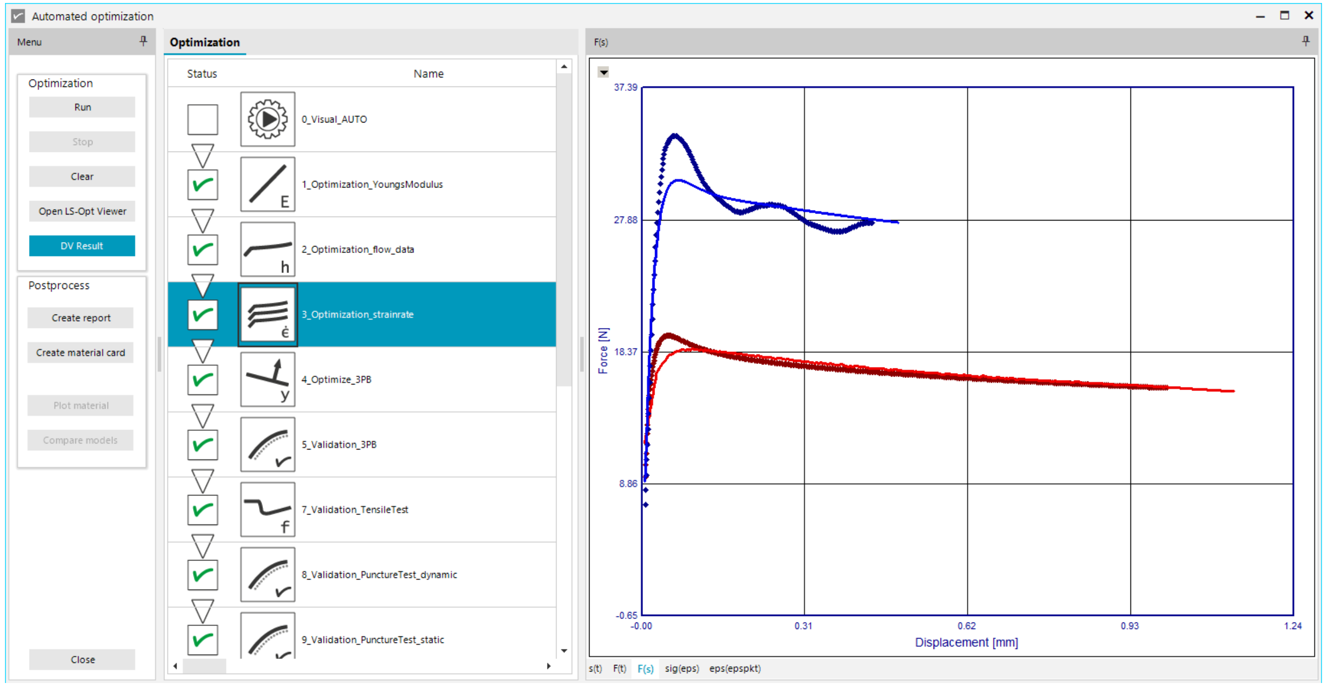
Commonly Used Material Models For Plastics

- ***MAT_024** - The workhorse (*MAT_081,*MAT_089,*MAT_123, …)*
- ***MAT_124 - The hidden***
- ***MAT_187 - The plastic expert***
- ***MAT_187L – efficient version (R11)***

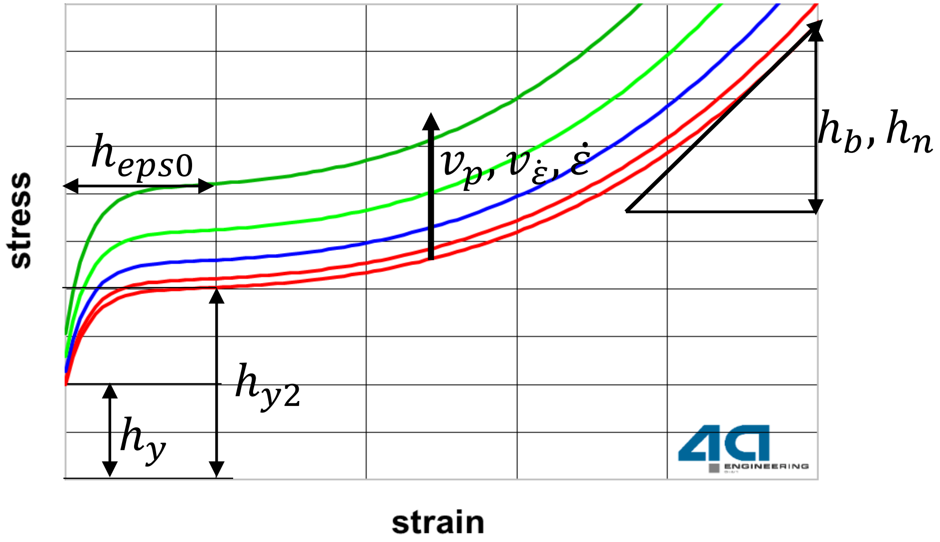


Material model	yield surface	Visco-elasticity	Visco-plasticity	Comp./tension asymmetry	plastic Poisson's ratio
*MAT_024	von Mises	✗	✓	✗	0.5
*MAT_124	2x von Mises	✓ Pronyseries	✓	✓	0.5
*MAT_187	linear; parabolic; piecewise linear	✓ Table	✓	✓	✓
*MAT_187L	linear	✗	✓	✓	✓

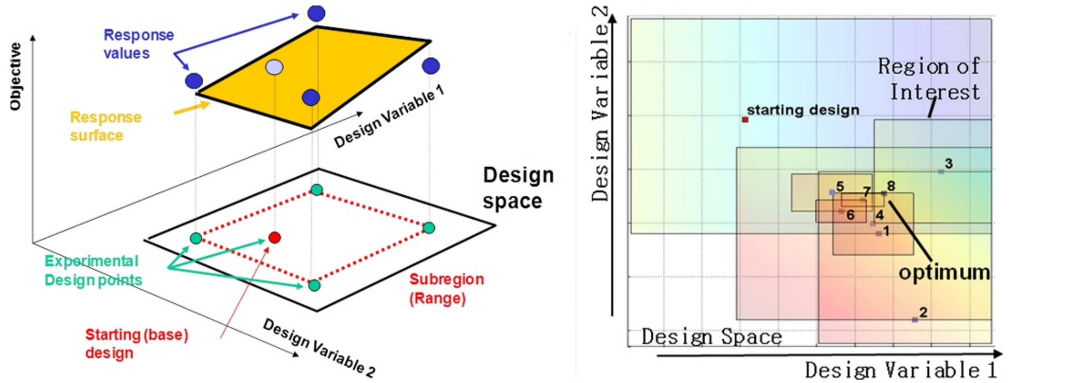
Workflow for Material Card Generation - AUTOFIT



parametrized material card



optimization – successive response surface method

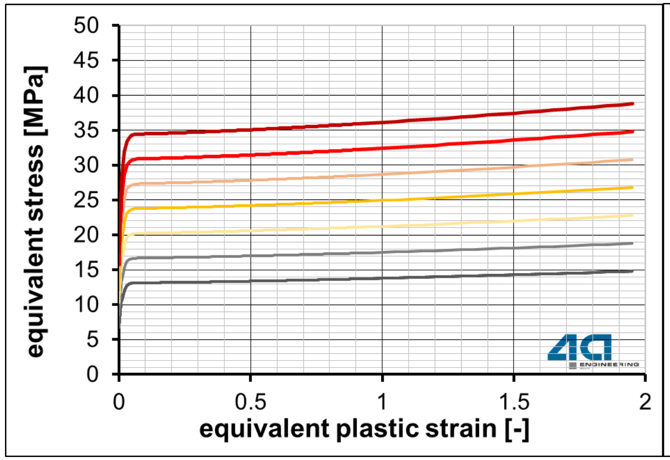


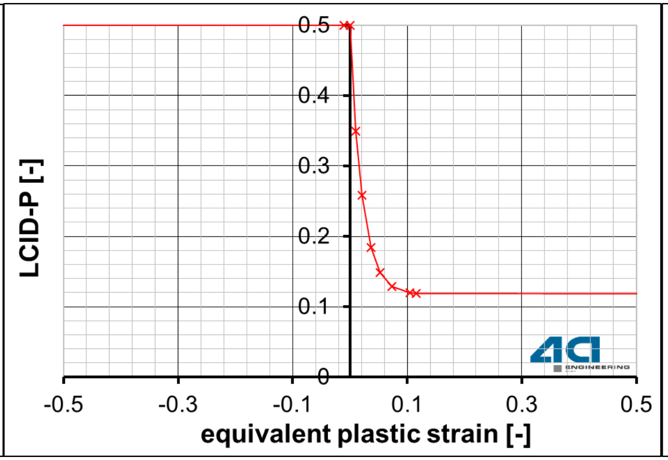
B.Hirschmann; rep_20030301_bhir_TT20

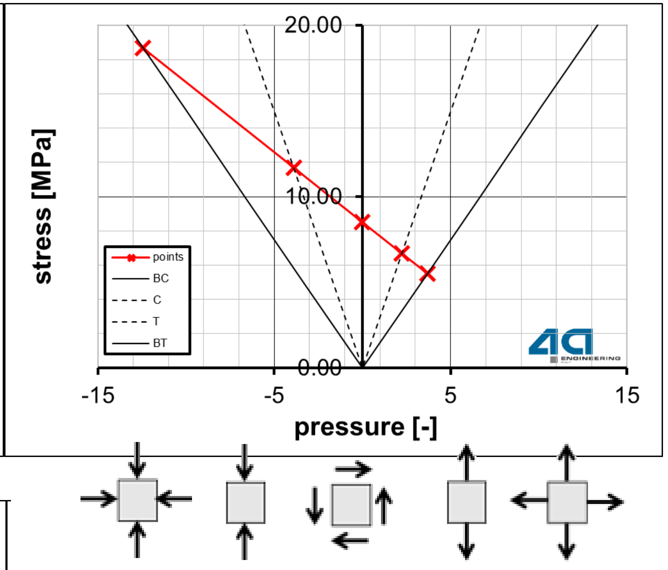
IN PHYSICS WE TRUST

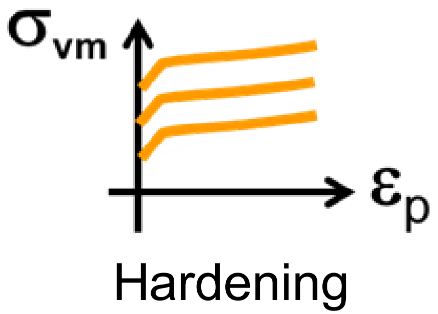
Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT

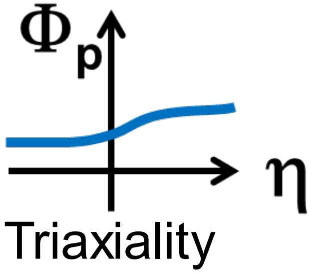
VALIMAT

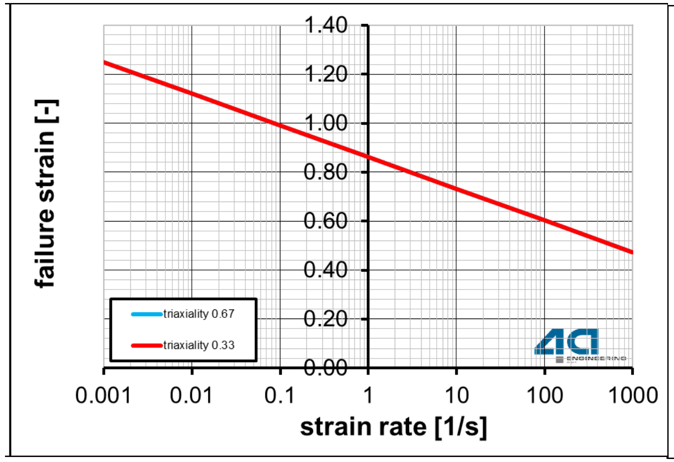


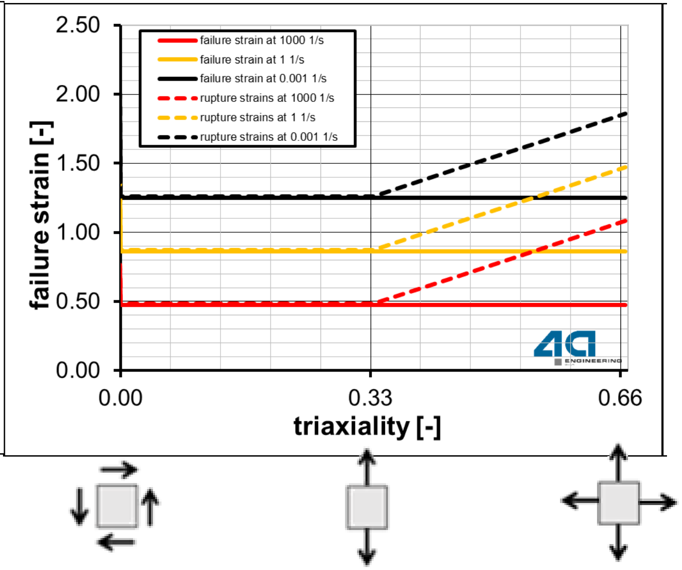


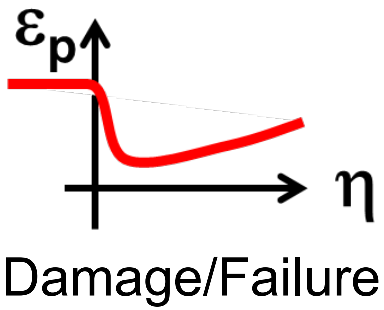






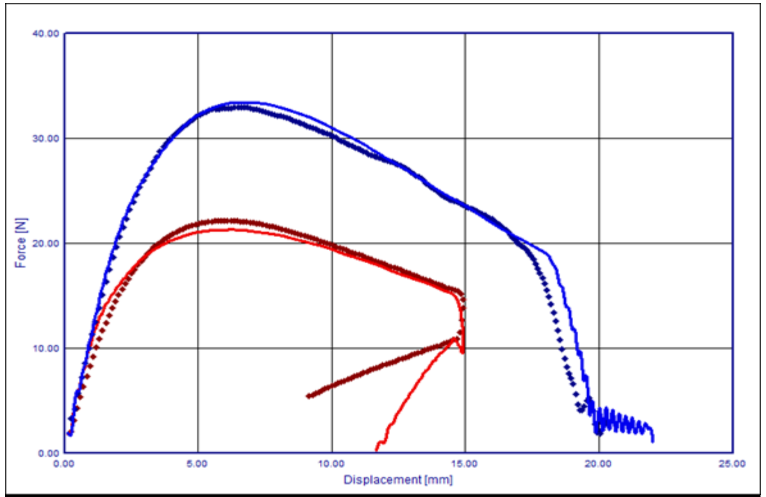




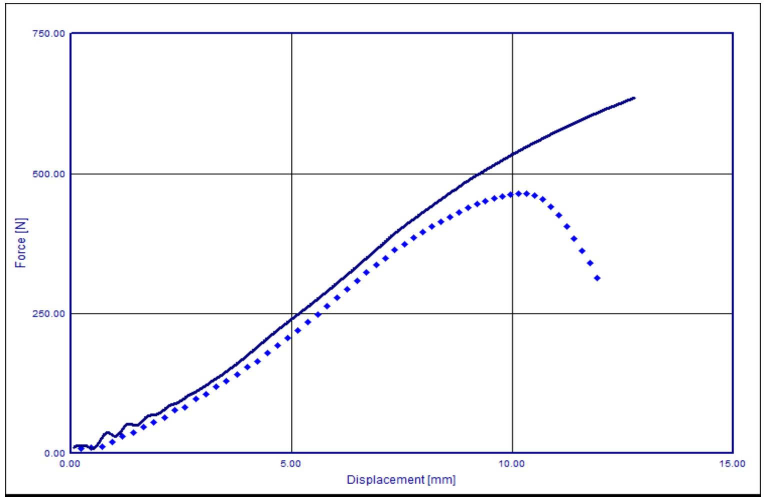


source: Benjamin Hirschmann, master thesis

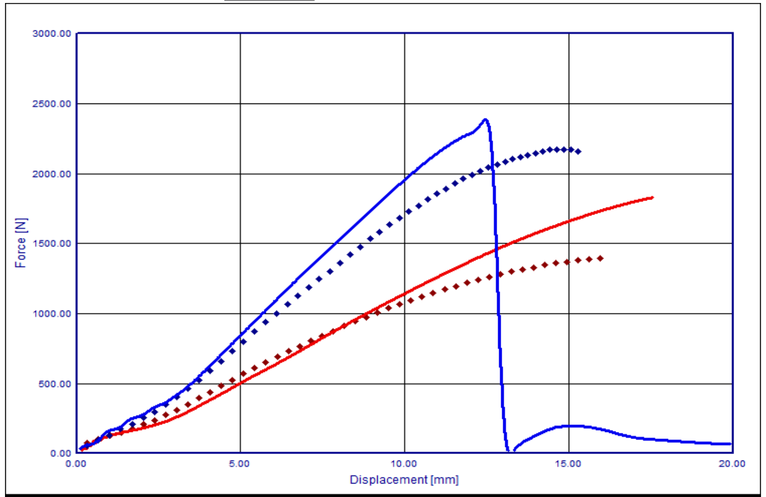
Workflow Result: *MAT_SAMP-1 with internal FM - AUTOFIT



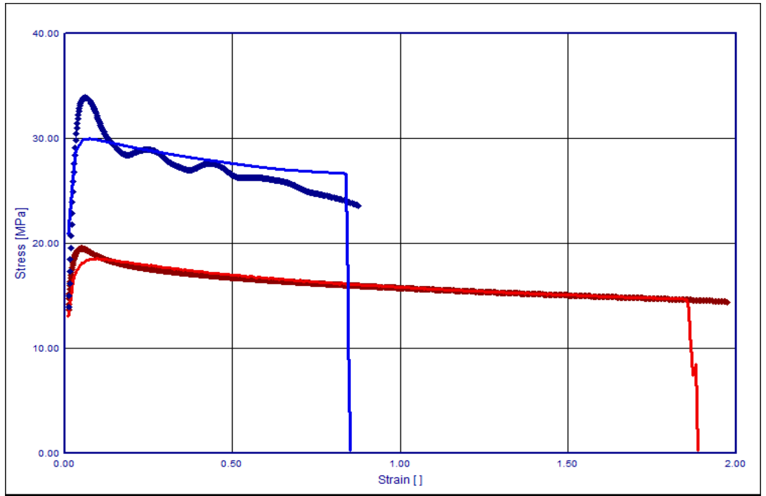
3 POINT BENDING



TENSION BENDING



PUNCTURE TEST



TENSION TEST

IMPETUS® ~ 3 m/s

static ~ 1mm/s

···· averaged test curves

— result of simulation

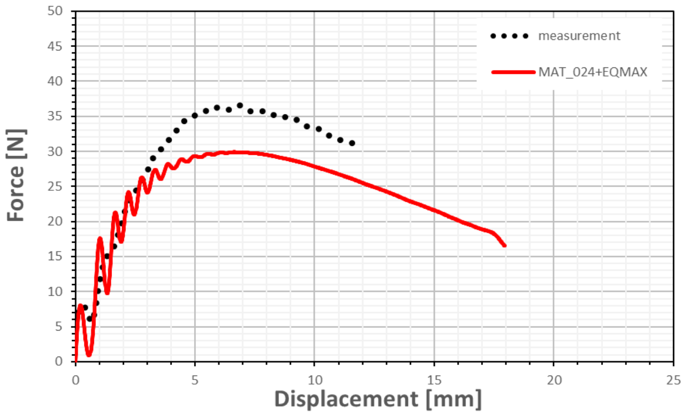
source: Benjamin Hirschmann, master thesis

Material Card Quality

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

Relative Numerical Cost of the Material Model – MAT_024

VALIMAT



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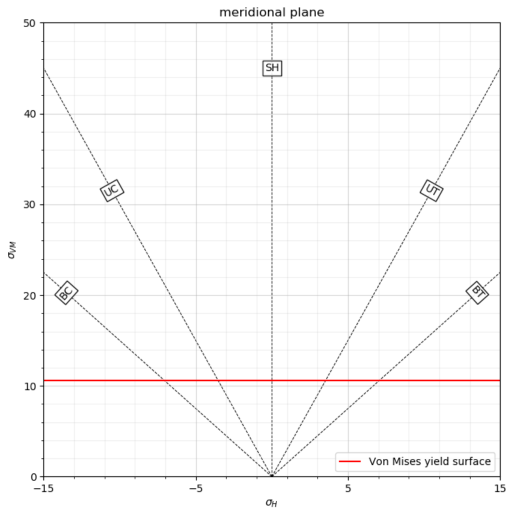
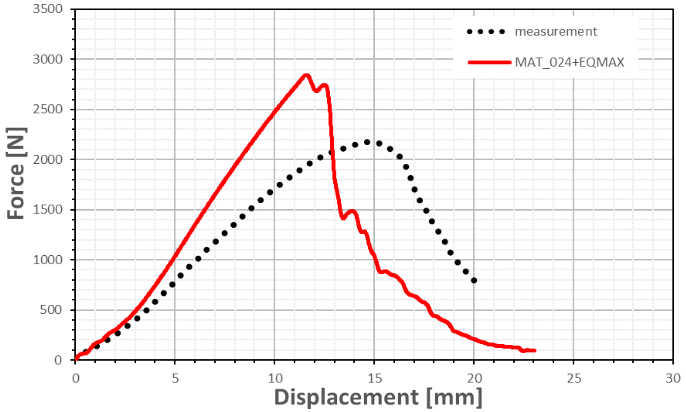
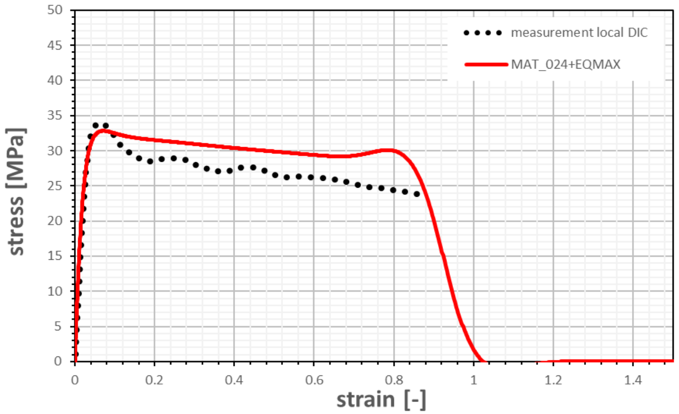




PUNCTURE TEST

IMPETUS™ ~ 3 m/s



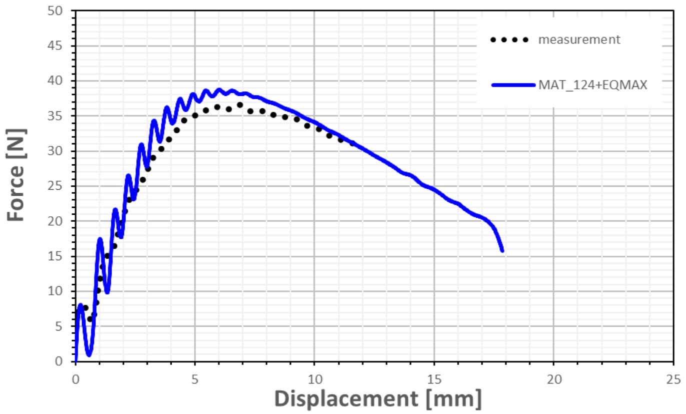
TENSION TEST

···· averaged test curves

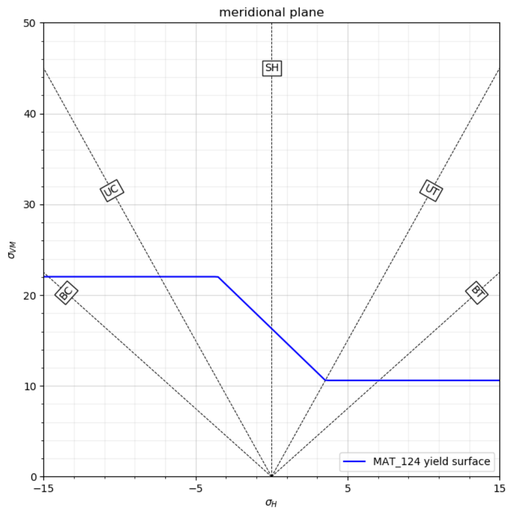
— result of simulation

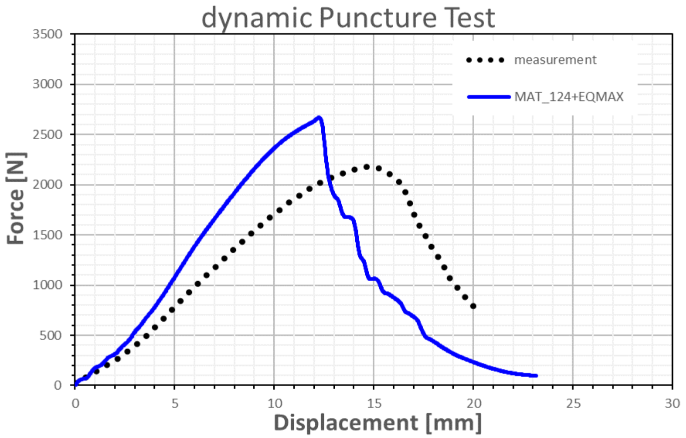
source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_124



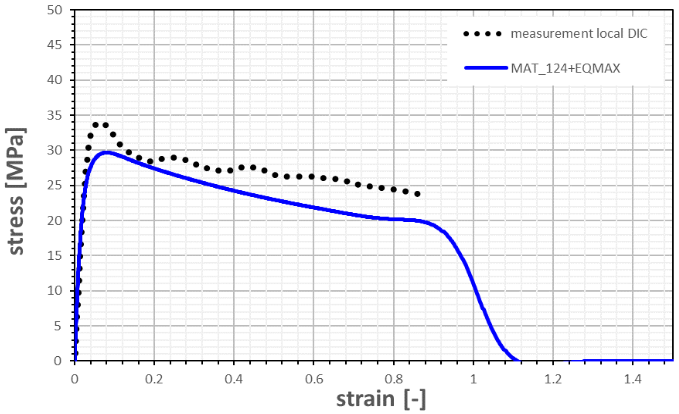
3 POINT BENDING





PUNCTURE TEST

IMPETUS™ ~ 3 m/s



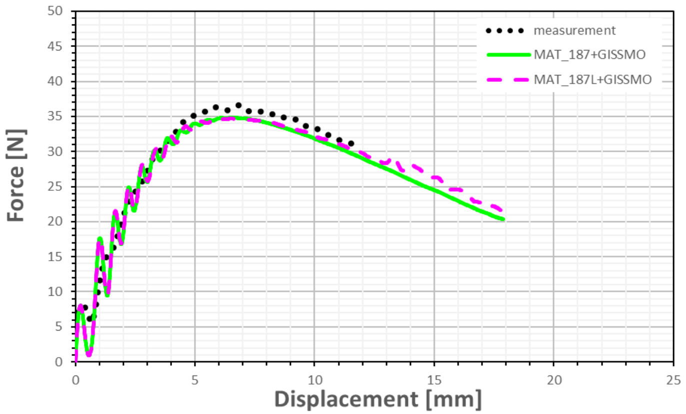
TENSION TEST

···· averaged test curves
— result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model – MAT_187

VALIMAT



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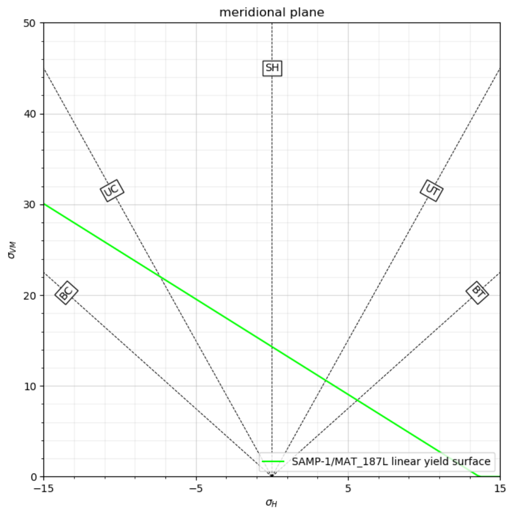
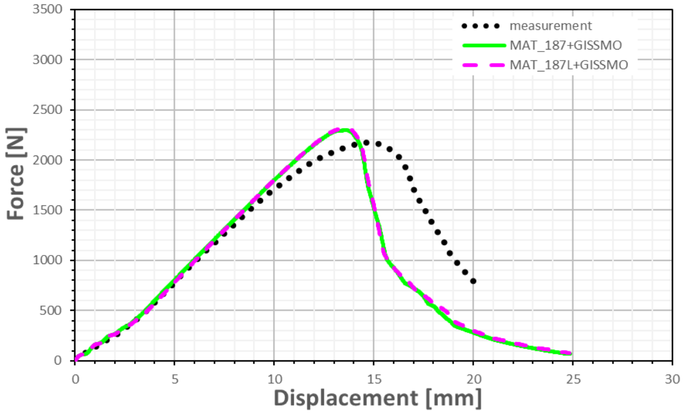
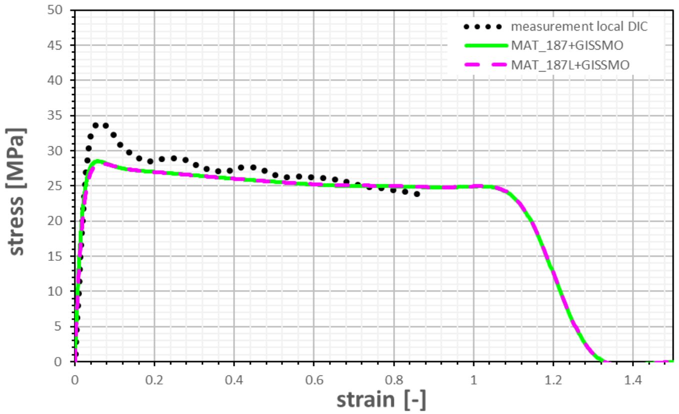




PUNCTURE TEST

IMPETUS™ ~ 3 m/s



TENSION TEST

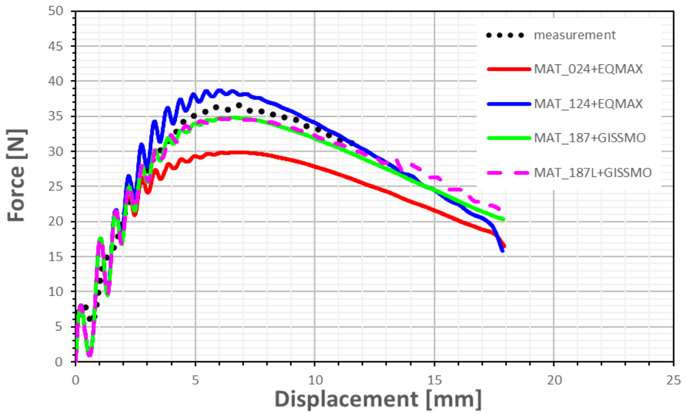
···· averaged test curves

— result of simulation

source: Benjamin Hirschmann, master thesis

Relative Numerical Cost of the Material Model

VALIMAT



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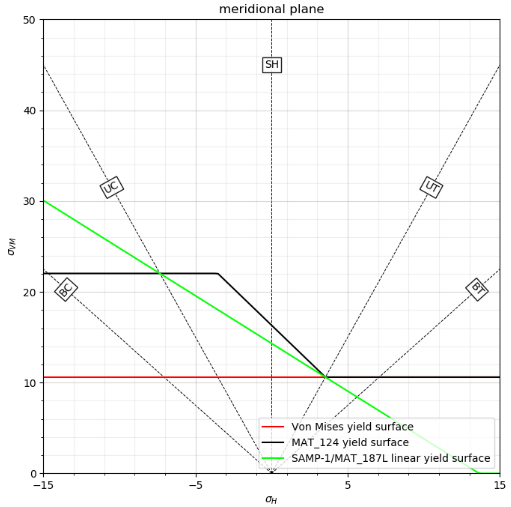

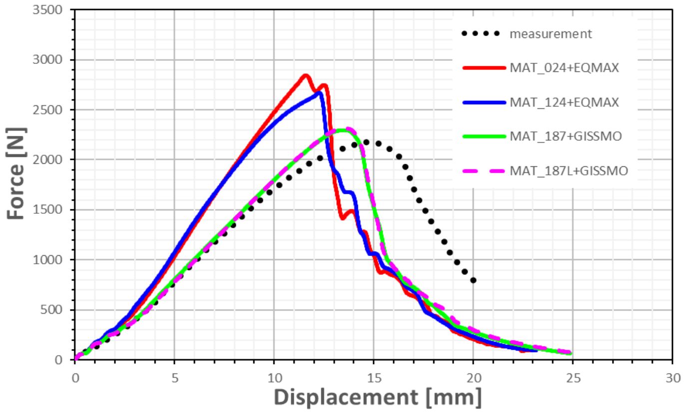

PUNCTURE TEST

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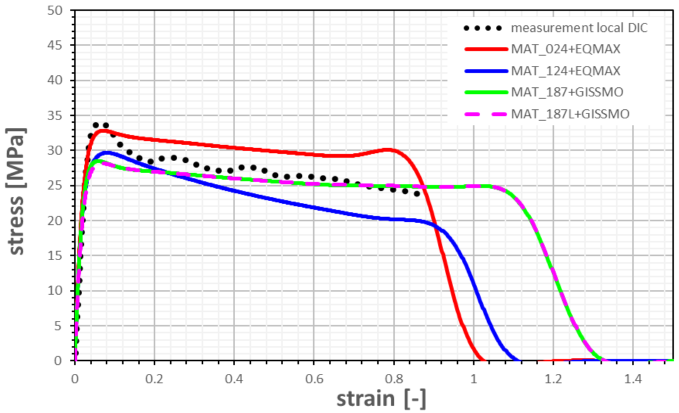

TENSION TEST

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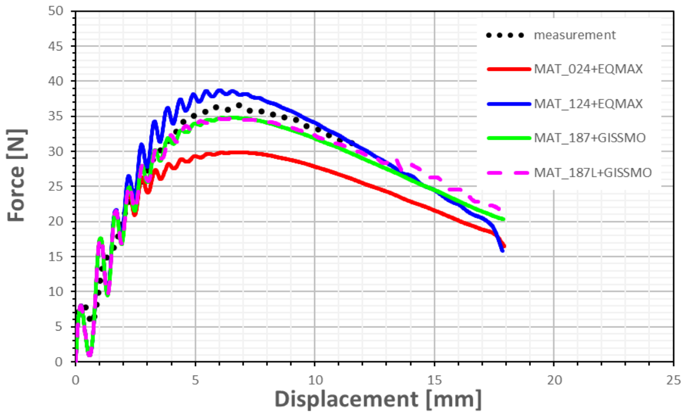
Relative Numerical Cost of the Material Model

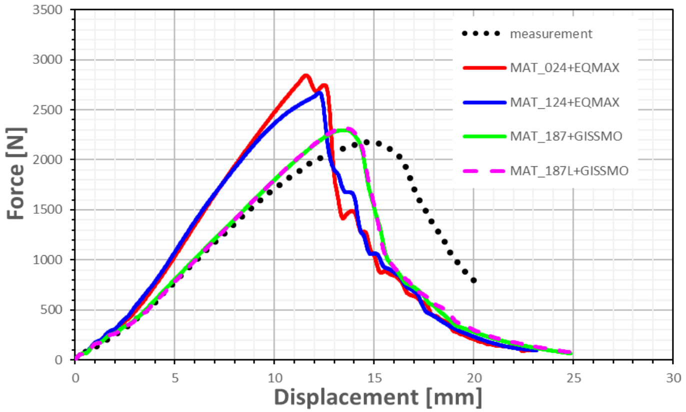
VALIMAT



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



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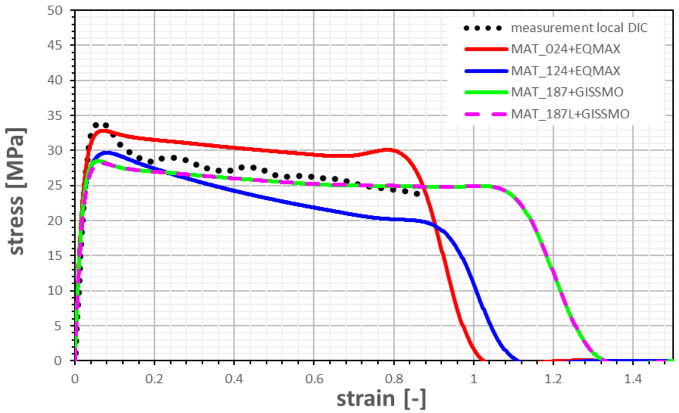

TENSION TEST

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Summary

- Use case for the material card was outlined
- Dynamic and static measurements for PPEG107HP
- Discussed material models to describe observed behavior

- We discussed quality criteria for the material card
- We investigated the relative numerical cost of the material model for **`*MAT_SAMP-1`** base card and **`*MAT_024`**, **`*MAT_124`** and **`*MAT_187L`** derivate cards.
- These showed that with **`*MAT_187L`** for a **relative numerical cost factor** of roughly **1.2** the **qualitative accuracy** of the simulation results could be **improved**.

Outlook

- Stepwise introduce a parameters and features of MAT_SAMP-1 (general yield surface,)
- Stability tests check load chases, element types, bending loop
- Accuracy: Localization depiction Tensile Test

Thank you for your Attention!