Thermo-mechanical characterization and modelling of battery cell components with IMPETUS® and VALIMAT®

13th European LS Dyna conference *6th October 2021*

M. Schwab, H. Pothukuchi, B. Hirschmann, M. Rollant excellence in …

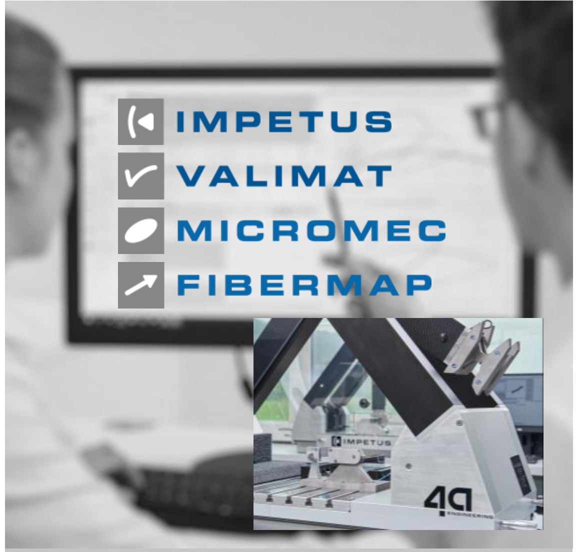
plastics simulation

testing equipment

lightweight products

4a-engineering - Business Units

Testing hard- and software



Seamless testing and simulation solution for automated material characterization

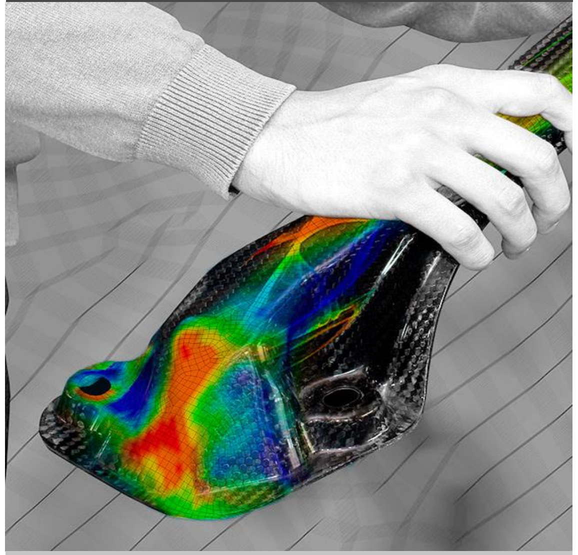
Material characterization

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

Validated material cards

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

Product development



From draft to craft – Engineering, simulation and prototyping

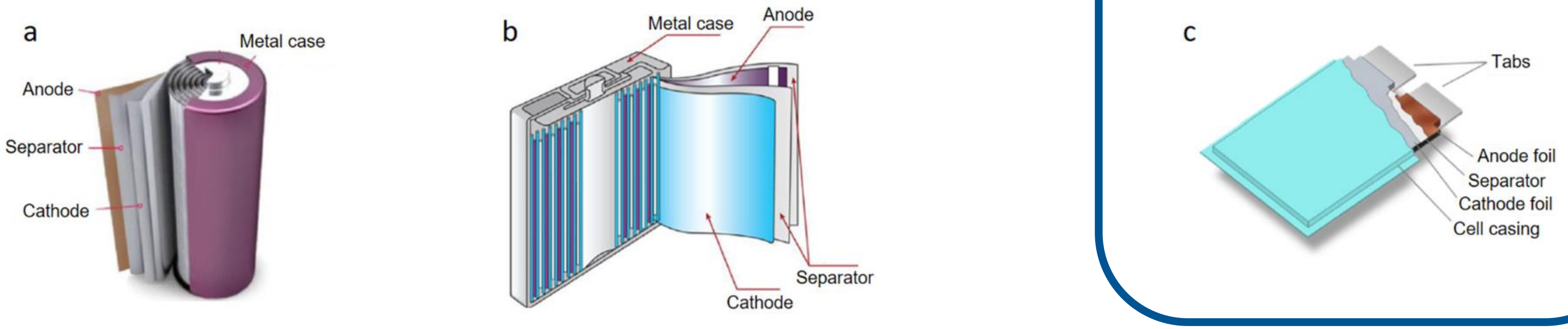
Agenda

- Motivation
- Mechanical behaviour of pouch foils
- Modelling and validation in LS Dyna
- Application Example
- Summary

Motivation

- different types of automotive Li-Ion battery cells:

casing type	hard case				soft case
cell format	cylindrical		prismatic		pouch
casing material	steel	aluminum	steel	aluminum	aluminum laminated film



Zubi, G.; Adhikari, R.S.; Sánchez, N.E.; Acuña-Bravo, W. Lithium-ion battery-packs for solar home systems: Layout, cost and implementation perspectives. J. Energy Storage 2020, 32, 101985

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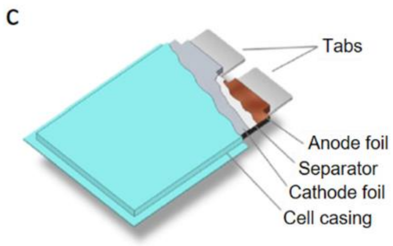
casing material	aluminum laminated film



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- Cell consists of many layers of thin foils (current collector, separators) and granular active material

- all internal components are flooded by liquid electrolyte, which ensures ion transport capability

- Cell casing: pouch foil (aluminum laminated film)
  - environmental protection (moisture, handling, …)
  - tightness
  - keep internal components in place
  - prone to mechanical loads

Motivation

Typical loads acting on pouch foil:

- external loads (e.g. shock, vibration, crash) introduced through:
  - cell fixation (e.g. bottom or circumferential)
  - terminal area
  - penetration

- internal loads:
  - gas generation
  - swelling
  - thermal runaway

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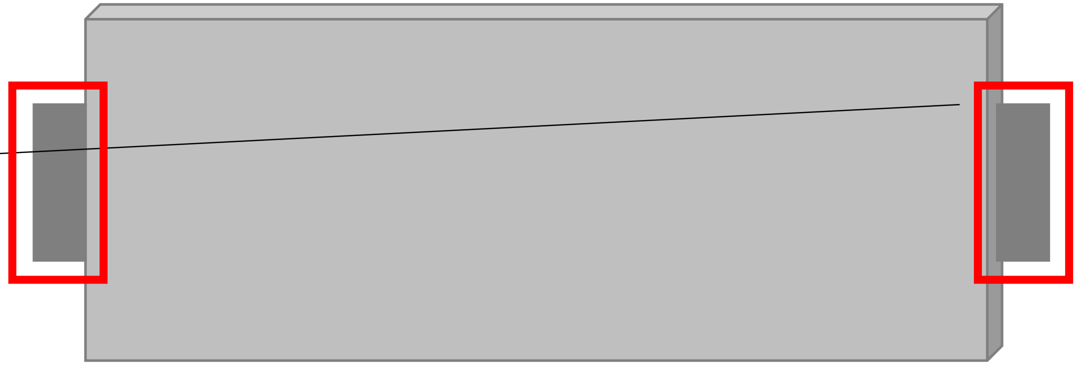

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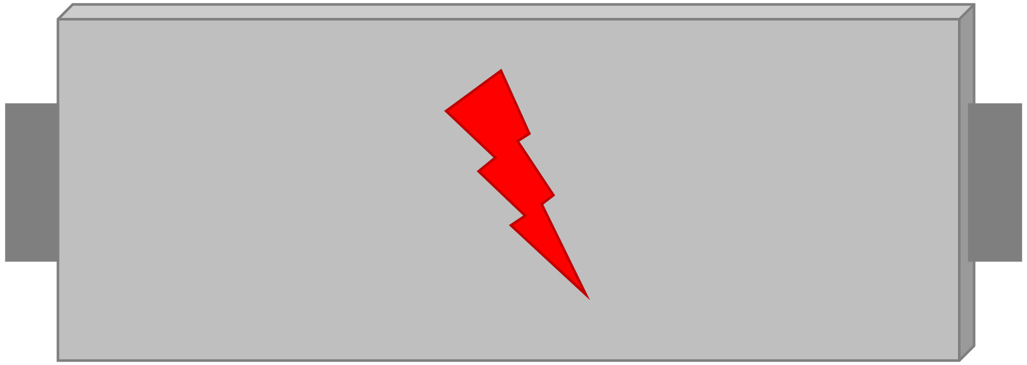

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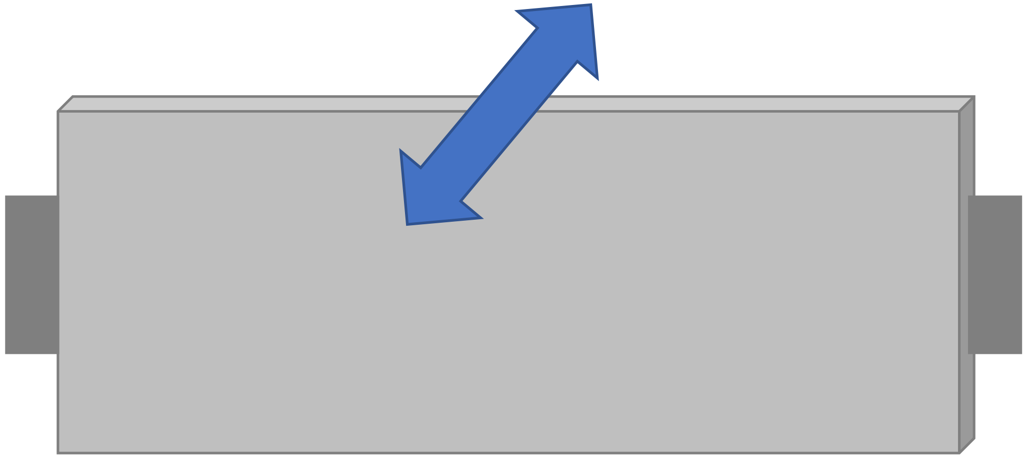

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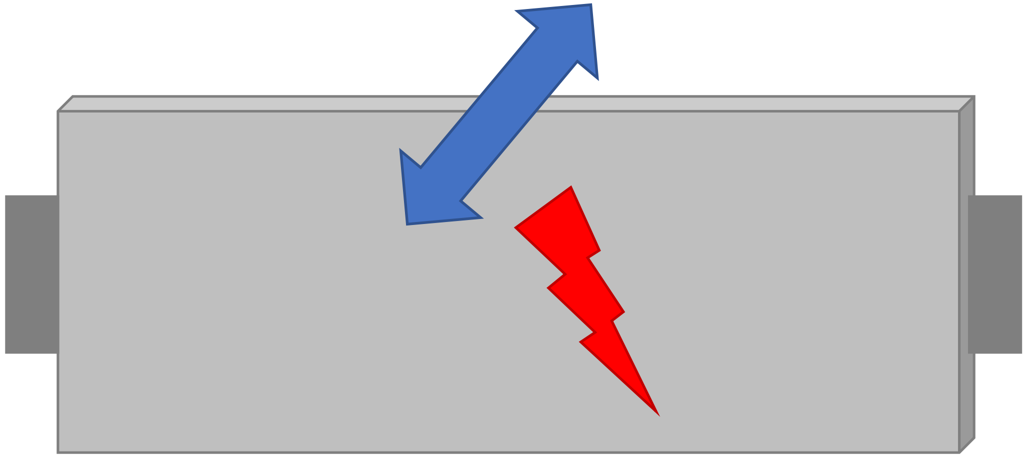


Motivation

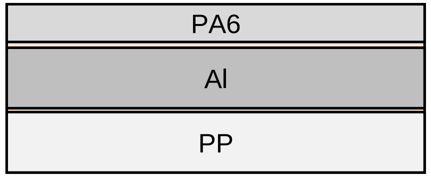
→ rupture of pouch foil leads to elektrolyte leakage → loss of electrical function
→ various external loads are transmitted through the pouch foil
→ internal loads are directly acting on pouch foil

→ FEM model of cell should represent casing and jelly separately
→ need of accurate material models of pouch foils

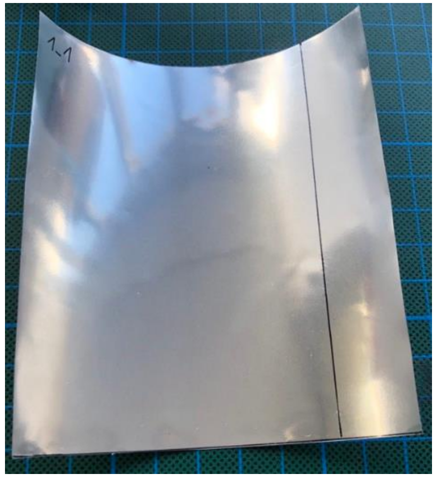
Mechanical characterization

Pouch foil constitution

- Composite of thin foils glued together

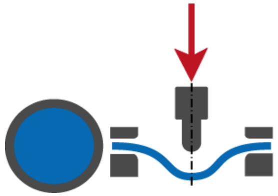


Layer material	thickness		Area weight
	M	SD	g/m²
Polyamide (JIS Z1714)	0.025	0.0025	-
Adhesive (Polyester-polyurethane	-	-	4-5
Aluminium foil (JIS A8021)	0.04	0.004	-
Adhesive (Urethane-free Adhesive)	-	-	2-3
Polypropylene	0.04	0.004	-
Total	0.111	0.011	



Mechanical characterization

Material Testing Setups

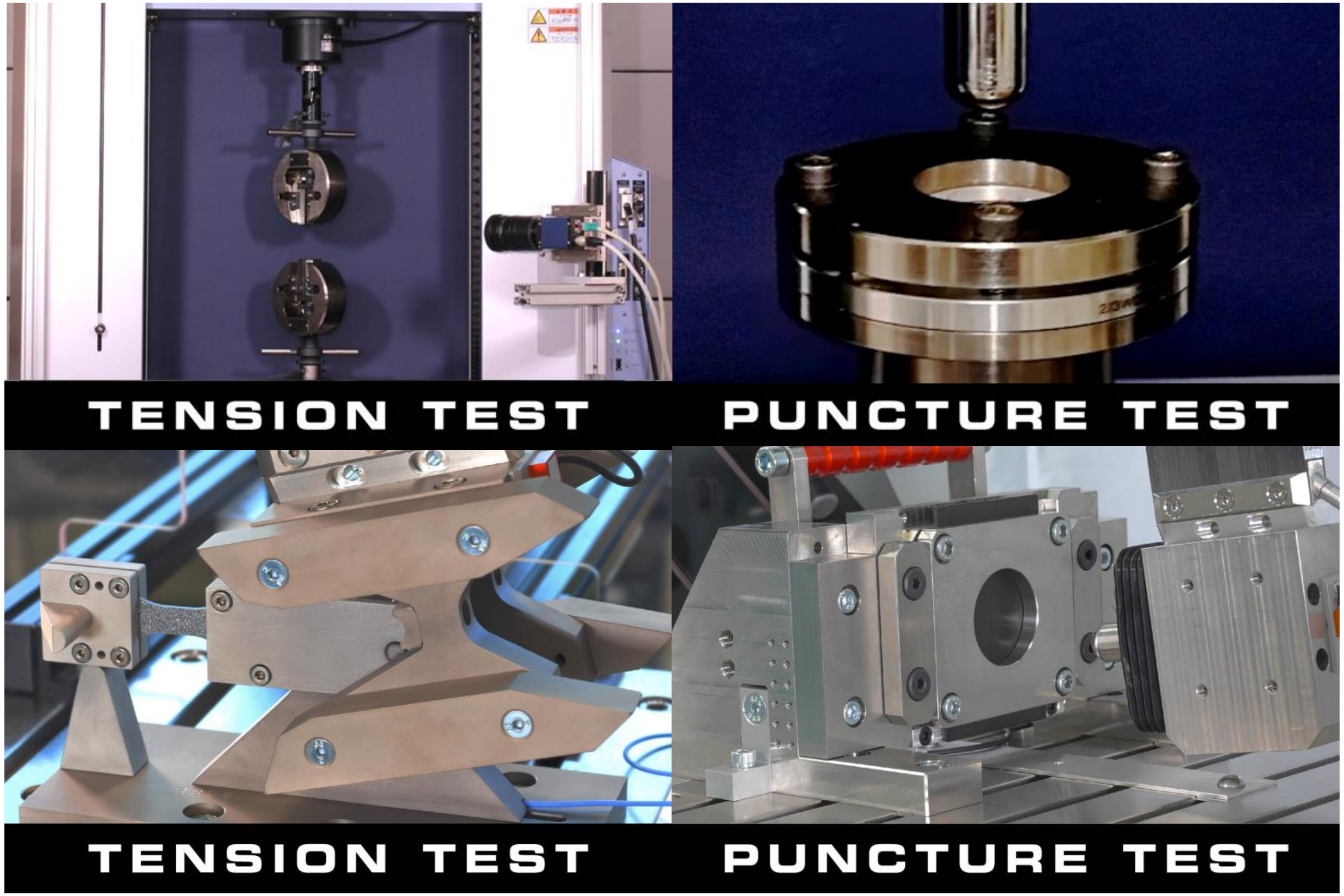


SHIMADZU AG-X

Quasistatic Test

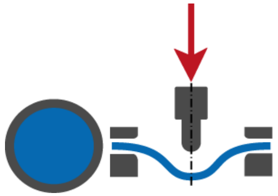
IMPETUS

Dynamic Tests



Mechanical characterization

Material Measurement Results at 23°C



SHIMADZU AG-X

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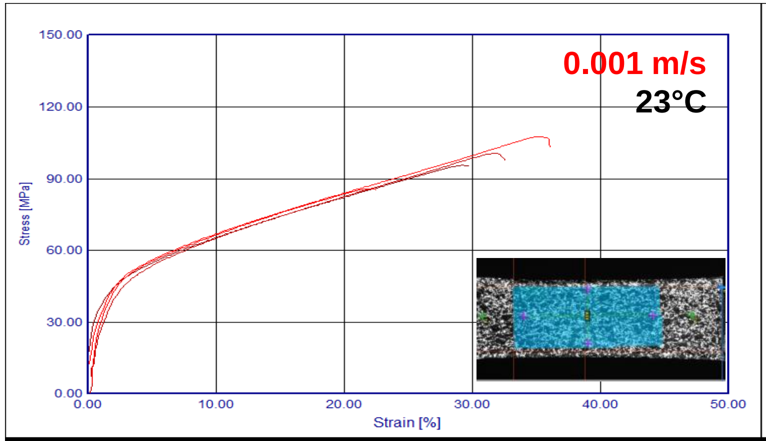
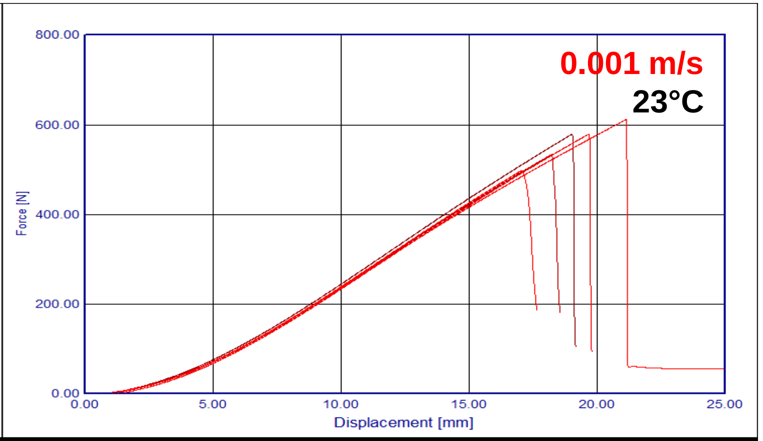


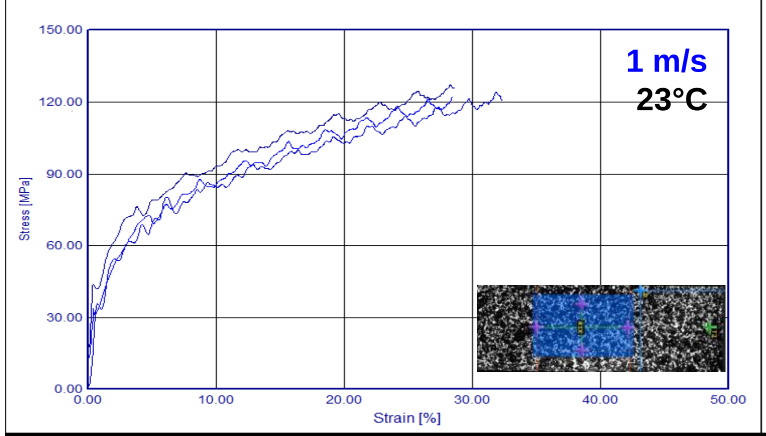
TENSION TEST



PUNCTURE TEST

IMPETUS

Dynamic Tests



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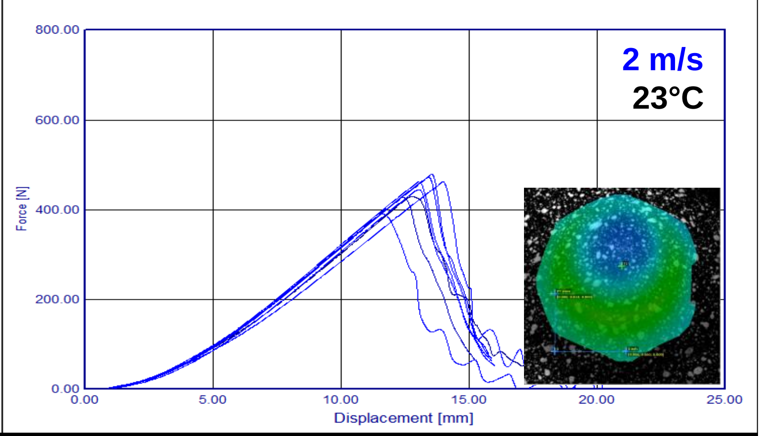
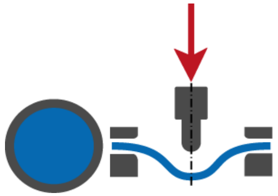


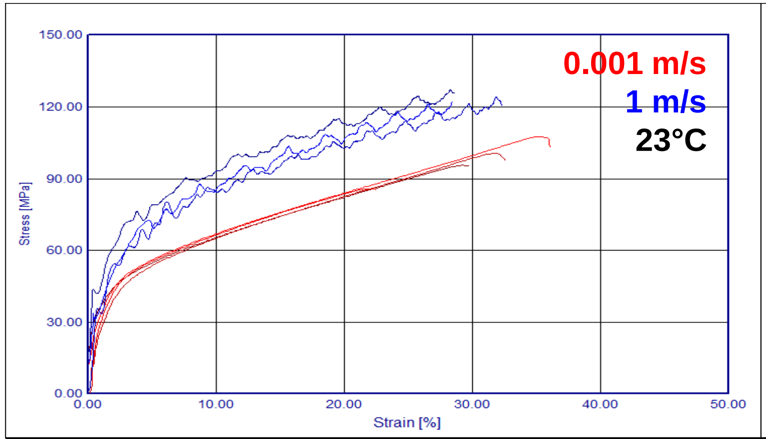
PUNCTURE TEST

Mechanical characterization

Material Testing Setups

- higher velocity v ↑:
  - Force→ σ_y ↑
  - failure strains ε_f ↓
- Higher Temperature T ↑:
  - Force → σ_y ↓
  - failure strains ε_f ↓





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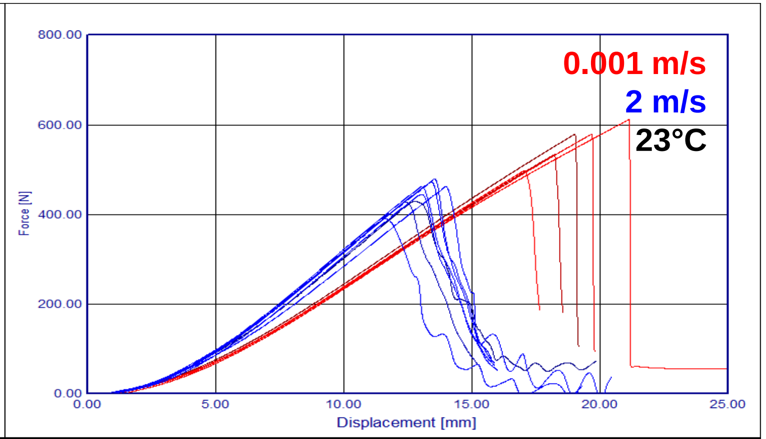
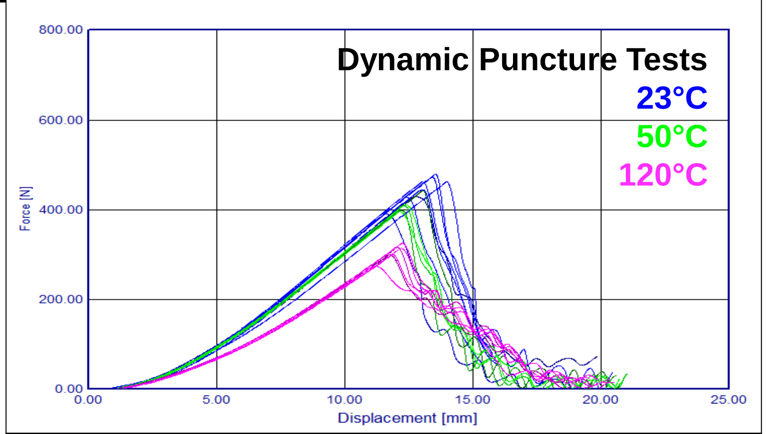


PUNCTURE TEST



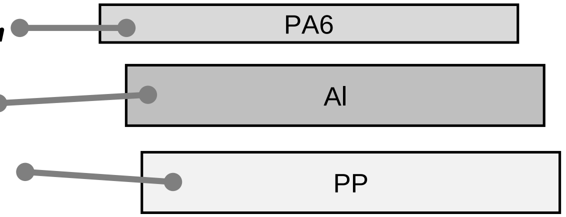
PUNCTURE TEST

— measurement curves

Mechanical characterization

Modelling approach

Initial Idea: **`*PART_COMPOSITE`**:

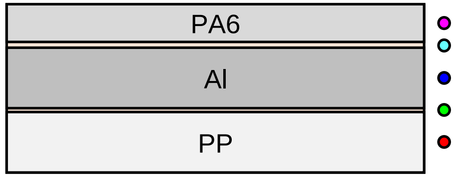


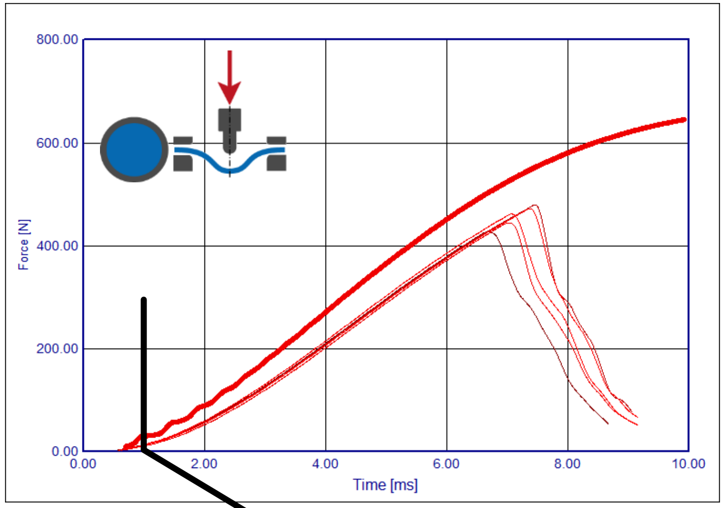
- E.g. ***`*MAT_187L`***
- E.g. ***`*MAT_024`***
- E.g. ***`*MAT_187L`***

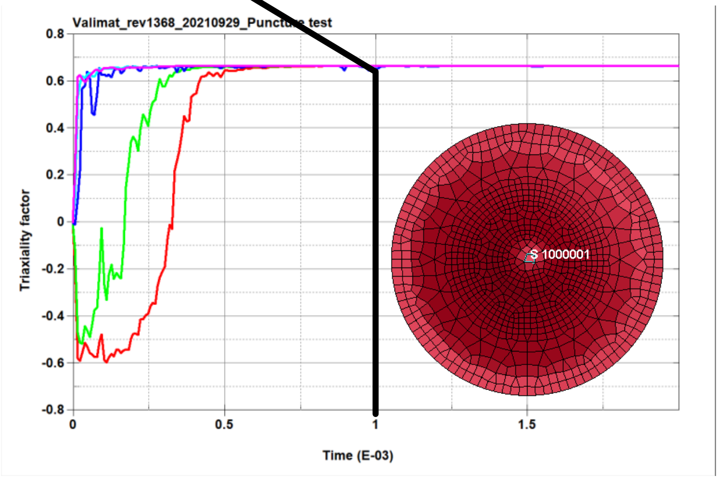
- Can we use a simplification? ✓
  - Basic ***`*MAT_024`*** for each layer ➔ **`*PART_COMPOSITE`**
  - SHELL ELFORM=16, 5IP
  - stress state homogeneous right after beginning
  - foil thickness small

➔Membrane Elements

➔Homogenized Material







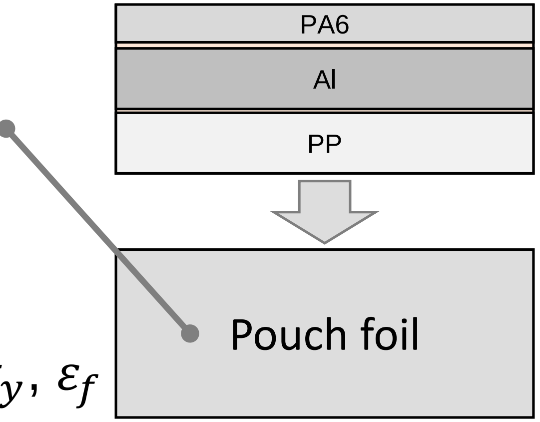
— measurement curves — simulation curves

Mechanical characterization

Modelling approach

Homogenized Approach:

- One material model ****MAT_?*** which can depict tests



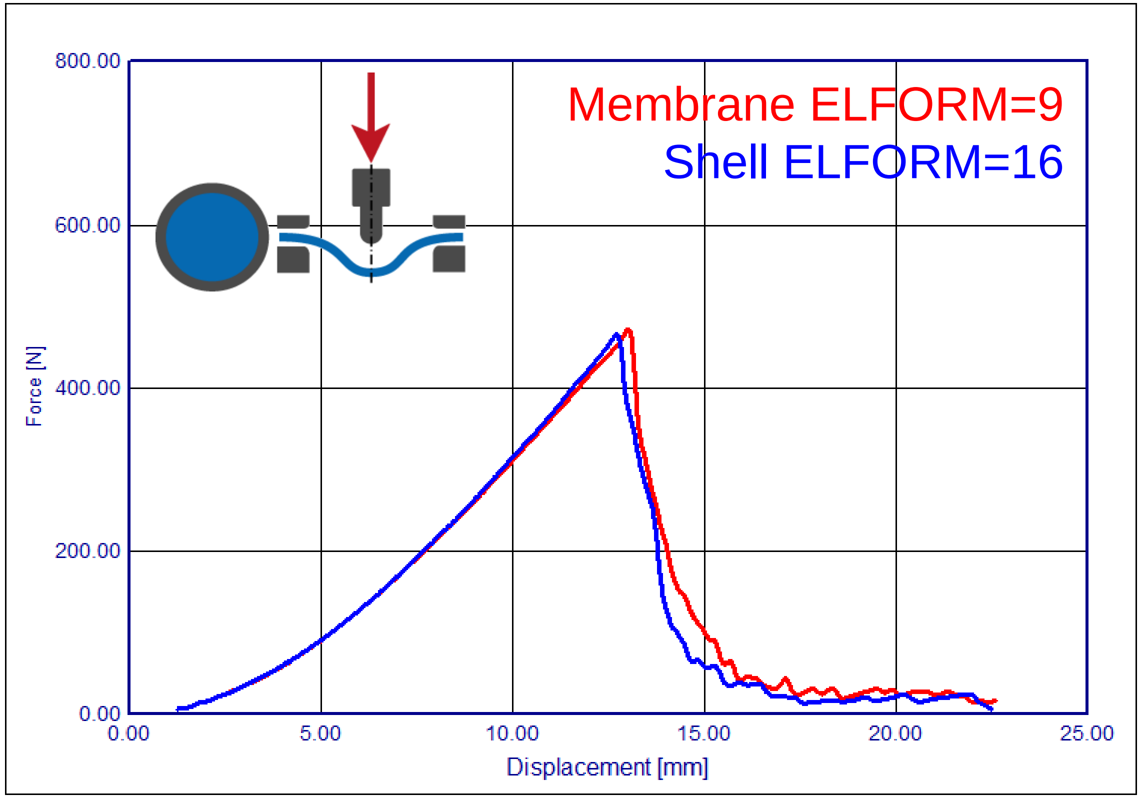
Material Tests showed:

- Temperature dependency: σ_y, ε_f
- strain rate dependency: σ_y, ε_f

➔ ****MAT_106***

➔ ****MAT_ADD_DAMAGE_GISSMO***
(**LCSDG**➔TABLE_3D; temp, strain rate, triax.)

(can't describe load type dependency of the polymers)



— simulation curves

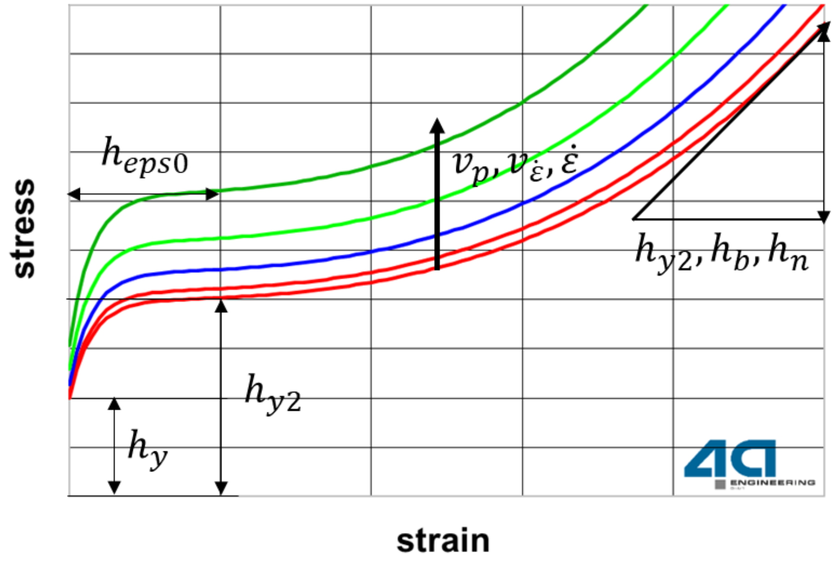
Mechanical characterization

Fitting approach

- Elasticity (mixture formula) (**R**everse **E**ngineering **RE**)
- Hardening at 23°C (**RE**)
- Viscoplasticity at 23°C (**RE**)
- 3D-DIC ➔ Friction Coefficient Settings
- Failure at 23°C (**RE**)
- Hardening Scaling Factor 50°C and 120°C (**RE**)
- Failure Scaling Factor 50°C and 120°C (**RE**)

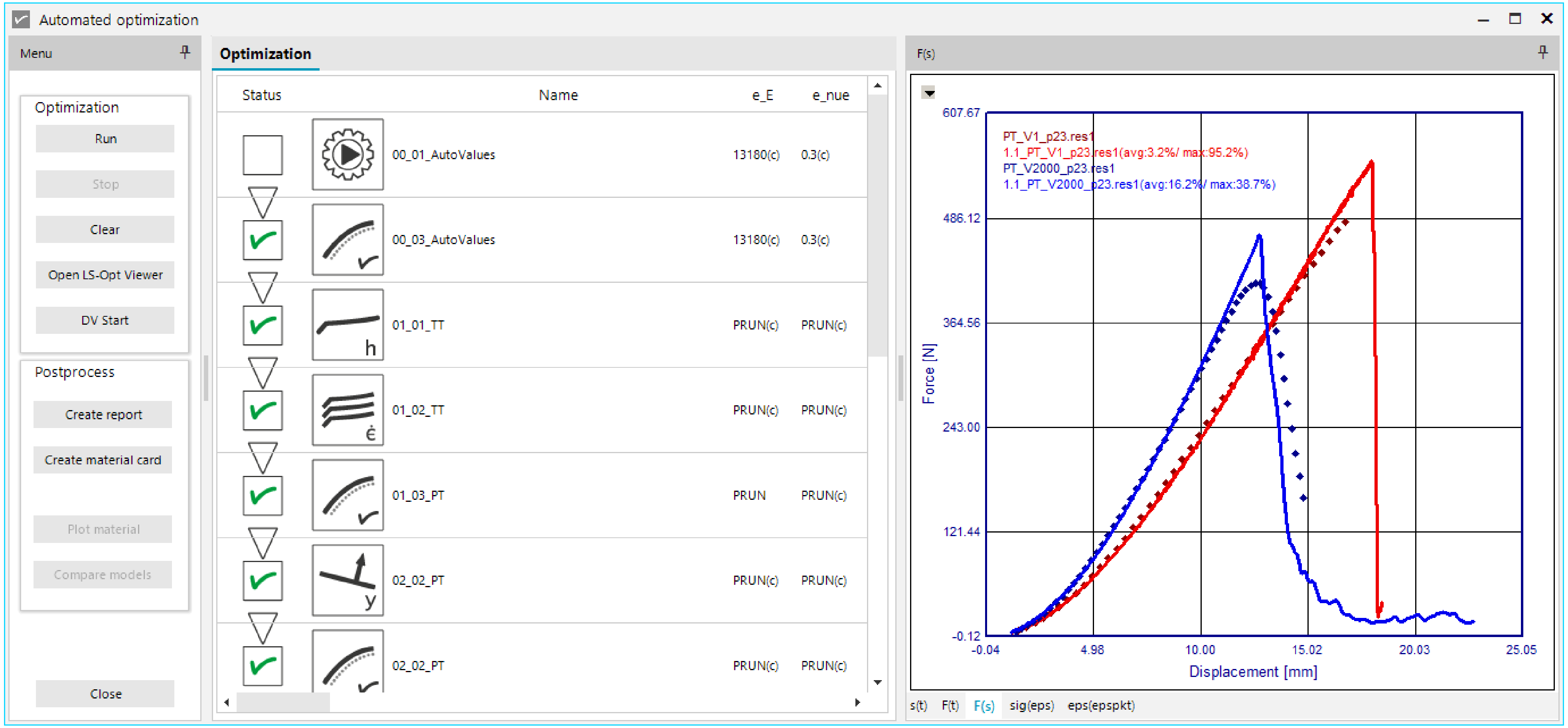
$$\sigma_{y,0} = \left(1 - h_b \cdot \varepsilon_{pl}{}^{h_n}\right) \cdot \left(h_{y2} - \left(h_{y2} - h_y\right) \cdot e^{-\frac{\varepsilon_{pl}}{h_{eps0}}}\right)$$

$$\sigma_y = \sigma_{y,0} \cdot \left(1 + \frac{1}{v_p} \cdot log\left(\frac{max\left(\dot{\varepsilon}_{pl}\,, v_{\dot{\varepsilon}}\right)}{v_{\dot{\varepsilon}}}\right)\right)$$



Mechanical characterization

Fitting approach – VALIMAT (AutoFit)

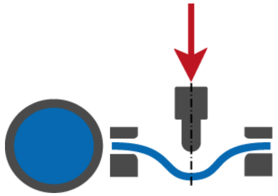


Status	Name	e_E	e_nue
☐	00_01_AutoValues	13180(c)	0.3(c)
☑	00_03_AutoValues	13180(c)	0.3(c)
☑	01_01_TT	PRUN(c)	PRUN(c)
☑	01_02_TT	PRUN(c)	PRUN(c)
☑	01_03_PT	PRUN	PRUN(c)
☑	02_02_PT	PRUN(c)	PRUN(c)
☑	02_02_PT	PRUN(c)	PRUN(c)

PT_V1_p23.res1
1.1_PT_V1_p23.res1(avg:3.2%/ max:95.2%)
PT_V2000_p23.res1
1.1_PT_V2000_p23.res1(avg:16.2%/ max:38.7%)

Mechanical characterization

Local Evaluation PT – 3D DIC

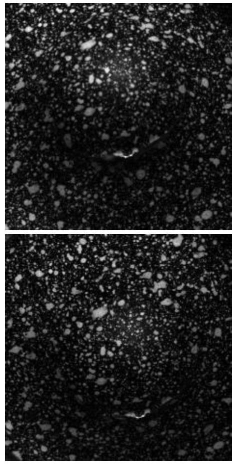


measurement

Photron

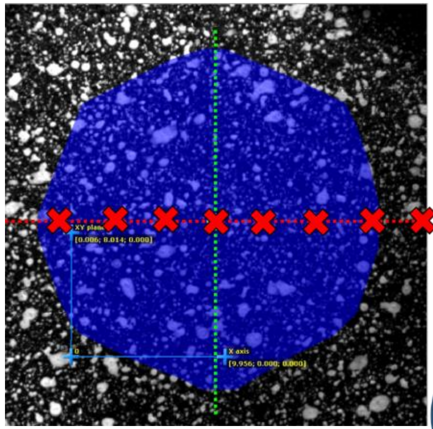
cam0

cam1

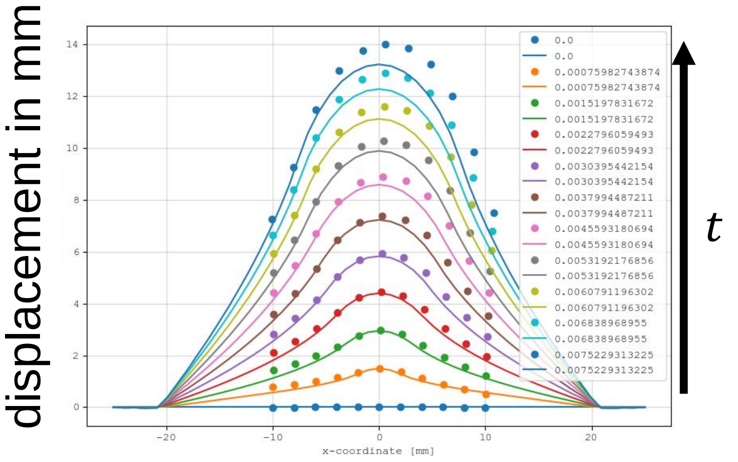


&

MERCURY RT

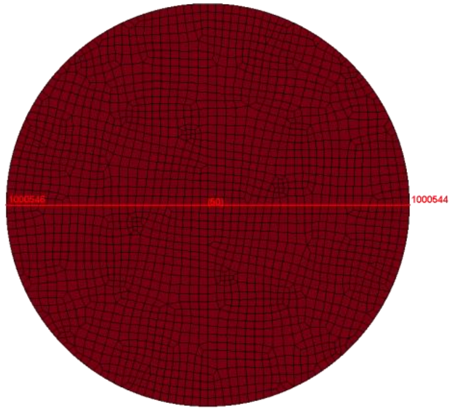


points

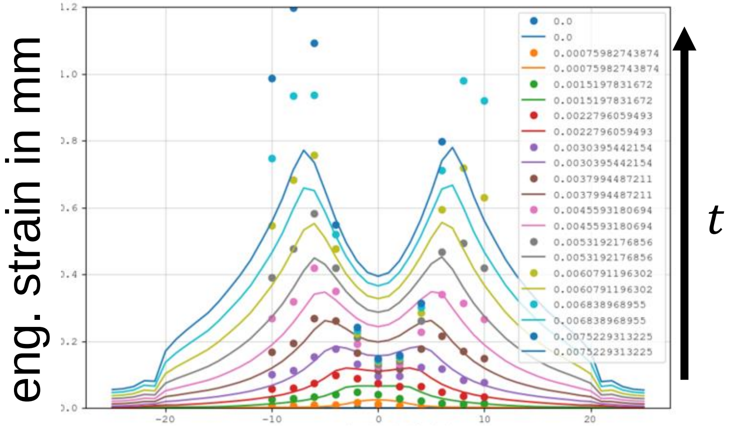


simulation

FEM
Nodal displacements
Over time
for all nodes in box



lines

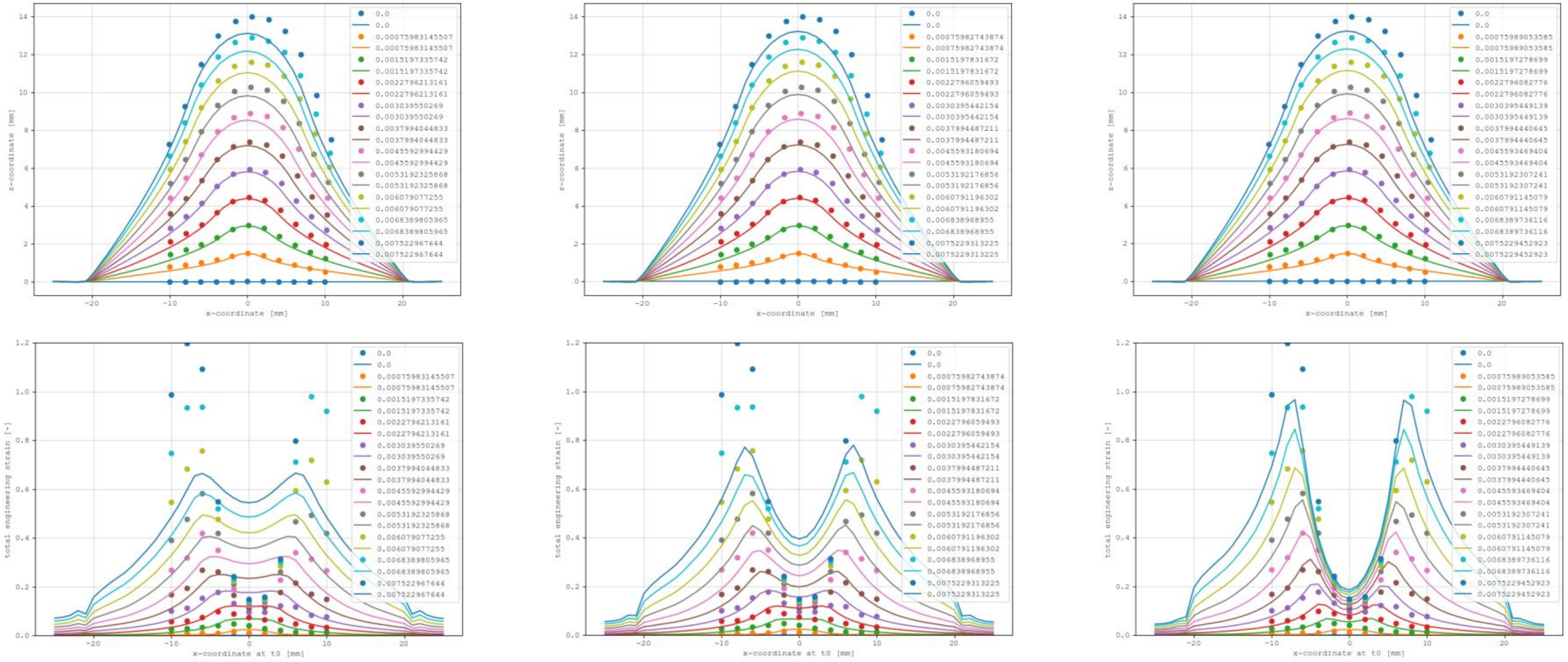


coordinate in mm

Mechanical characterization

Local Comparison PT – 3D DIC vs. `*MAT_024` (homogenized)

- Friction coefficient influences local strains ➔ failure strains



Friction coeff. 0.1

Friction coeff. 0.3

Friction coeff. 1.0

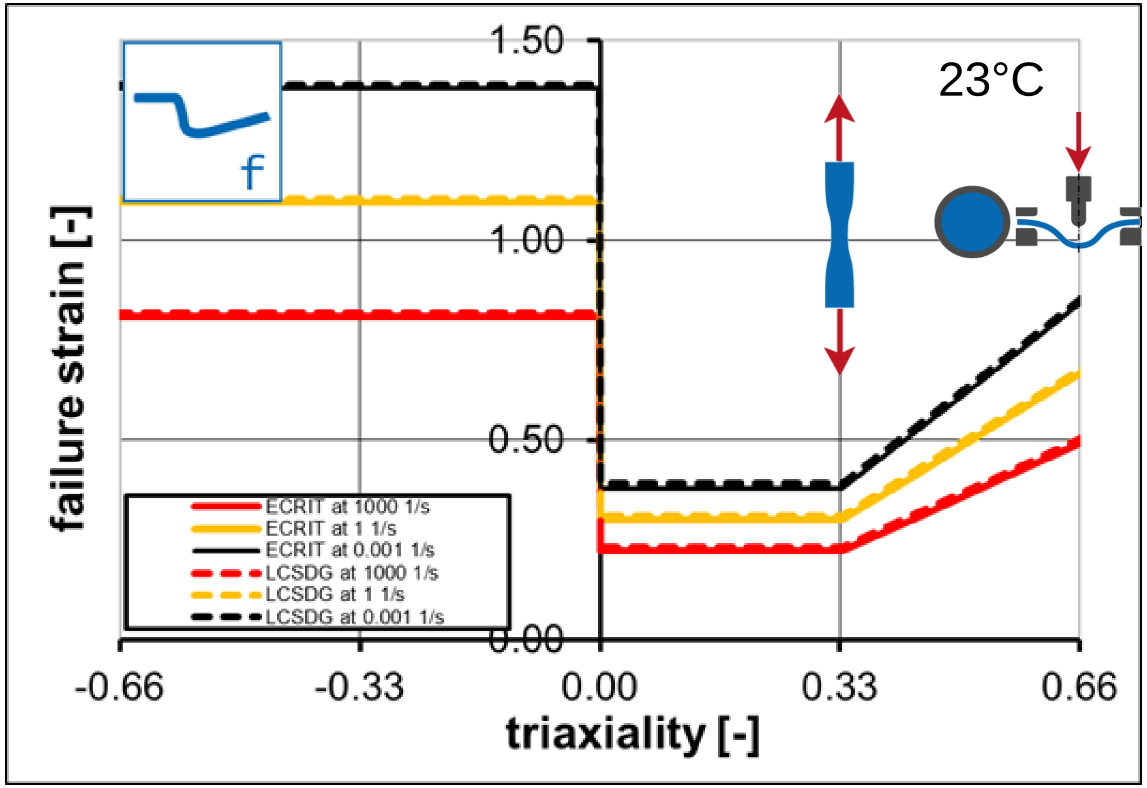
local z-disp

local eng. strains

Mechanical characterization

failure modelling

- Failure occurs abruptly
- Measurements 2 load types:
  - Tensile test (triaxiality ~1/3)
  - Puncture test (triaxiality ~2/3)
- Fitted the failure strains for 23°C
  ➔ ***MAT_ADD_DAMAGE_GISSMO**
  - Tensile Test at 23°C strain rate dependent
  - Puncture Test 23°C
  - Scaled Failure strains to Puncture tests at 50°C and 120°C



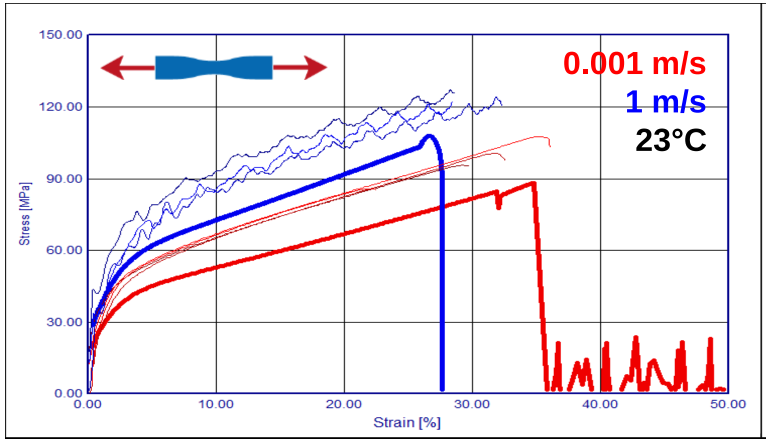
LCSDG: Failure strain curve/table or function

ECRIT: Critical plastic strain (material instability)

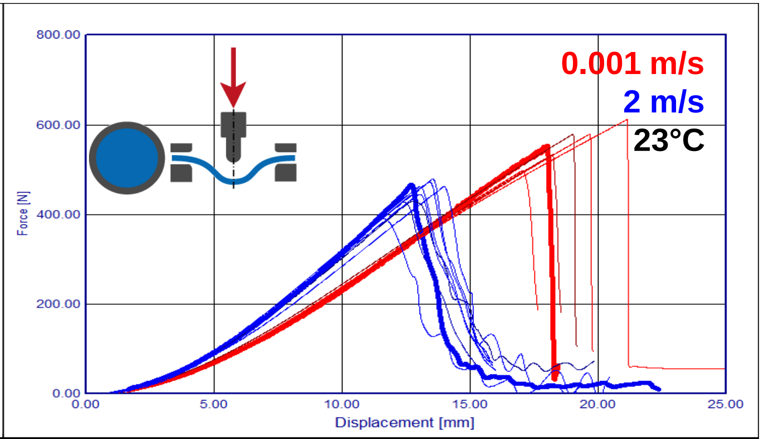
Mechanical characterization

Calibrated Material Model

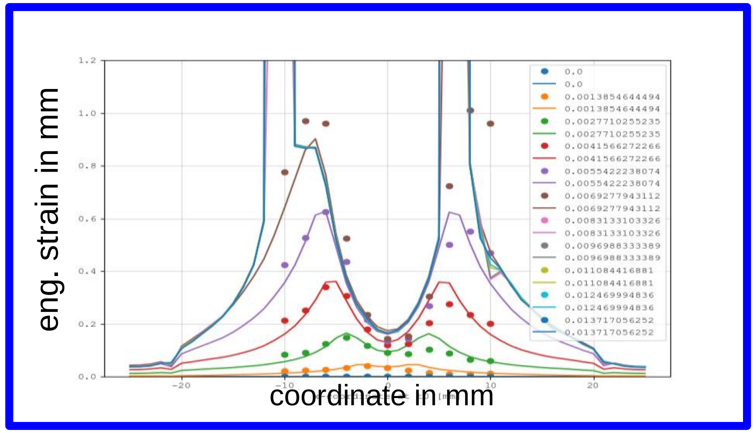
- Load type dependency:
  - ***MAT_106** (simple Mises)
  - ***MAT_255** (just UT➔UC, no further reduction BT)
- Membrane Idealization ➔ BT more important

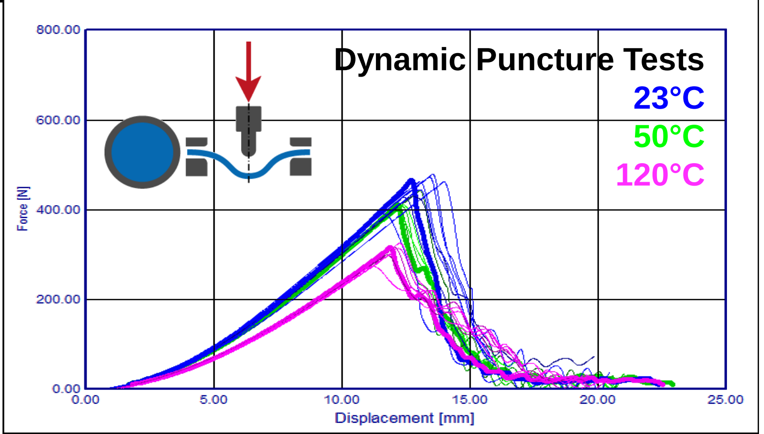


TENSION TEST



PUNCTURE TEST





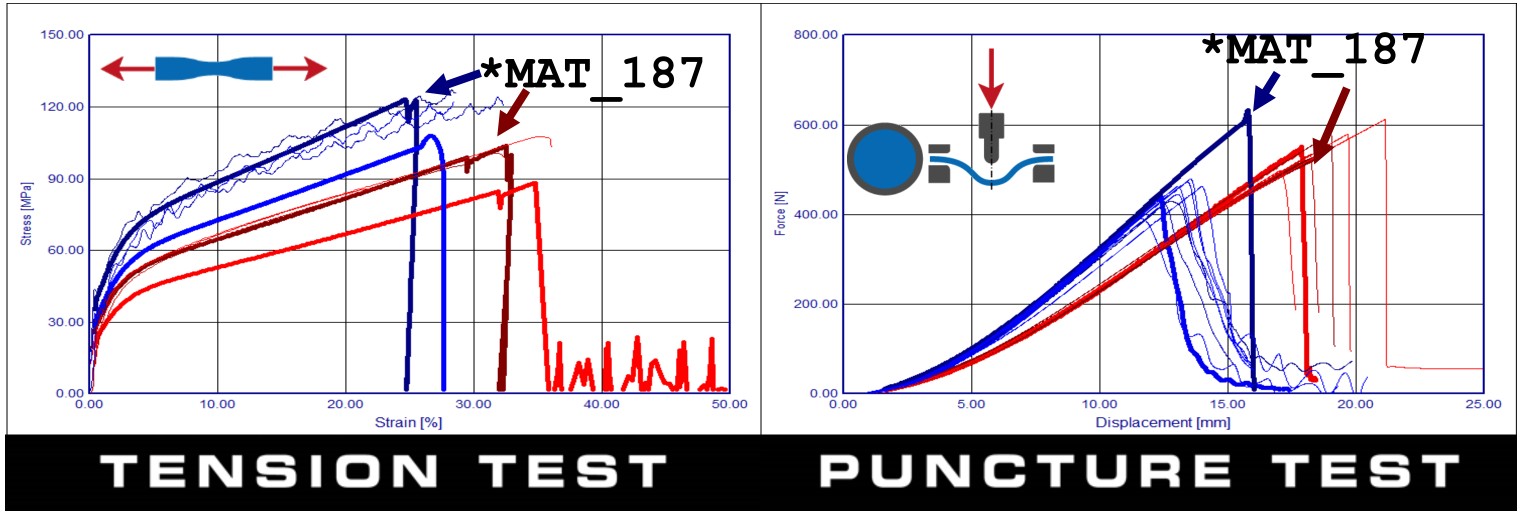
PUNCTURE TEST

— measurement curves — simulation curves

Mechanical characterization

yield surface `*MAT_024` vs `*MAT_187`

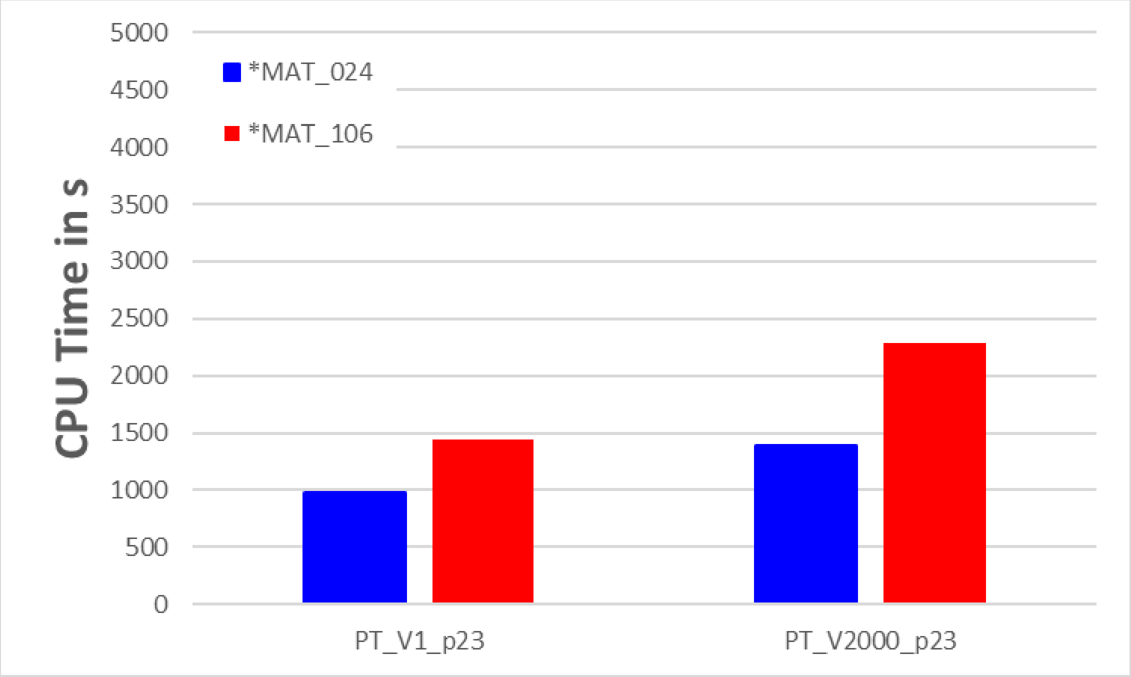
- With a different shape of the yield surface (**`*MAT_187`**) the tensile test and the puncture test can be depicted.
- The failure strains would have to be adjusted for this material mode.
- With this formulation we lose the temperature dependency.



Mechanical characterization

computational efficiency (**`*MAT_024`**/**`*MAT_106`** + **`*MAT_ADD_DAMAGE_GISSMO`**)

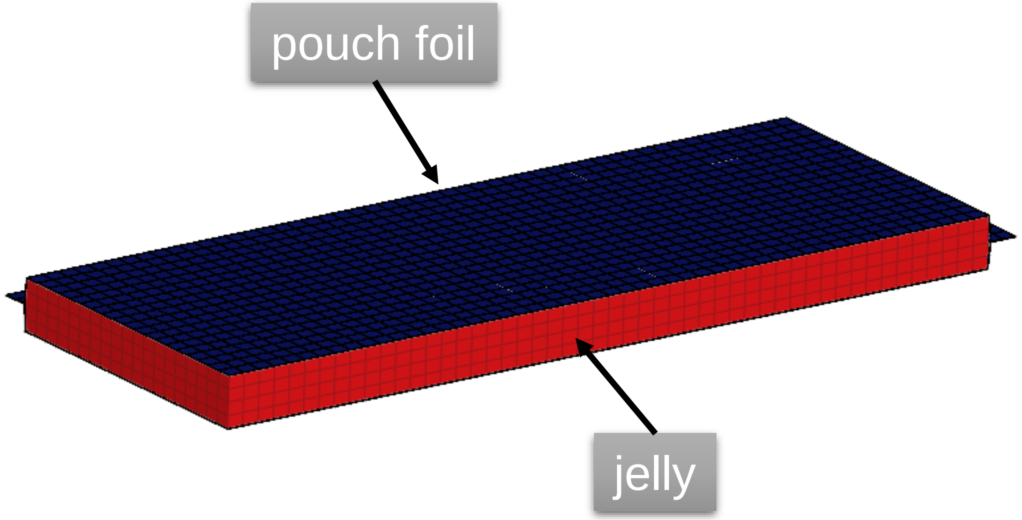
- Only slight computational time increase
- No thermal Solver just:
  `*LOAD_THERMAL_LOAD_CURVE`



Demonstrator model: pouch cell

*MAT_106 + *MAT_ADD_DAMAGE_GISSMO

- Test of calibrated material model in demonstrator model:
  - simplified model of pouch cell
    - pouch: **8976** Membrane Elements (ELFORM=9)
    - jelly: solid elements
    - cell surface not constrained
  - simulation of internal pressure due to gas generation (***LOAD_SEGMENT***)
    - variation of gas generation rate
    - variation of temperature (***LOAD_THERMAL_LOAD_CURVE***)
  - prediction of leakage pressure level



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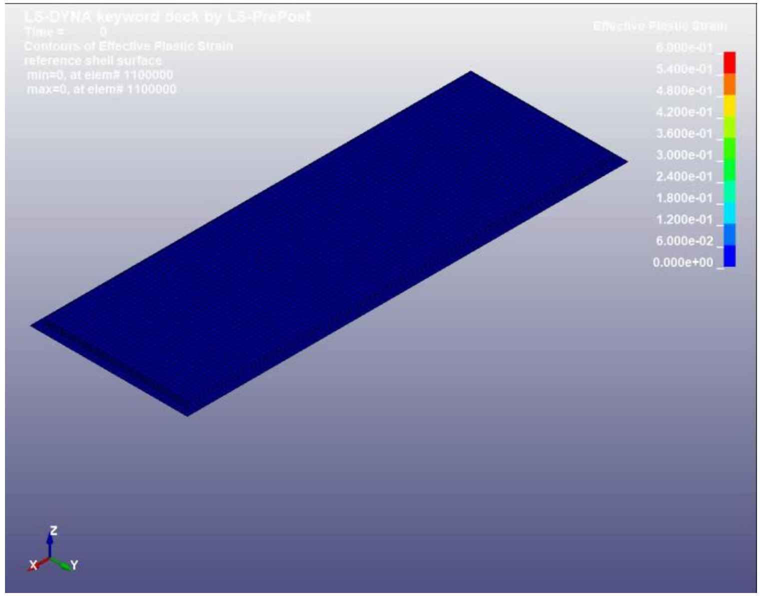

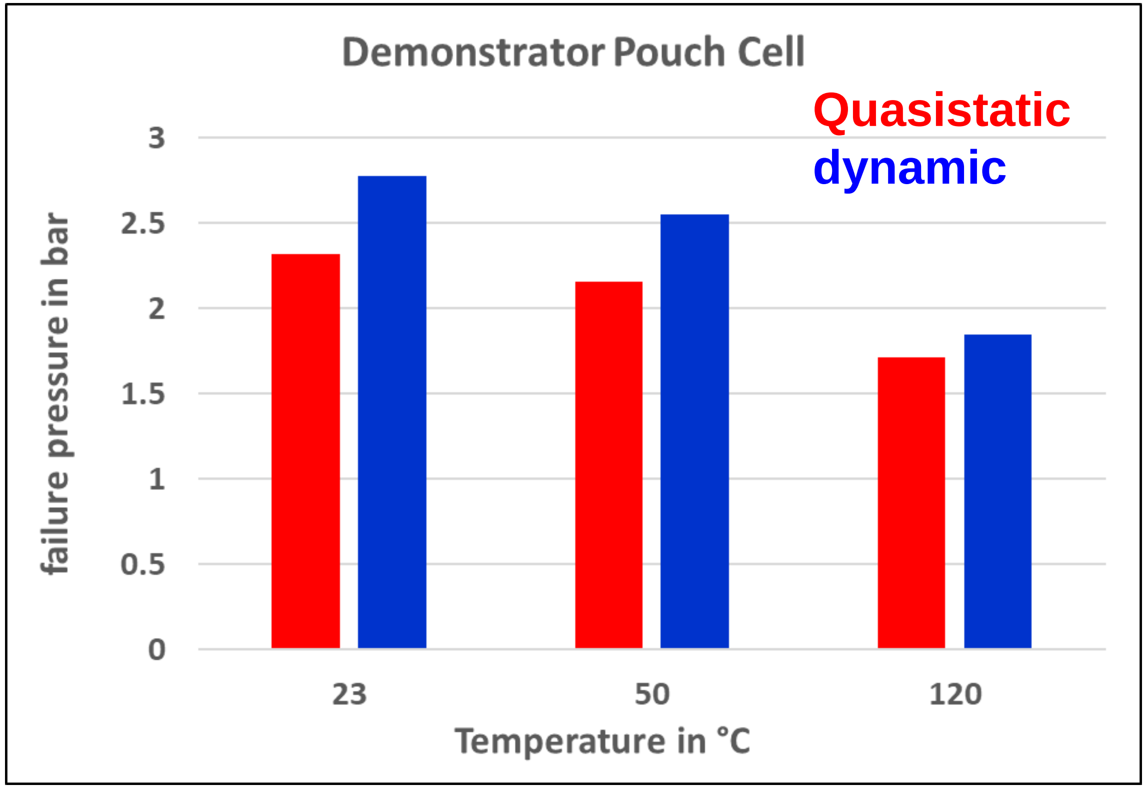

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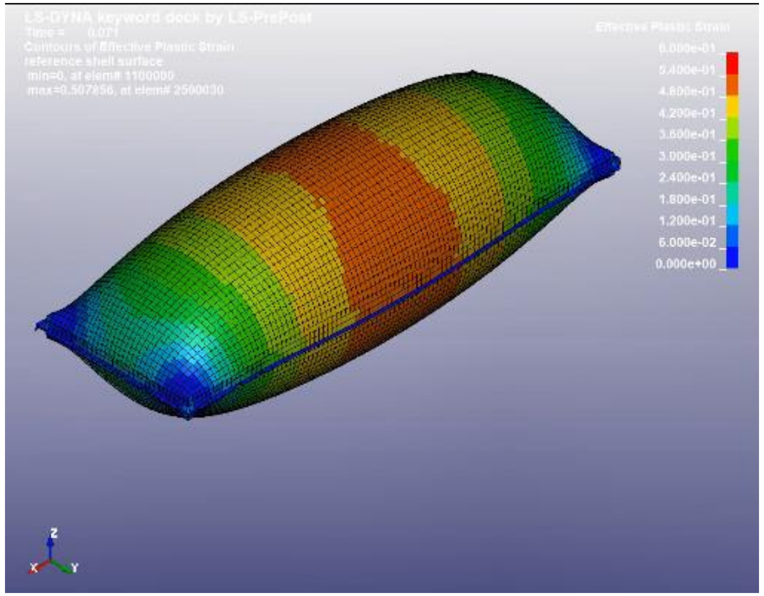
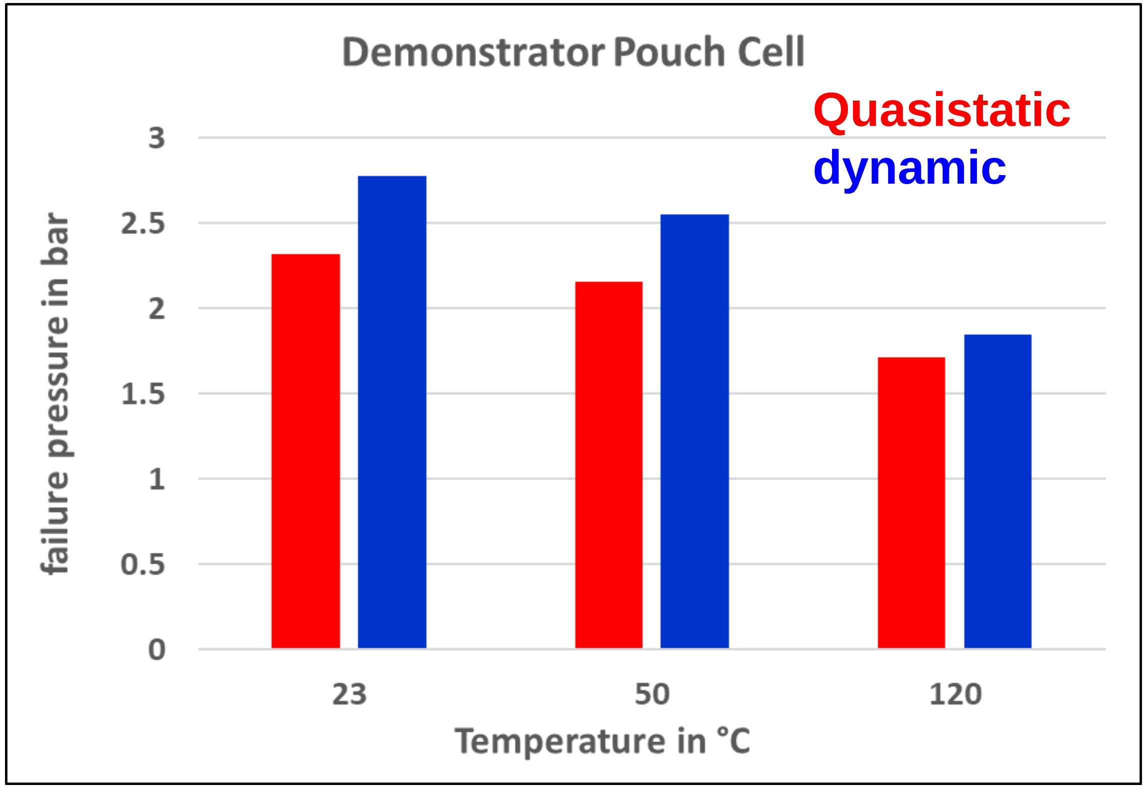
  - prediction of leakage pressure level





Summary

- rupture of pouch foil leads to eletrolyte leakage → loss of electrical function
- various external loads are transmitted through the pouch foil
- internal loads are directly acting on pouch foil

- FEM model of cell should represent casing and jelly separately
- need of accurate material models of pouch foils

- pouch foils exhibit temperature and strain rate dependent mechanical behaviour
- homogenized modelling with membrane elements sufficient
- simulation of internal pressure due to gas generation to illustrate mechanical behaviour

[YouTube CHANNEL]

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