Battery cell and pack casings in crash and thermal runaway – modelling and characterisation

automotive CAE grand challenge *19th – 20th October 2021*

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excellence in …

plastics simulation

testing equipment

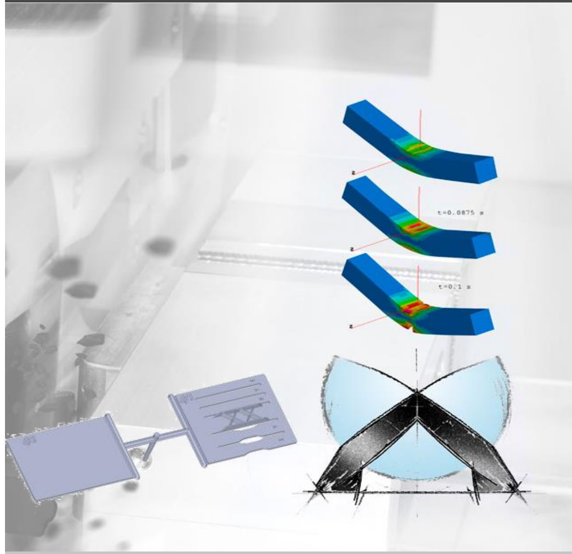
lightweight products

4a-engineering - Business Units

Testing hard- and software

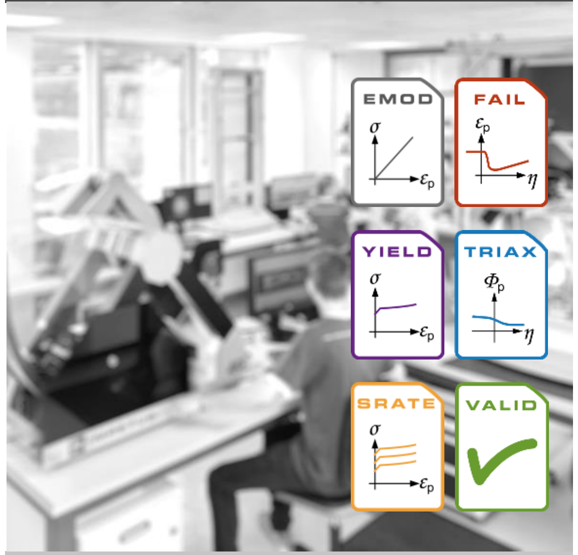
Seamless testing and simulation solution for automated material characterization

Material characterization



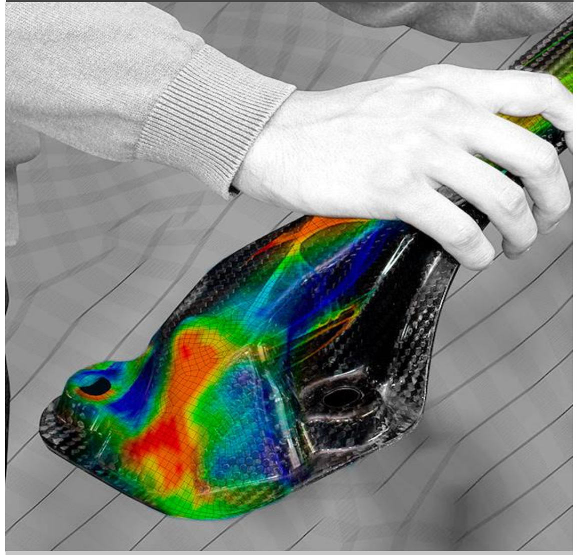
Static and dynamic material characterization from specimen to component validation – all under one roof

Validated material cards



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

Product development

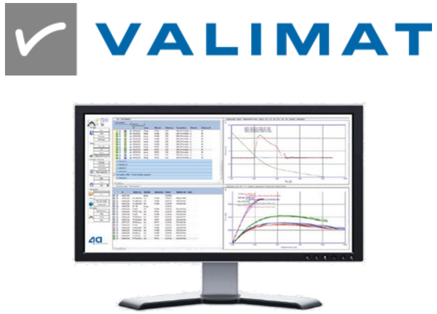


From draft to craft – Engineering, simulation and prototyping

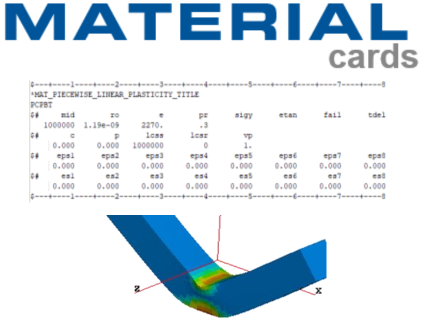
4a engineering – efficient characterisation and modelling

Material

Testing

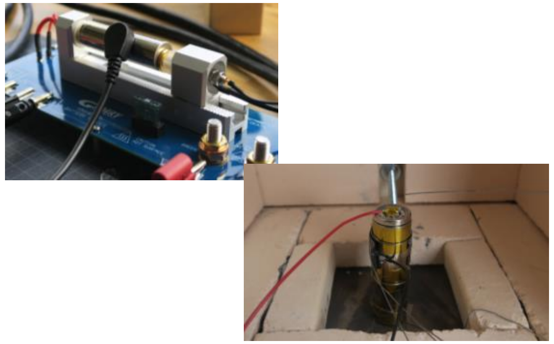


Identification

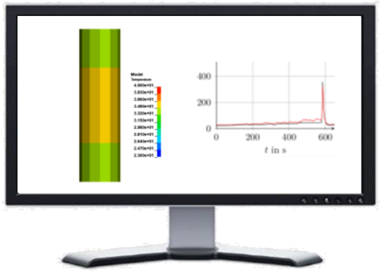


Material model

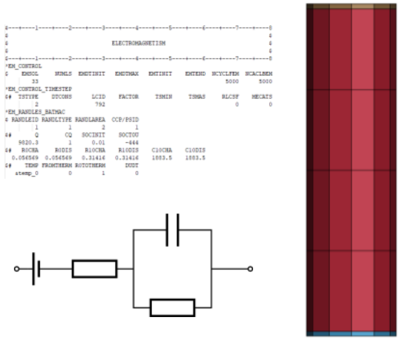
Battery Cell



Testing



Identification



FE Model

Agenda

- Motivation
- Part I: Modelling and characterisation of pouch foils
  - Thermo-mechanical behaviour of pouch foils
  - Modelling and validation in LS Dyna
  - Application Example
- Part II: Impact of cell thermal runaway on polymeric/SMC battery pack cover
  - Cell thermal runaway characterisation in pack configuration
  - Post TR characterisation of SMC cover
- Summary

Motivation

Abuse scenarios of battery cells:

	mechanical abuse	electrical abuse	thermal abuse
	deformation, crash → causes short circuit between electrodes (ISC)	ISC generates heat due to high current	heat input activates exothermic reaction of cell constituents
role of cell casing: (e.g. pouch foil)	• environmental protection • keep electrolyte within cell once ruptured: • loss of electrical function • electrodes prone to SC	• protection against electrical fields (dielectric strength)	• sustain overpressure due to gas generation in case of TR: • rapid gas generation • rupture • venting

Motivation

Abuse scenarios of battery cells:

	mechanical abuse		electrical abuse		thermal abuse
	deformation, crash → causes short circuit between electrodes (ISC)	→	ISC generates heat due to high current	→	heat input activates exothermic reaction of cell constituents
role of cell surroundings (e.g. pack cover	• load transfer in case of crash		• protection against electrical fields (dielectric strength)		once venting occurs: • sustain overpressure due to gas generation • sustain hot gas flow • no fire outside of battery pack

Motivation

before and up to ISC:

→ thermo-mechanical cell behaviour needs to be modelled

→ part I with focus on pouch cell casing

after ISC / in case of TR:

→ interaction between cell and surroundings needs to be considered

→ part II: example smc battery pack cover thermo-mechanical behaviour and erosion in TR

Agenda

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  - **Thermo-mechanical behaviour of pouch foils**
  - **Modelling and validation in LS Dyna**
  - **Application Example**
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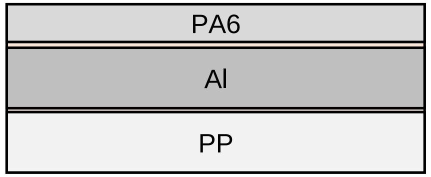
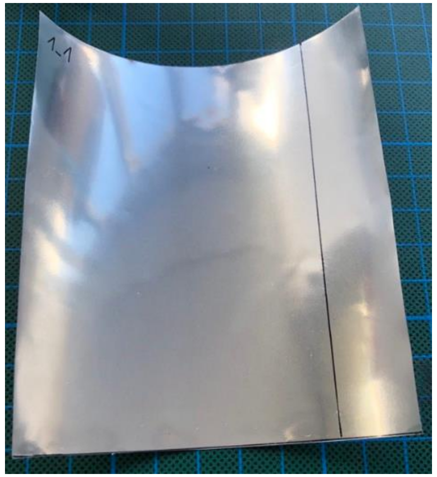
Mechanical characterization

Pouch foil constitution

- Composite of thin foils glued together



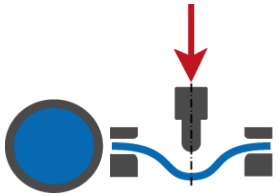


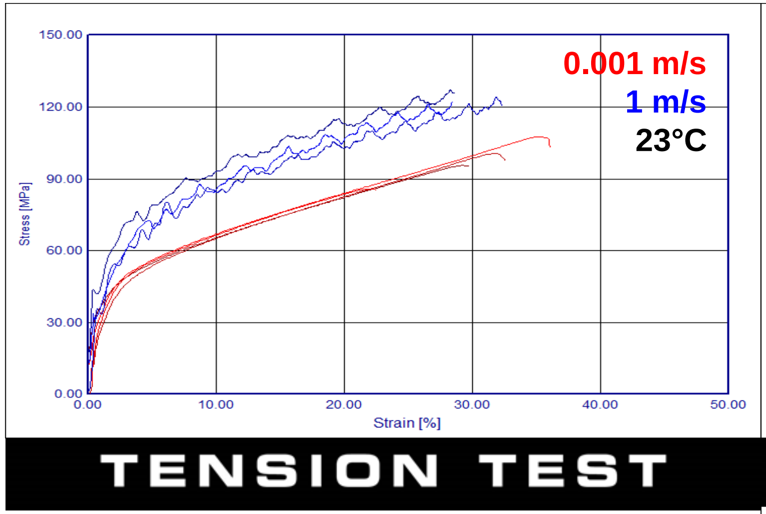
Layer material	thickness		Area weight
	M	SD	g/m²
Polyamide (JIS Z1714)	0.025	0.0025	-
Adhesive (Polyester-polyurethane	-	-	4-5
Aluminium foil (JIS A8021)	0.04	0.004	-
Adhesive (Urethane-free Adhesive)	-	-	2-3
Polypropylene	0.04	0.004	-
Total	0.111	0.011	

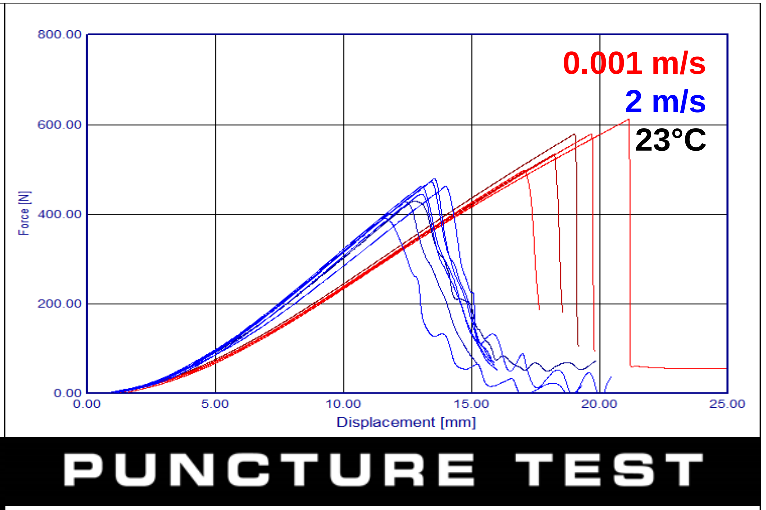
Mechanical characterization

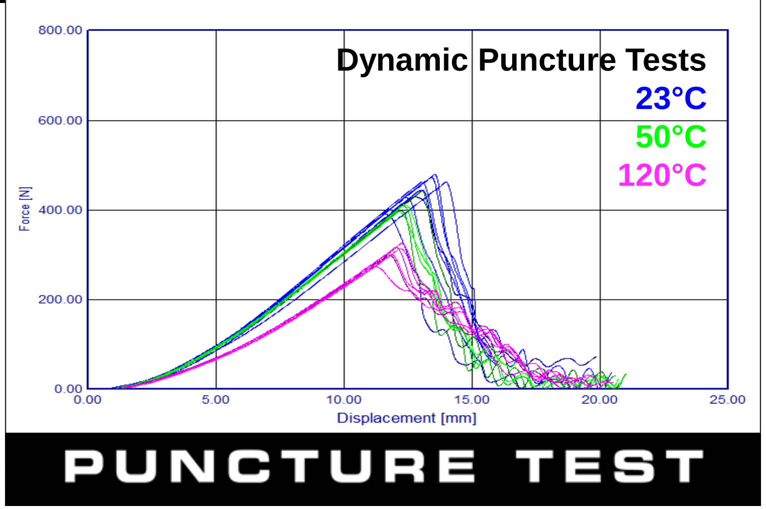
Experimental results

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







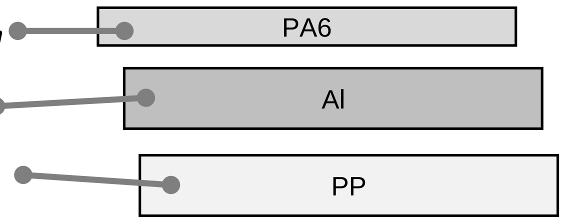


— measurement curves

Mechanical characterization

Modelling approach

Initial Idea: ***PART_COMPOSITE**:

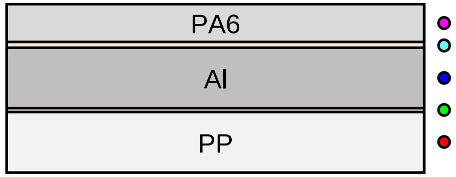


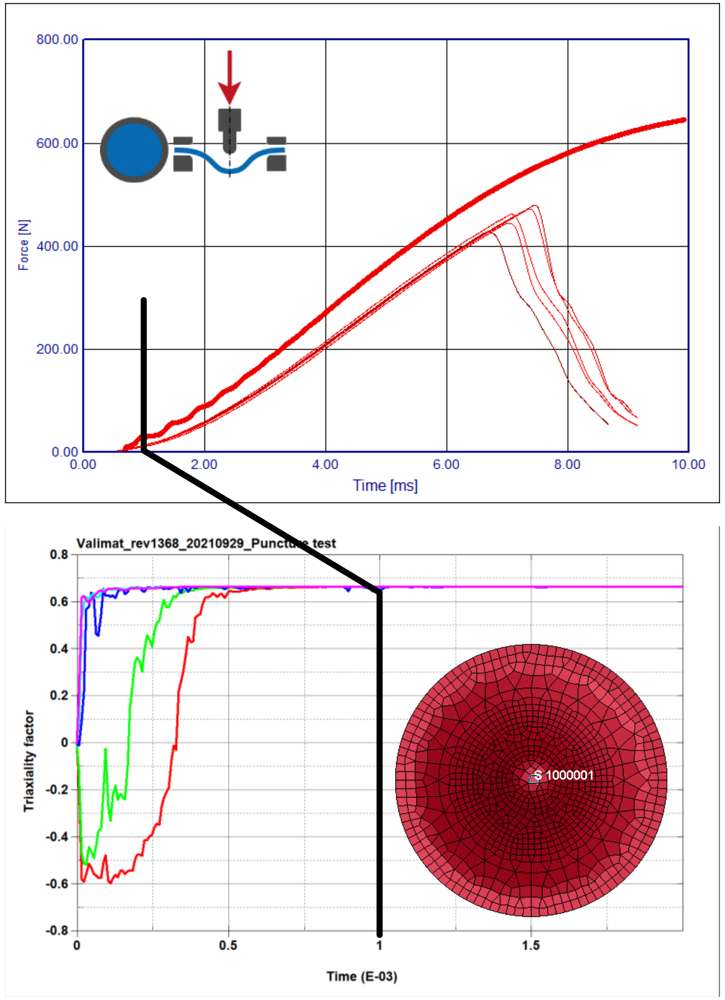
- E.g. ***MAT_187L***
- E.g. ***MAT_024***
- E.g. ****MAT_187L***

- 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**





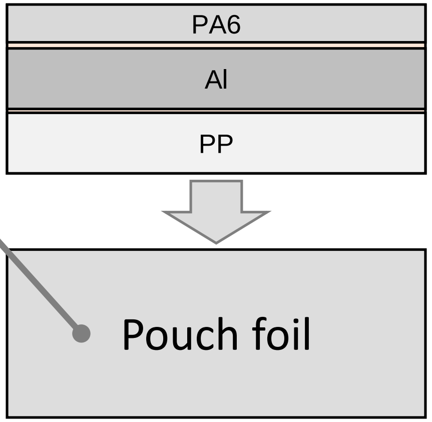
— measurement curves — simulation curves

Mechanical characterization

Modelling approach

Homogenized Approach:

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



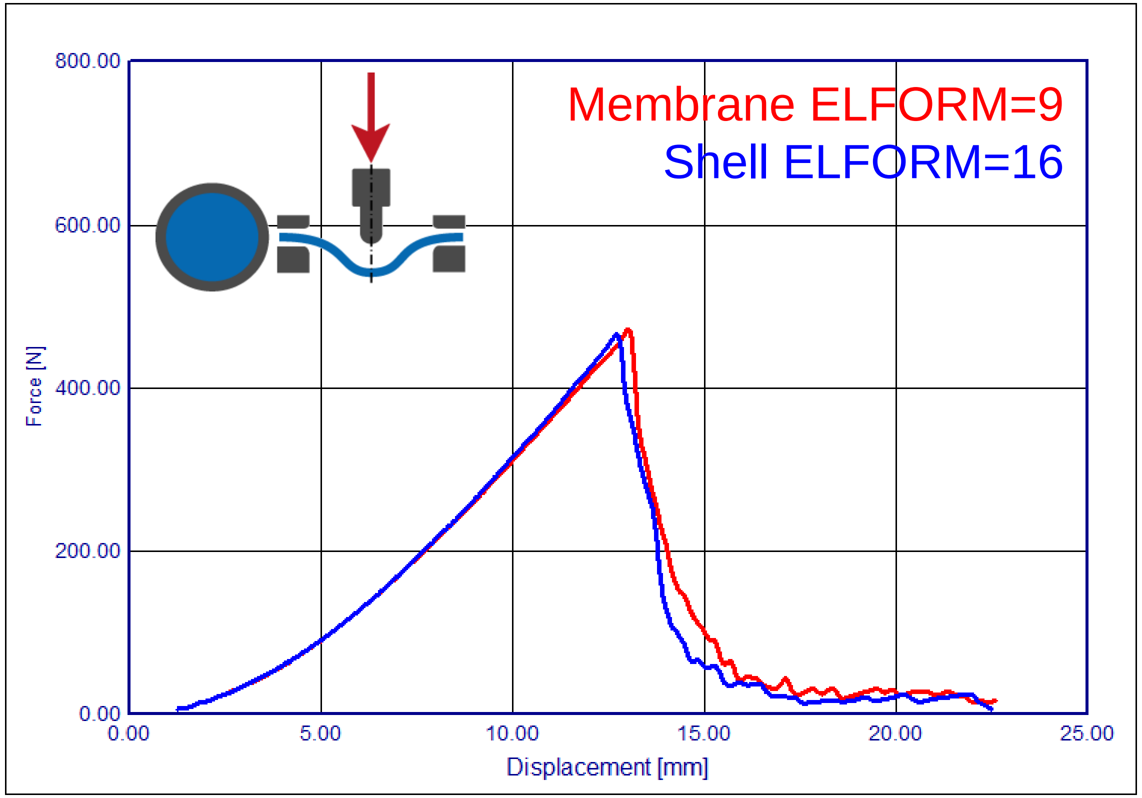
Material Tests showed:

- 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

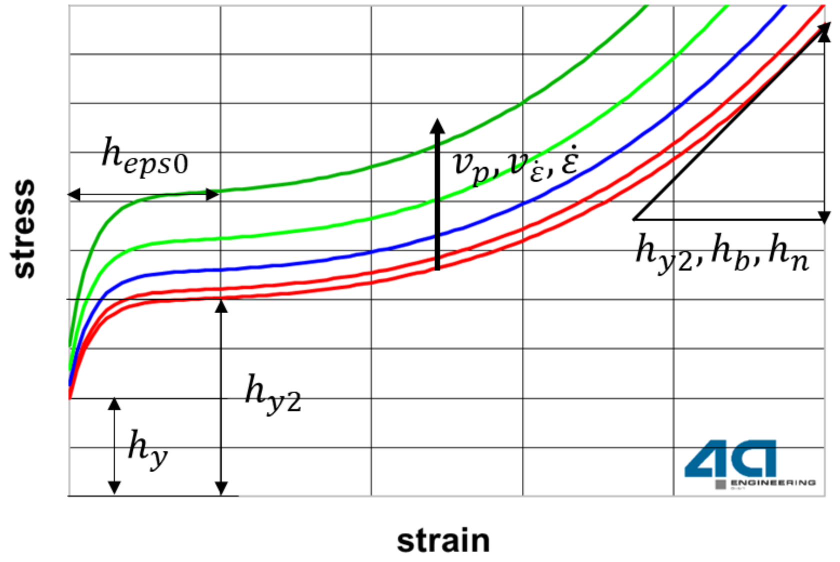
Mechanical characterization

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**)

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

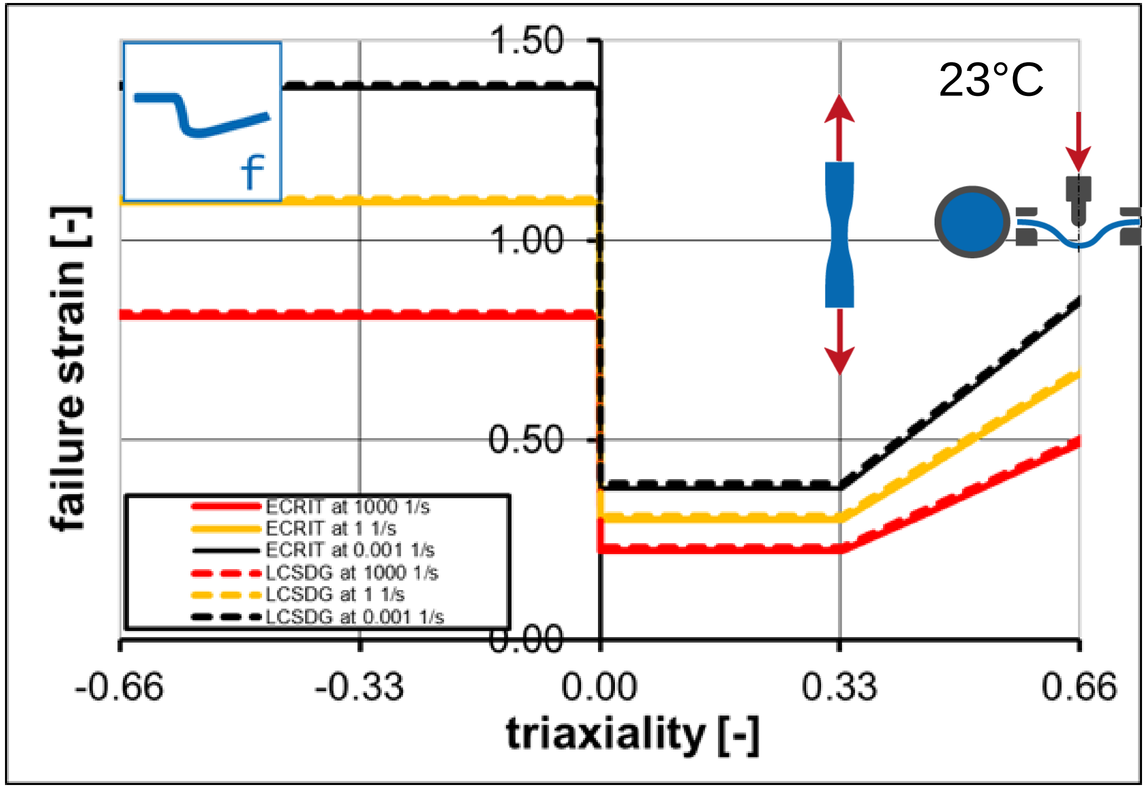
$$\sigma_y = \sigma_{y,0} \cdot \left(1 + \frac{1}{v_p} \cdot log\left(\frac{max\left(\dot{\varepsilon}_{pl}, v_{\dot{\varepsilon}}\right)}{v_{\dot{\varepsilon}}}\right)\right)$$



Mechanical characterization

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



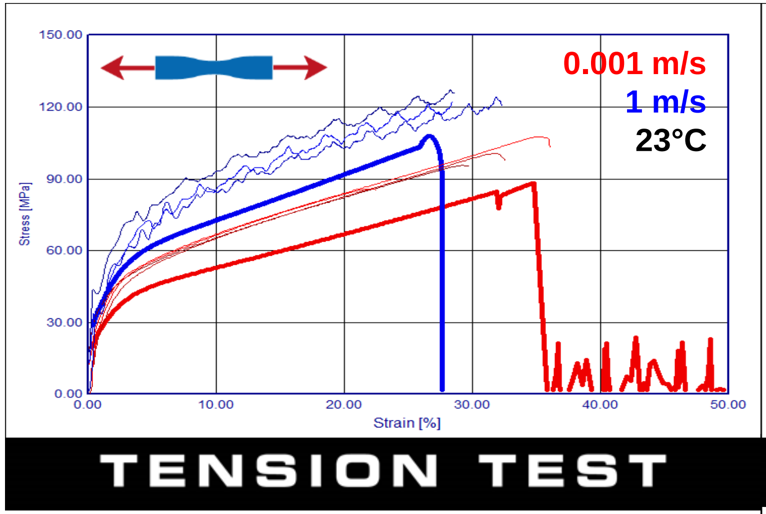
LCSDG: Failure strain curve/table or function

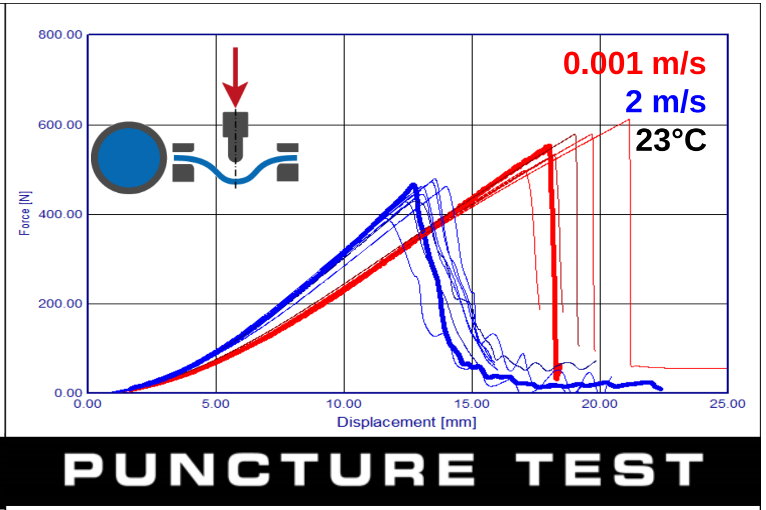
ECRIT: Critical plastic strain (material instability)

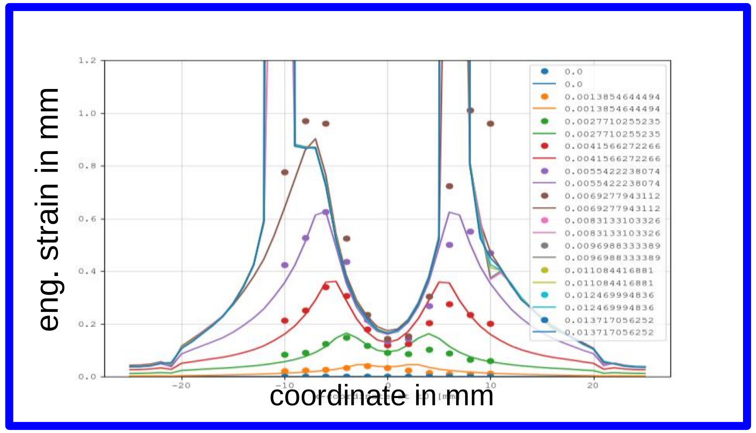
Mechanical characterization

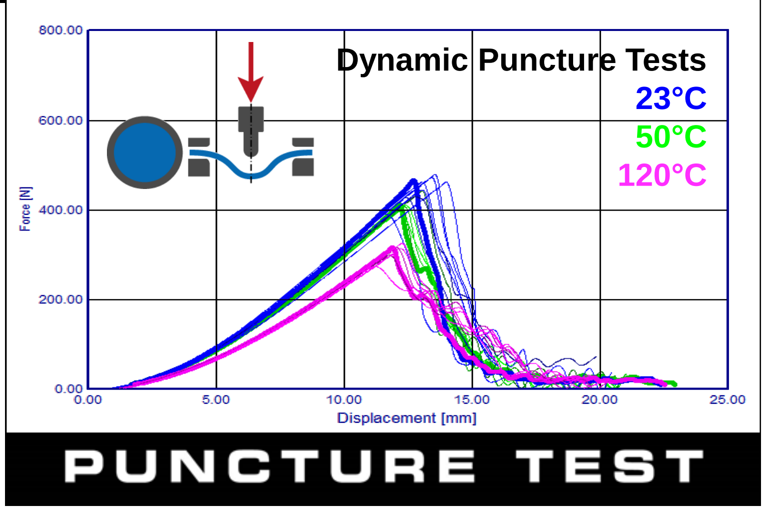
Calibrated Material Model

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







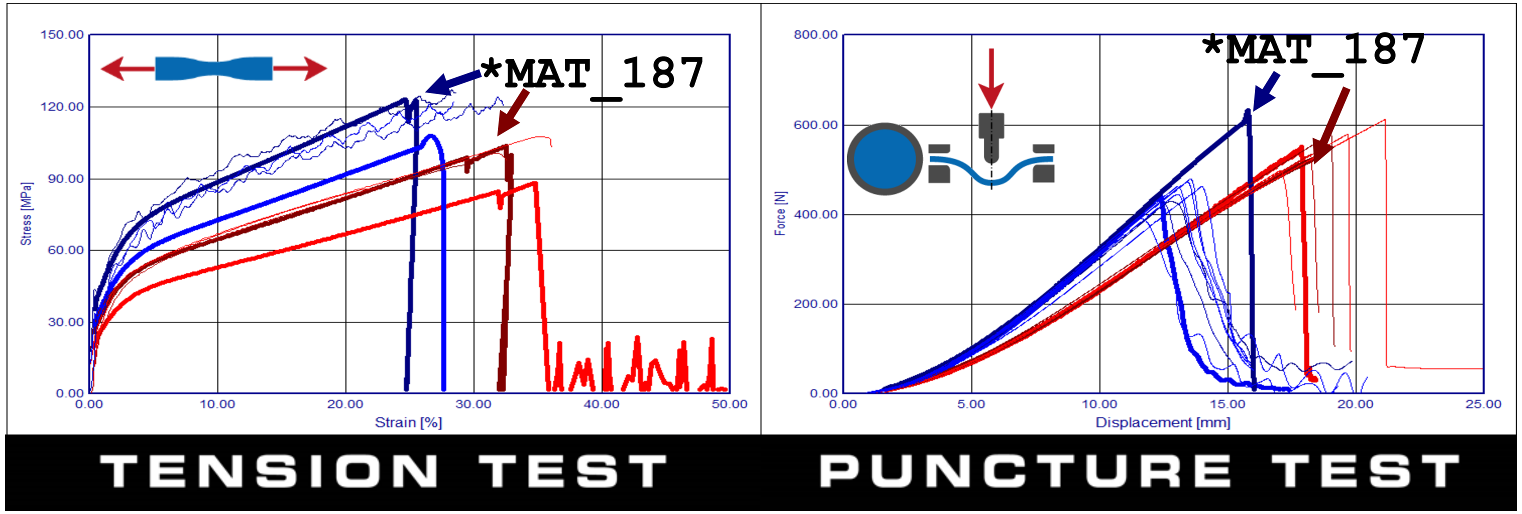


— measurement curves — simulation curves

Mechanical characterization

yield surface *MAT_024 vs *MAT_187

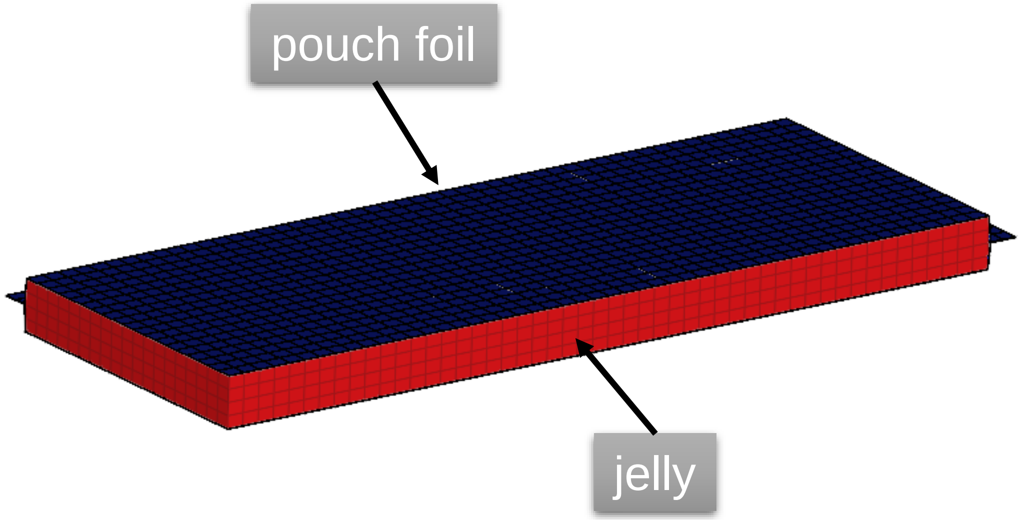
- With a different shape of the yield surface (*MAT_187) the tensile test and the puncture test can be depicted.
- The failure strains would have to be adjusted for this material mode.
- With this formulation we lose the temperature dependency.



Demonstrator model: pouch cell

*MAT_106 + *MAT_ADD_DAMAGE_GISSMO

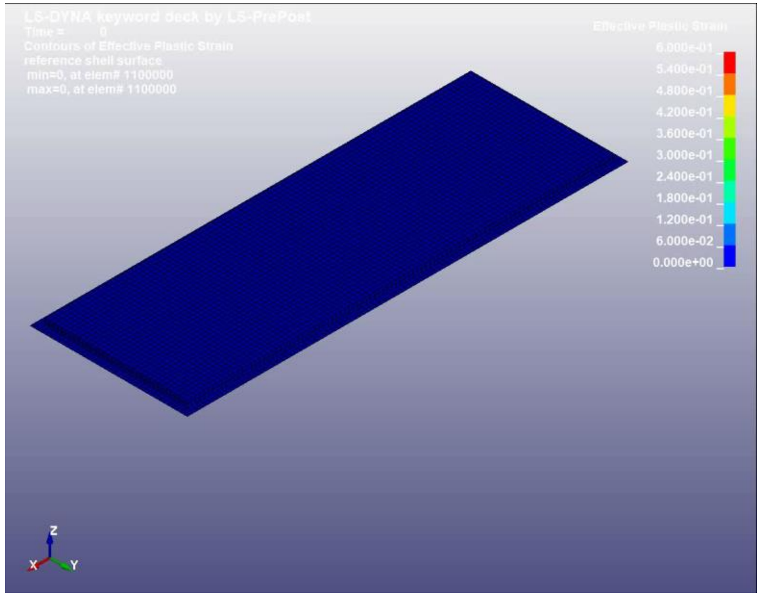
- Test of calibrated material model in demonstrator model:
  - simplified model of pouch cell
    - pouch: **8976** Membrane Elements (ELFORM=9)
    - jelly: solid elements
    - cell surface not constrained
  - simulation of internal pressure due to gas generation (***LOAD_SEGMENT**)
    - variation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

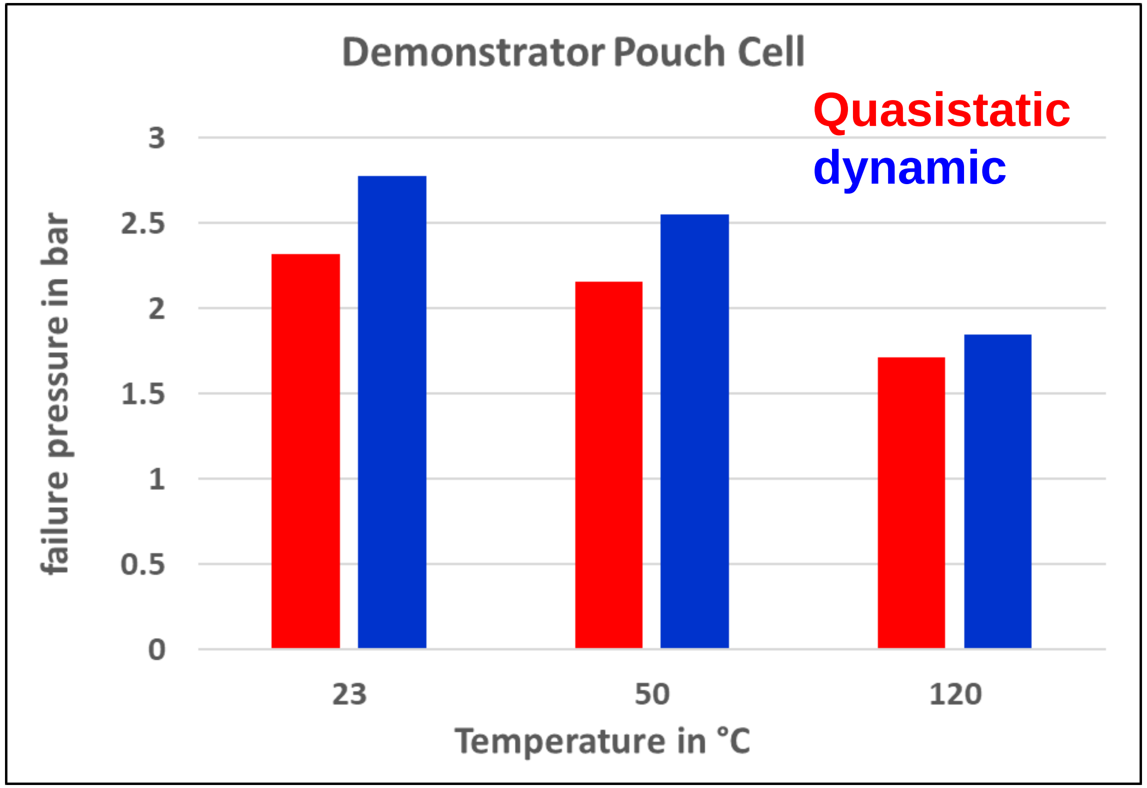


Demonstrator model: pouch cell

*MAT_106 + *MAT_ADD_DAMAGE_GISSMO

- Test of calibrated material model in demonstrator model:
  - simulation of internal pressure due to gas generation (****LOAD_SEGMENT***)
  - prediction of leakage pressure level





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IN PHYSICS WE TRUST

Demonstrator model: pouch cell

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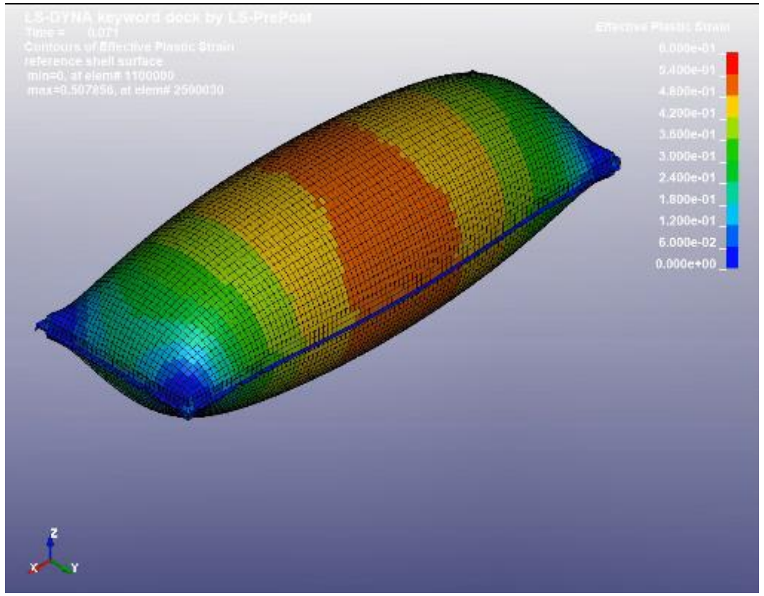

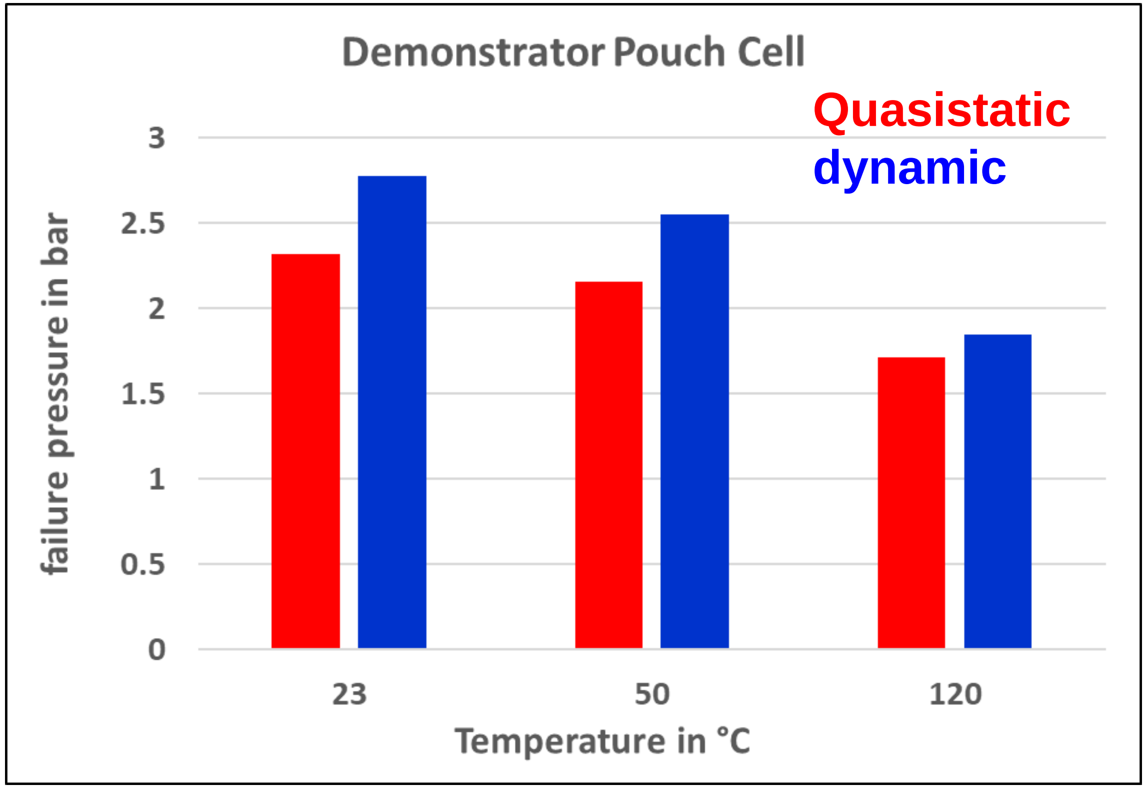

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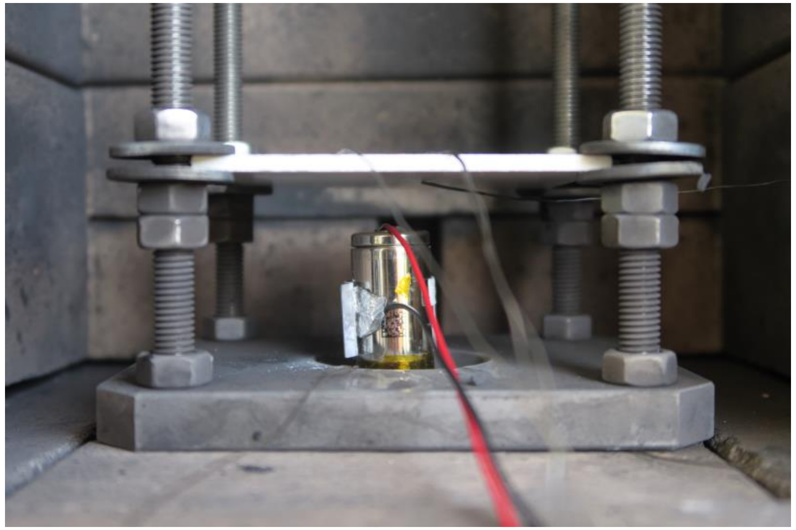
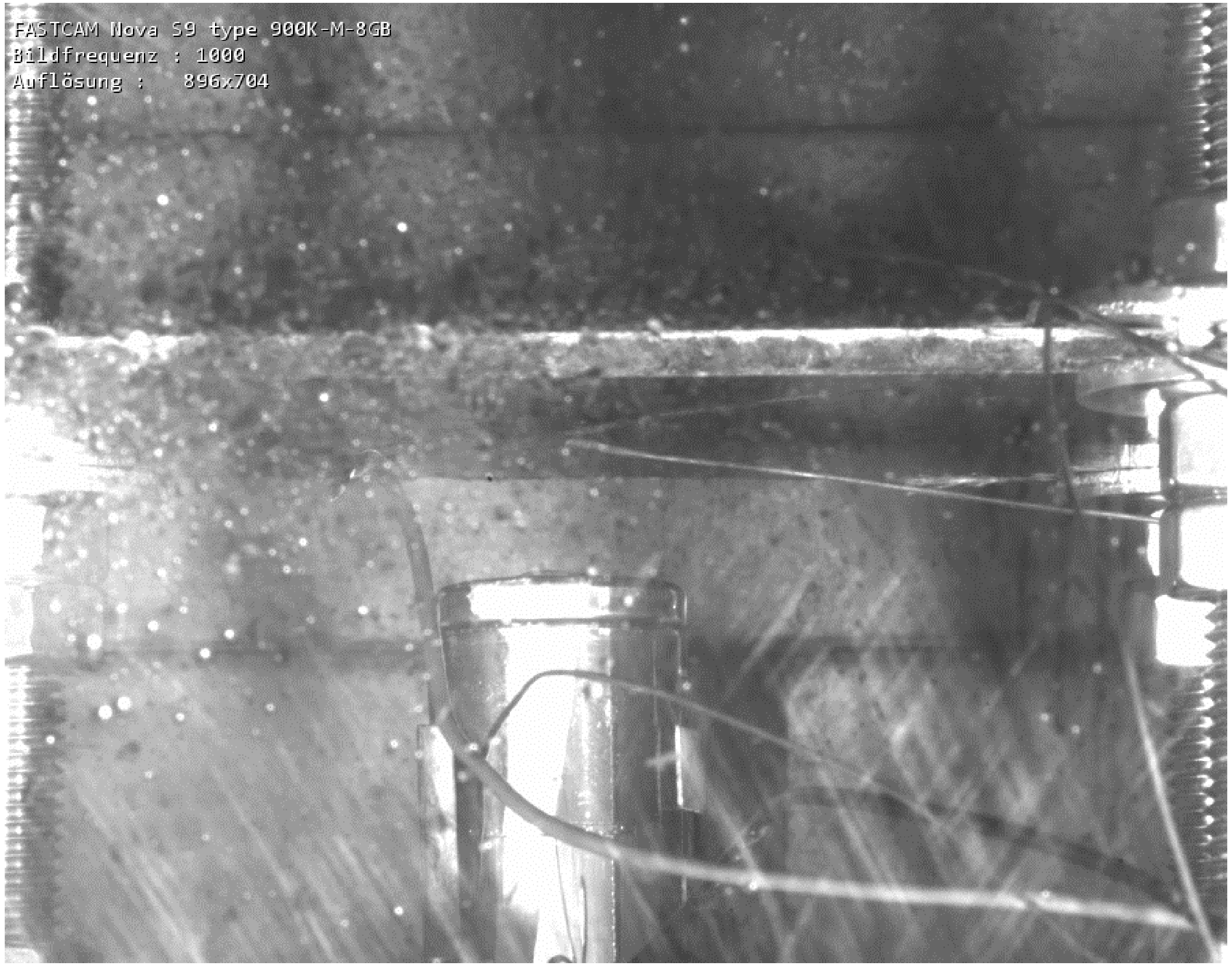
Characterisation of thermal runaway impact



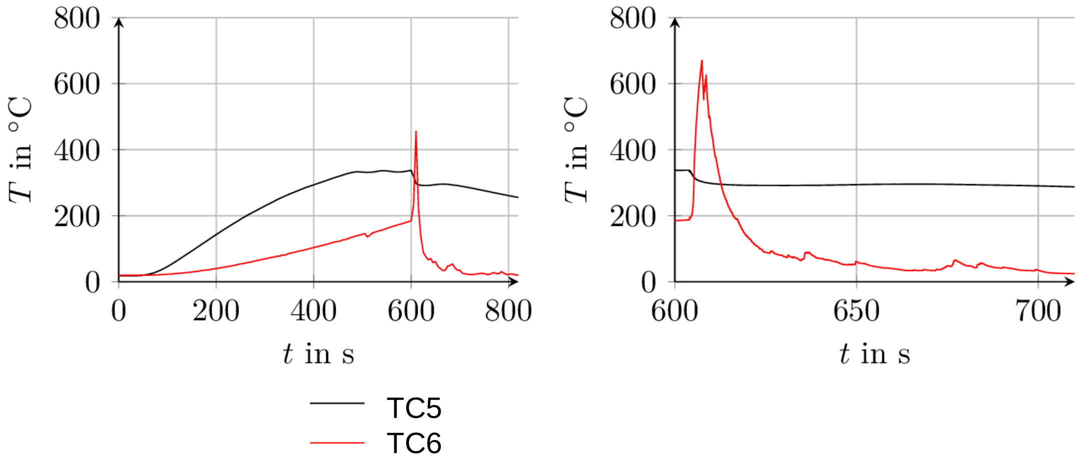
- thermal runaway induced by overheating at the bottom
- temperature measurement at plate and cell with 6 thermocouples
- voltage measurement
- video recording with high speed camera

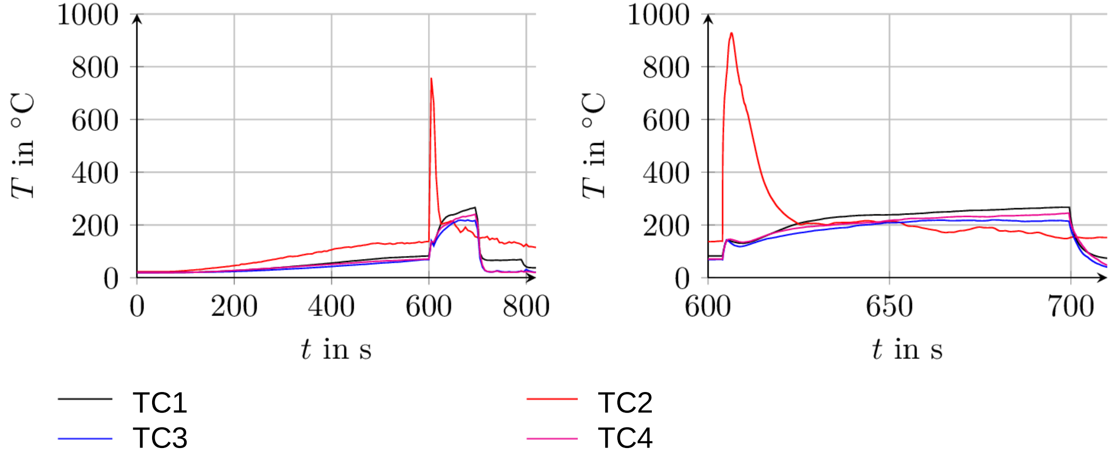
Characterisation of thermal runaway impact



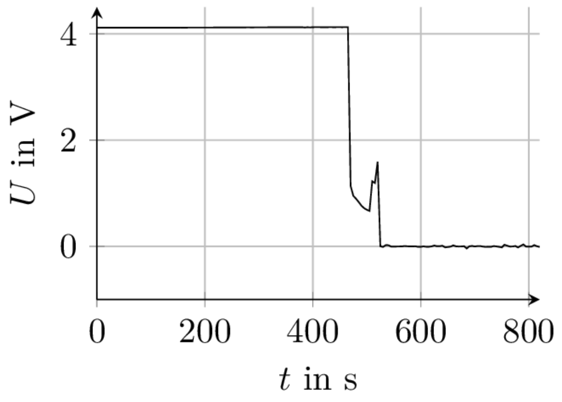
Characterisation of thermal runaway impact

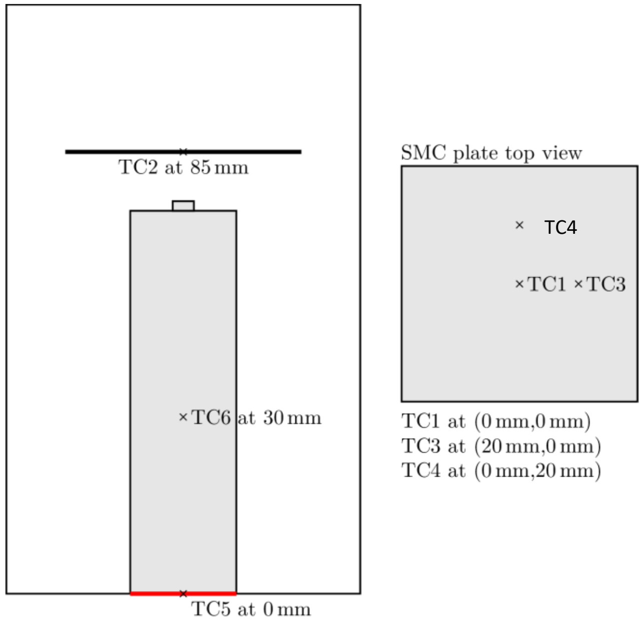
Measured temperatures on cell and SMC plate





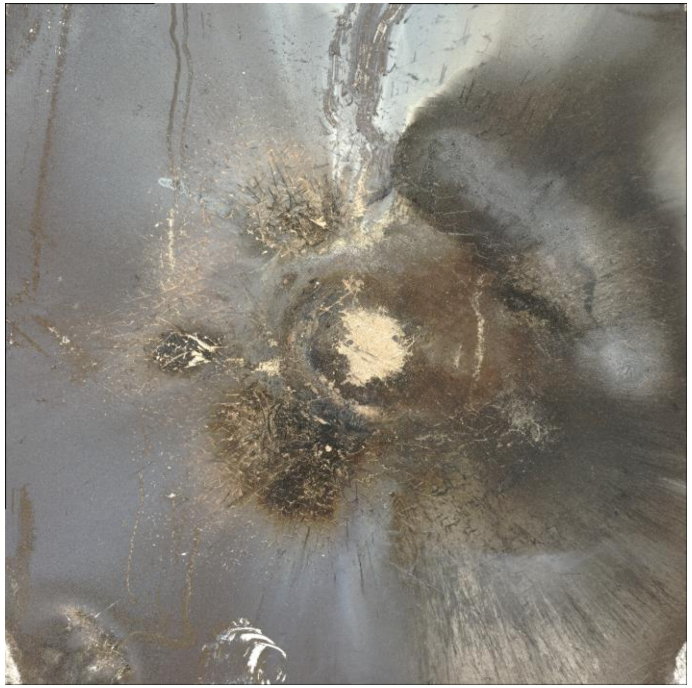
cell type	diameter [mm]	length [mm]	mass before [g]	mass after [g]	SOC [%]	OCV [V]	remarks
18650	18.2	65.26	45.3	23.3	100	4.12	

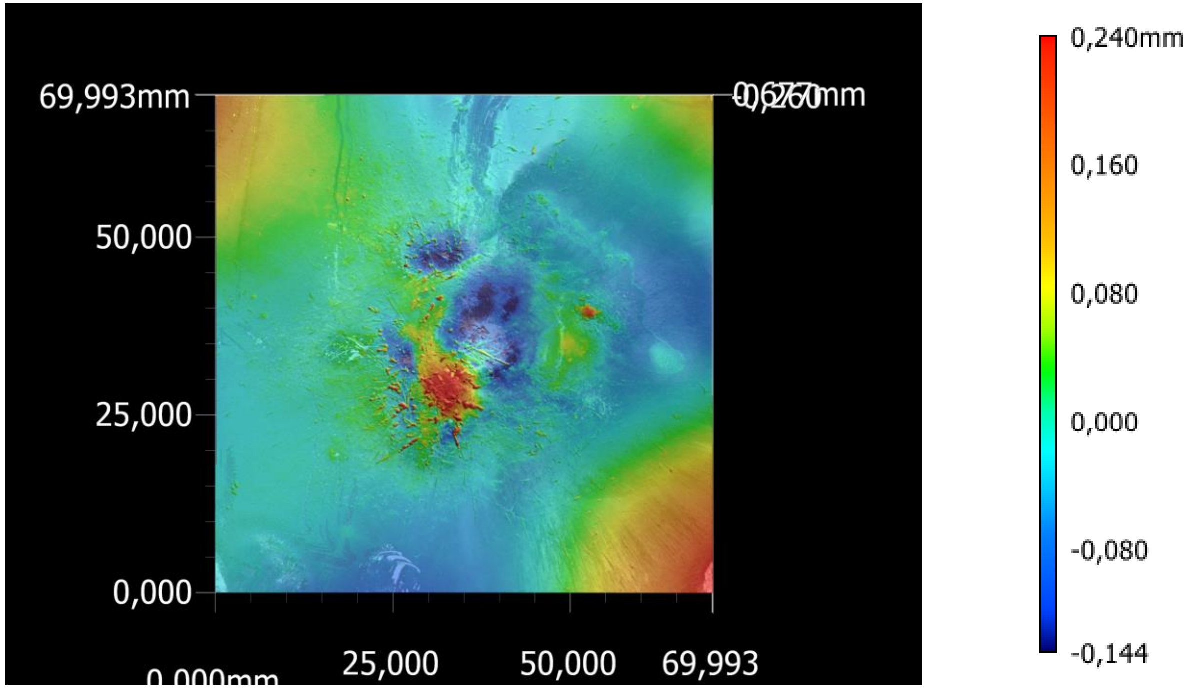




Characterisation of thermal runaway impact

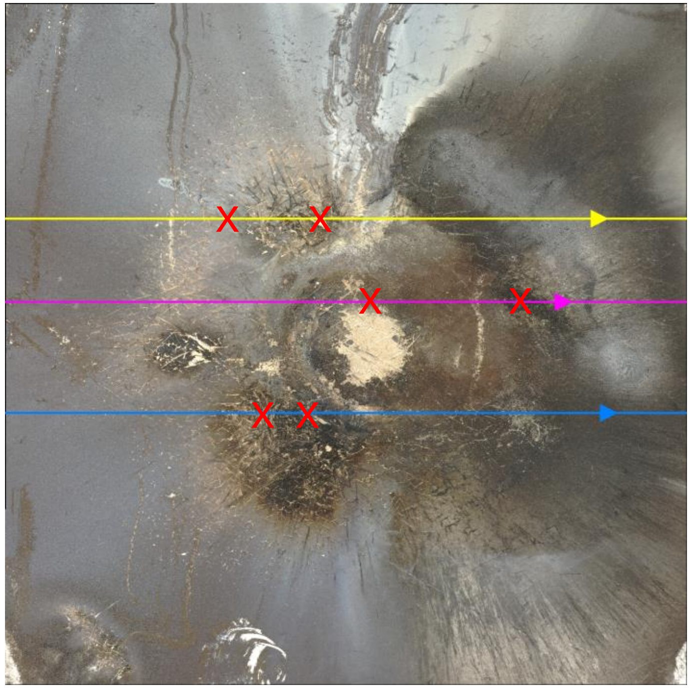
SMC plates after thermal runaway tests: 3D surface measurements

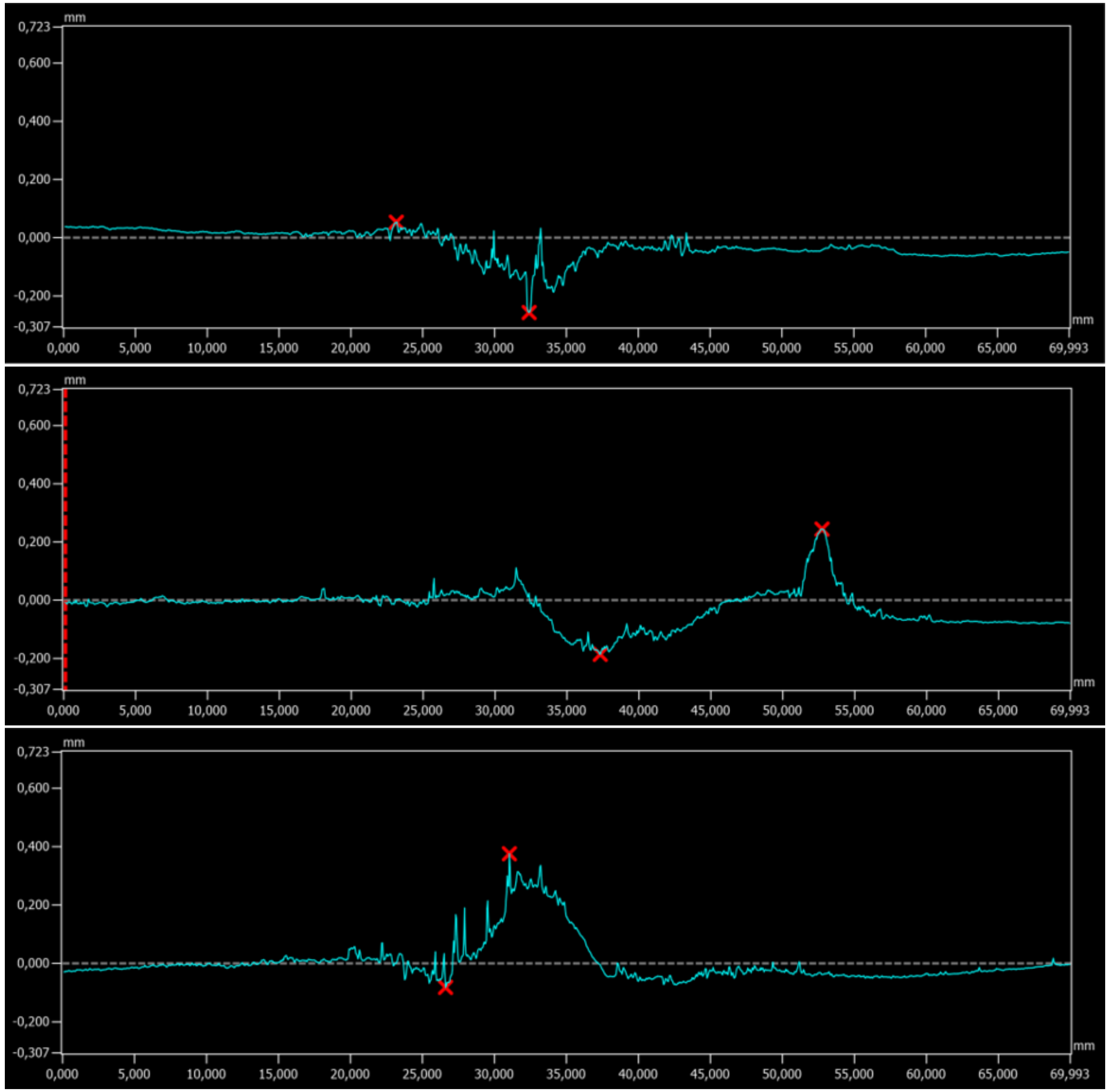




Characterisation of thermal runaway impact

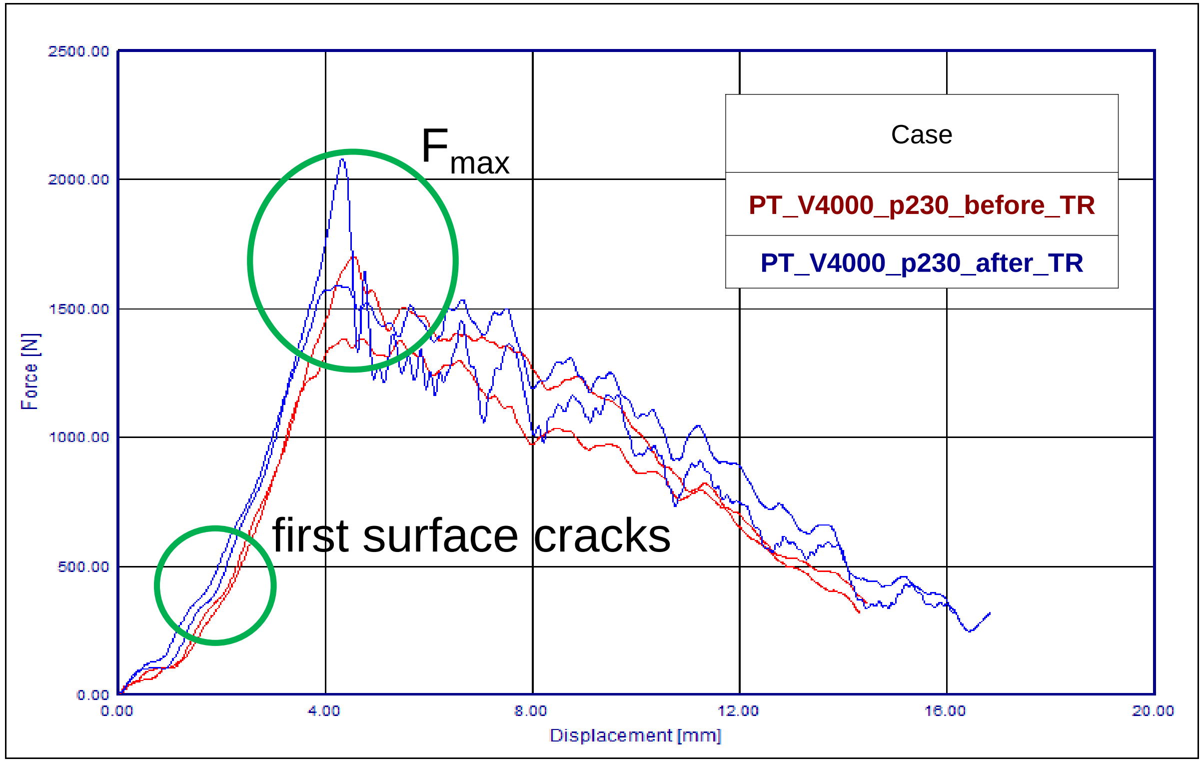
3D surface measurements

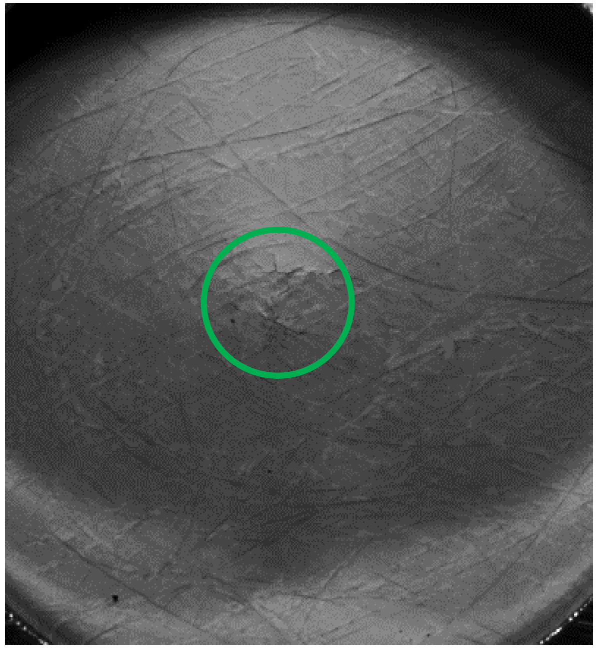




Characterisation of thermal runaway impact

Mechanical performance before and after thermal runaway – puncture test



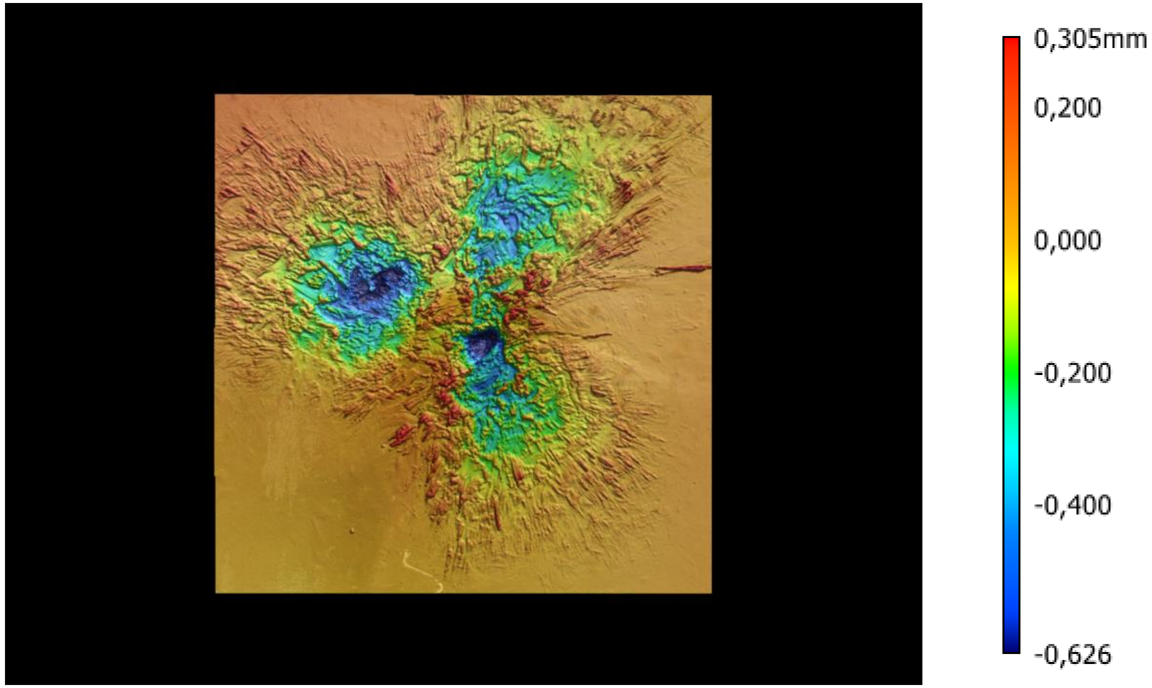


first surface cracks

F_{max}

Characterisation of thermal runaway impact

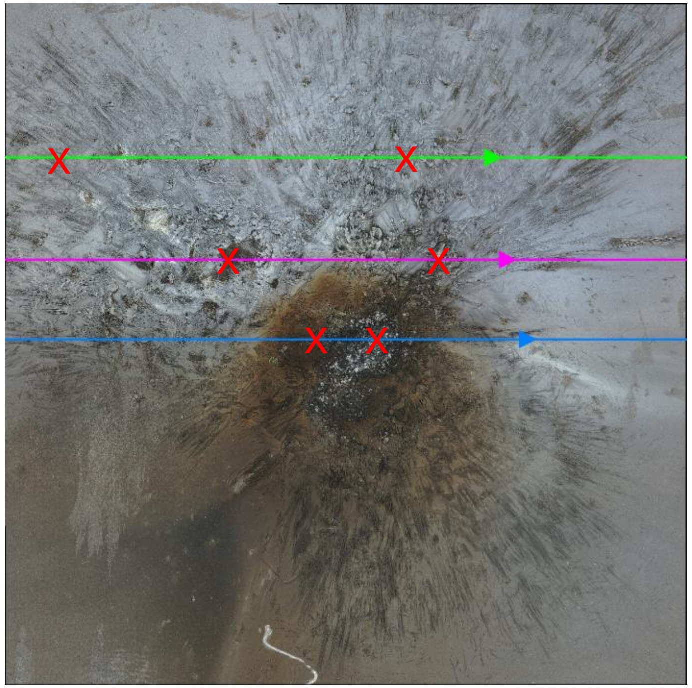
comprarison of different SMC material with similar base properties

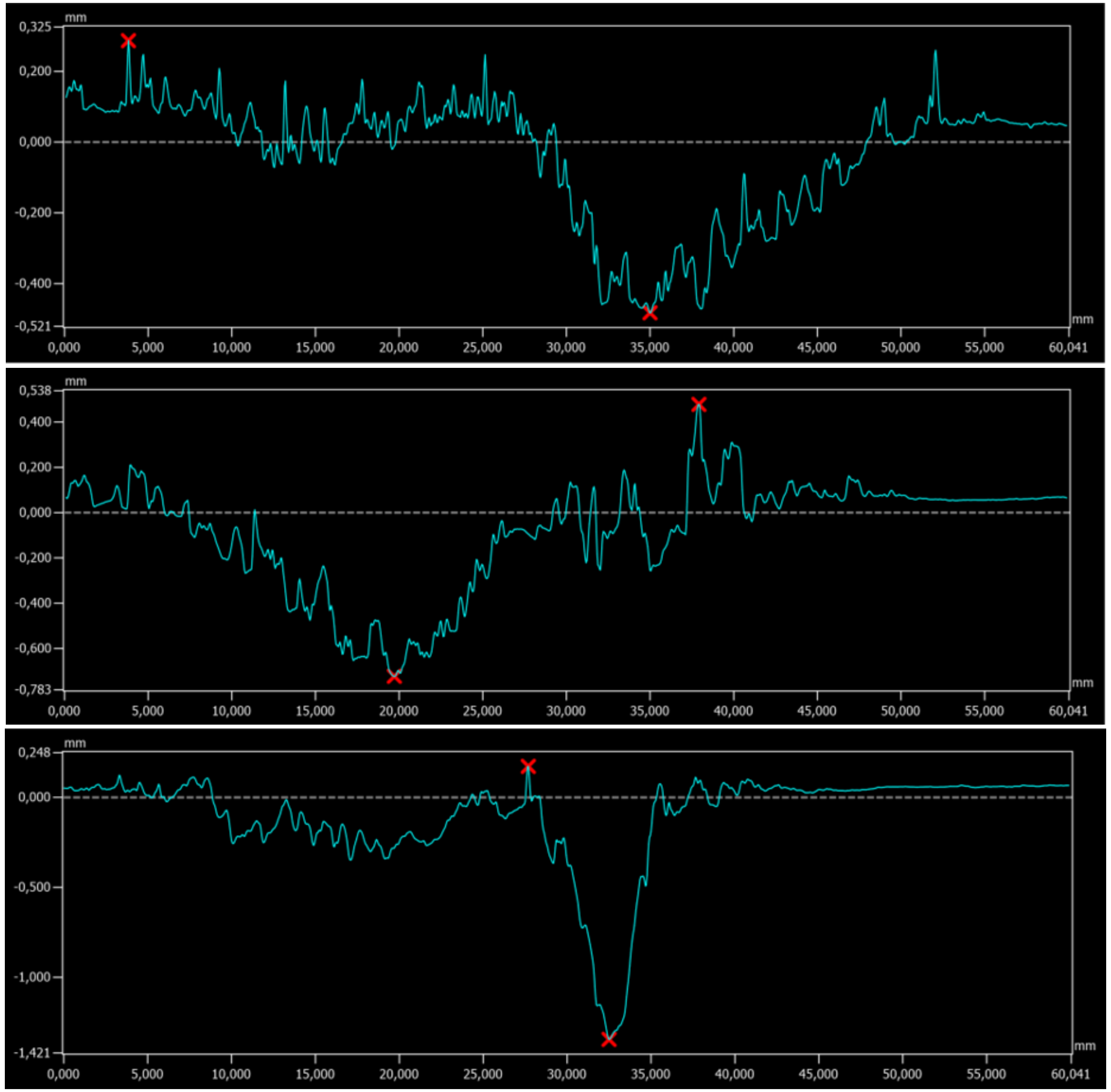


Significant material erosion in case of different SMC material

Characterisation of thermal runaway impact

comprarison of different SMC material
with similar base properties





Significant material erosion in case of different SMC material

Summary

- thermo-mechanical cell behaviour relevant before and up to internal short circuit
- once internal short circuit has happened and thermal runaway is caused, interaction between cell and its surroundings needs to be considered

- FEM model of cell should represent casing and jelly separately
- cell casing features important, safety relevant functions
- pouch foils exhibit temperature and strain rate dependent mechanical behaviour

- vent gas during thermal runaway causes high heat impact in addition with erosion due to emitted particles
- SMC is able to sustain thermal runaway – without significant decrease in mechanical performance
- material erosion varies depending on actual material selection

YouTube CHANNEL

MATERIAL cards

VALIMAT

IMPETUS

4advanced Customer Orientation

4advanced Leadership in Technologies

4advanced Motivated & Professional Team

4advanced High Quality Outcome & Success