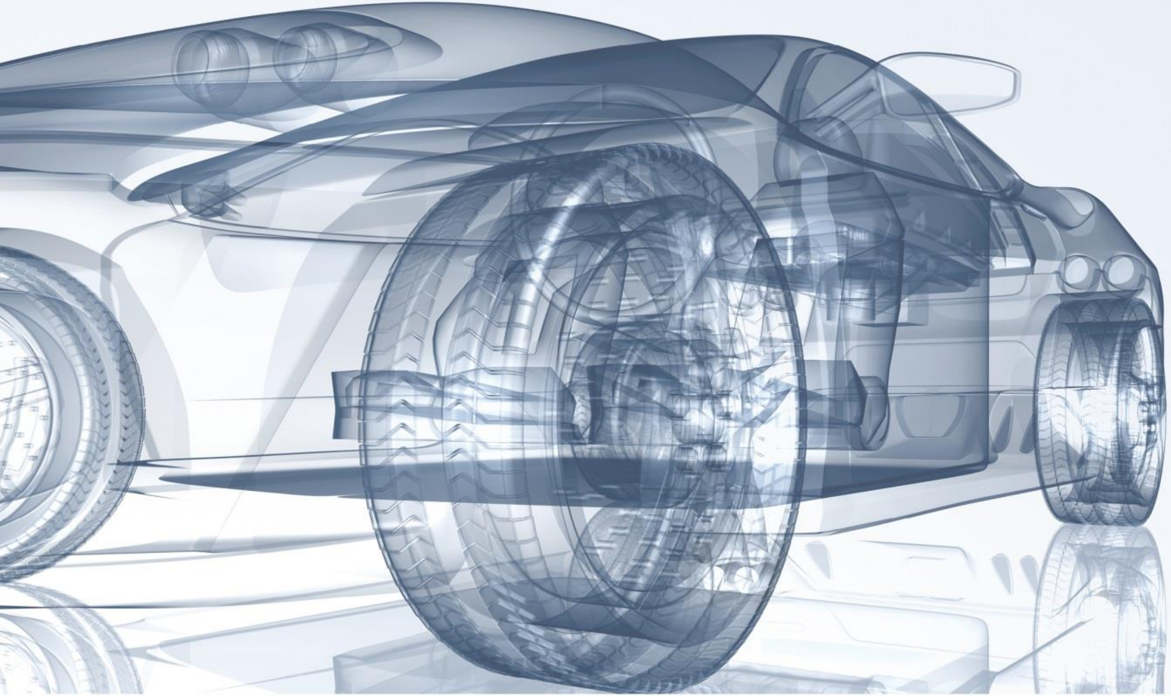
evs 30



The 30th International Electric Vehicle Symposium & Exhibition

October 9–11, 2017

Messe Stuttgart, Germany

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Simon Franz Heindl

Introducing an approach to predict the time-dependent mechanical, electrical and thermal behaviour of Li-ion batteries due to crash loads

Stuttgart, Germany
October 10, 2017

Agenda

- Motivation
- Key research question
- Approach
- Virtual safety assessment
- Conclusion

Motivation

- Electric vehicles are <u>as safe as</u> vehicles with conventional (gas, diesel) drive!?


Source: abcnews.go.com


Source: money.cnn.com

Source: dailytech.com

Motivation

- EV/xHEV earn excellent crash test ratings
- EV/xHEV show a similar standard of safety as conventional drive vehicles*
- All vehicles have to pass crash tests independent of their source of energy

*http://www.dekra-elektromobilitaet.de/de/sicherheit
https://www.adac.de/infotestrat/tests/crash-test/elektroauto/

Crash test ratings for (hybrid) electric vehicles

Marke & Modell	Gesamtbewertung					
Lexus NX	2014	★★★★★	82%	82%	69%	71%
Tesla Model S	2014	★★★★★	82%	77%	66%	71%
Audi A3 Sportback e-tron	2014	★★★★★	82%	78%	66%	68%
Kia Soul EV	2014					
Nissan e-NV200 Evalia	2014					

2013 - Bewertungen

Marke & Modell	Gesamt
Lexus IS	2013
Mitsubishi Outlander PHEV	2013
Renault ZOE	2013
BMW i3	2013

Source: euroncap.com

Marke & Modell	Sicherheitsausrüstung	Gesamtbewertung				
Toyota C-HR	Standard	★★★★★	95%	77%	76%	78%

2016 - Bewertungen → ÜBER 2016 BEWERTUNGEN

Marke & Modell	Sicherheitsausrüstung	Gesamtbewertung				
Toyota Prius	Standard	★★★★★	92%	82%	77%	85%
Hyundai Ioniq	Standard	★★★★★	91%	80%	70%	82%
Kia Niro	Standard	★★★★☆	83%	80%	57%	59%

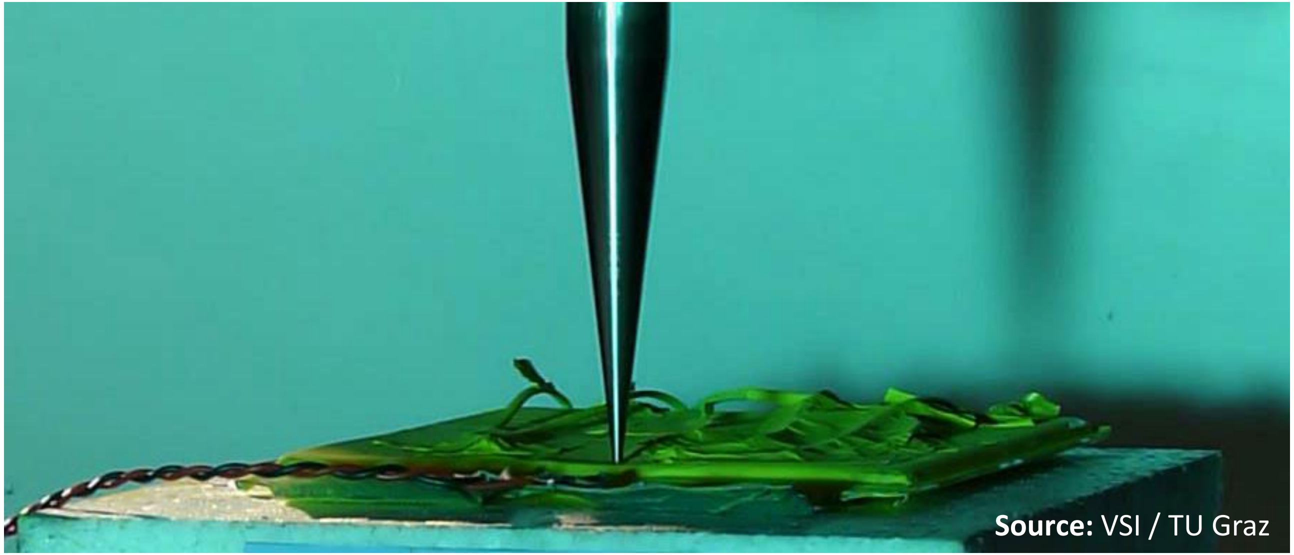
2015 - Bewertungen → ÜBER 2015 BEWERTUNGEN

Marke & Modell	Gesamtbewertung					
Lexus RX	2015	★★★★★	91%	82%	79%	77%

Source: euroncap.com

Motivation

When electric vehicles crash …



… what happens to the battery?

Motivation

- To avoid battery damage OEMs take precautions
  - Battery position outside of crumple zone
  - Protect battery by crash absorbers

Battery installed in the (safe) center of the car

Source: ecomento.com

- Disadvantages
  - Installation space ➔ design constraints
  - Energy density ➔ cruising range

- Extra effort for EV/xHEV to ensure safety level and competitive performance!

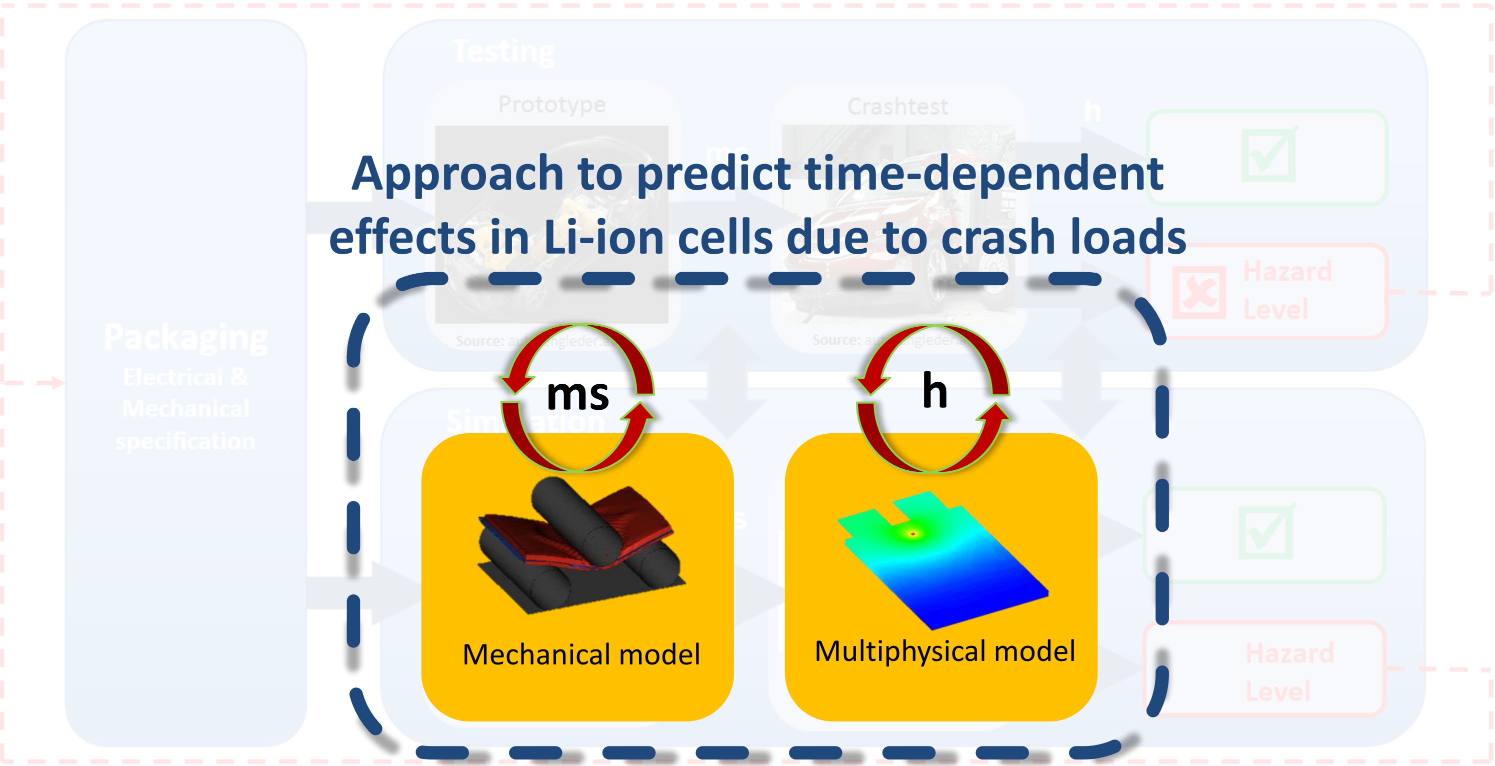
Key research question

- Vehicle safety topics for EV/xHEV
  - Effects of mechanical load on battery cells
  - Cell internal processes during short circuits
  - Hazard assessment methods (virtual and real)

Mistreatment of Li-ion cell with cone-shaped penetrator

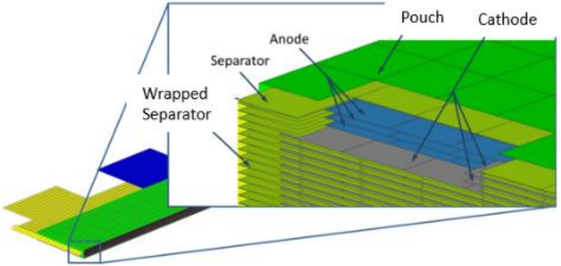
- Key research question
  - How to correlate mechanical loads and electrical-thermal reactions of the cell?

Approach


Approach to predict time-dependent effects in Li-ion cells due to crash loads
ms
h
Mechanical model
Multiphysical model

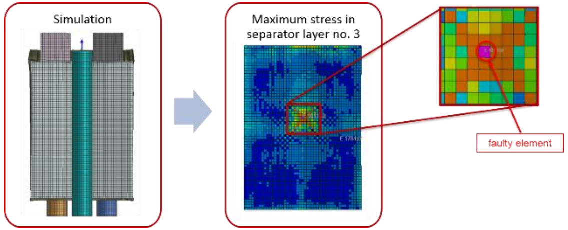
Approach

Micro-scale FE cell model



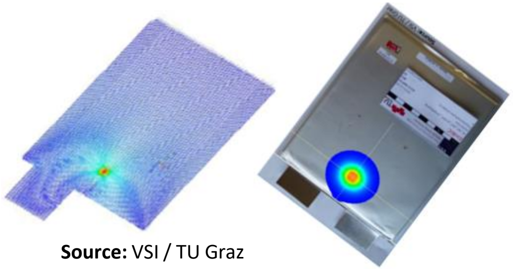
Source: VSI / TU Graz

Geometry interface tool



Source: VSI / TU Graz

Electrical-thermal simulation

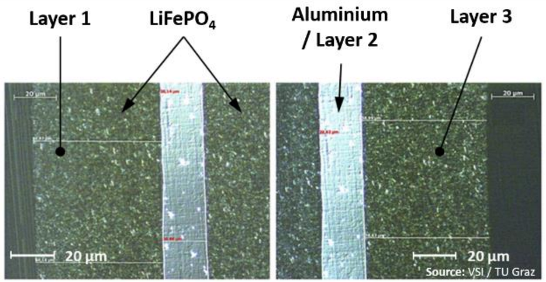


Source: VSI / TU Graz

Micro-scale FE cell model

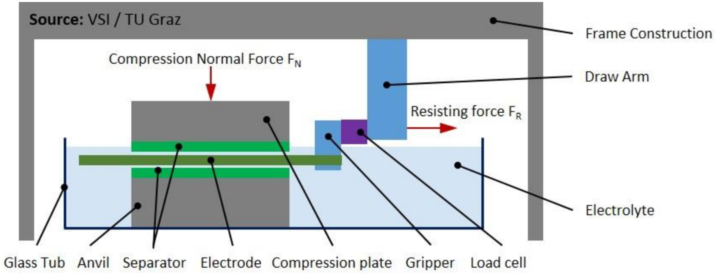
- Detailed FEA mesh showing every layer of the cell
- Material characterization tests
  - Tension / compression tests
  - Friction tests of components in wet electrolyte
  - Puncture penetration of separator material
- Model validation by quasi-static and dynamic tests

Determination or layer thickness



Source: VSI / TU Graz

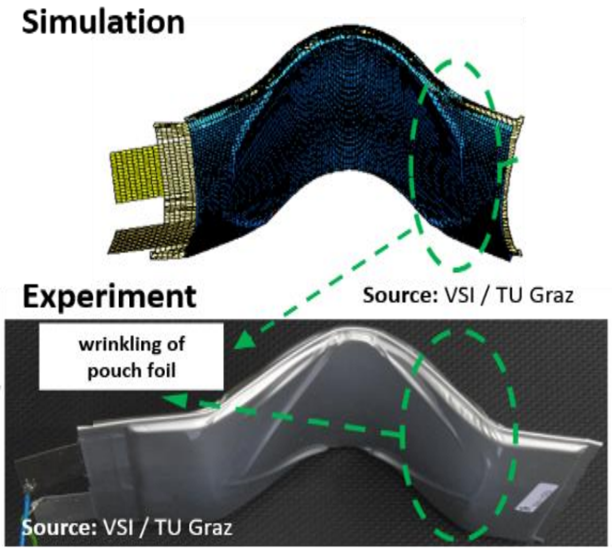
Friction test rig



Micro-scale FE cell model

- Mechanical load scenarios (quasi-static / dynamic)
  - 3-point-bending
  - Penetration / indentation
  - Folding / buckling
- Calculation of mechanical status of the cell
  - Stress, strain, …

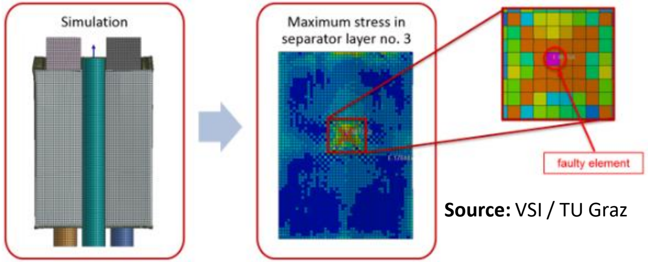
Comparison of experiment and mechanical simulation (3-point-bending load scenario)



Geometry interface tool

- Import mesh with mechanical status from PAM-CRASH
- Application of a mechanical failure criterion
  - Any algorithm can be implemented
  - Detection of separator damage
- Export mesh to AVL FIRE
  - Mesh translation from PAM-CRASH to AVL FIRE
  - Insertion of a “short circuit element”

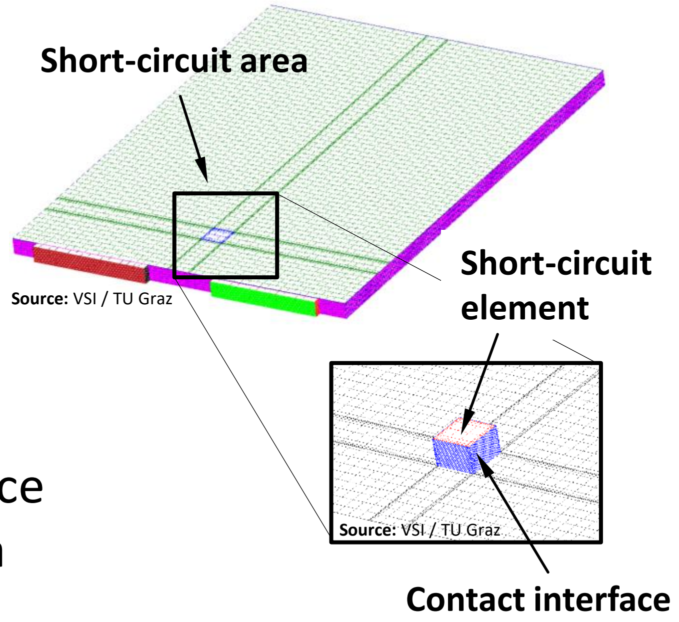
Mechanical failure criterion detects damaged region of the separator



Source: VSI / TU Graz

Electrical-thermal simulation

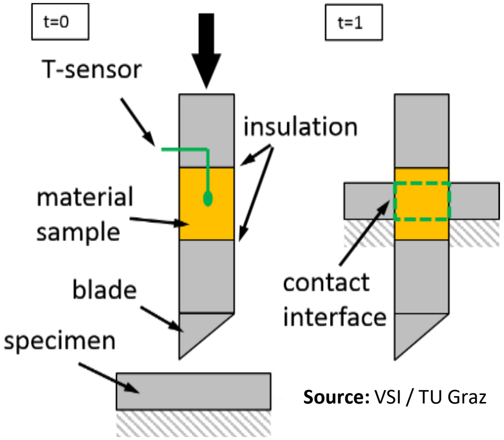
- Electro-thermal battery model in AVL FIRE® with an add-on short-circuit feature (short-circuit model)
- Separator failure in the mechanical model is converted to a "short-circuit area"
- Short-circuit effects controlled by an ohmic resistance at the interface between healthy and damaged area



Electrical-thermal simulation

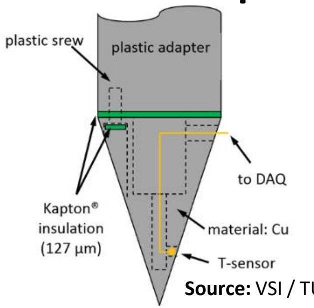
- Validation of the battery model
  - Material characterization (e.g. spec. heat capacity, …)
  - Relevant range of temperature and c-rate
- Special experiments to get short-circuit model parameters
  - High-temperature charge/discharge
  - Penetration tests “Smart-Cone” and “Smart-Stamp”

“Smart-Stamp” test principle



Source: VSI / TU Graz

“Smart-Cone” penetrator



Source: VSI / TU Graz

Electrical-thermal simulation

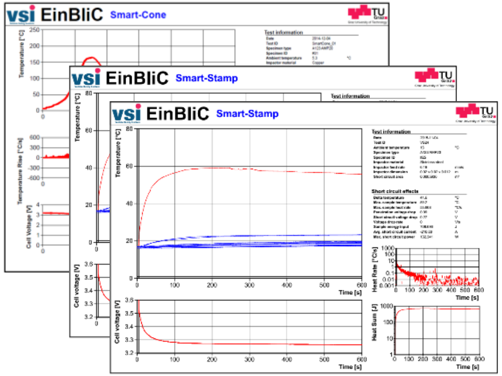
- Analysis of all experimental data
  - Influence of material pairing, geometry, …
  - Typical values for temperature rise, peaks, …

- Short-circuit model
  - Contact resistance is main model parameter
  - Normalization of quantities to surface area (e.g. W/mm²)
  - Simulation emulates typical heat release

$$\mathbf{P(t)} = \Delta P \cdot t \quad | \quad P < Pmax$$

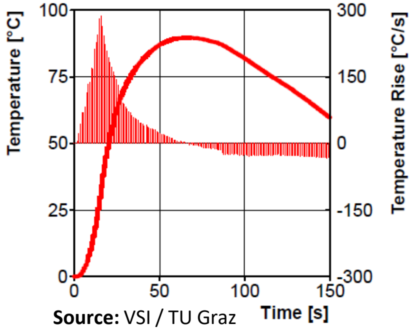
$$\mathbf{P(t)} = P_{max} \cdot e^{-\frac{t}{\tau}} \quad | \quad P \geq Pmax$$

Heat release during experiment



Source: VSI / TU Graz

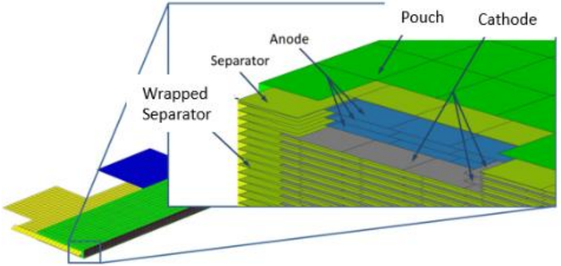
Typical shape of heat release curve



Source: VSI / TU Graz

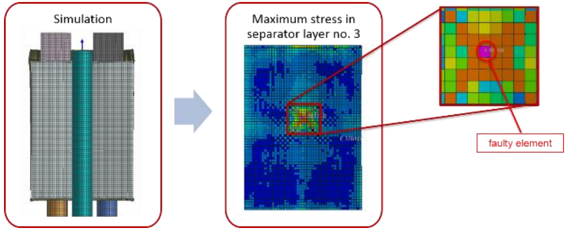
Approach

Micro-scale FE cell model



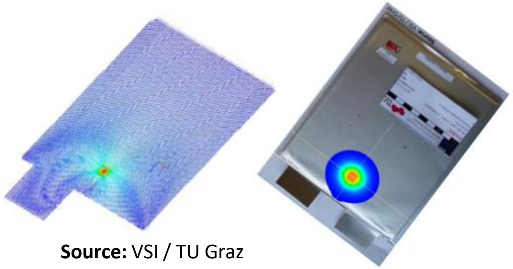
Source: VSI / TU Graz

Geometry interface tool



Source: VSI / TU Graz

Electrical-thermal simulation



Source: VSI / TU Graz

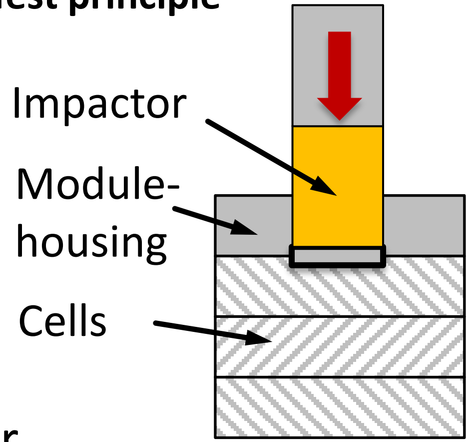
Proof-of-concept

- Hardware
  - Module (Alu) (3s1p)
  - Impactor (steel, 15x15mm)

- Mechanical failure criterion for separator
  - Equivalent stress

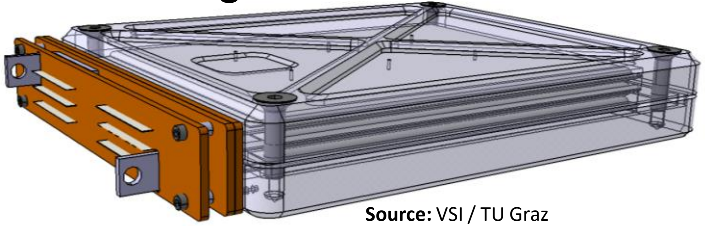
$$\sigma_{eq} = \sqrt{\left[\sigma_{11}^2 + \sigma_{22}^2 - \sigma_{11}\sigma_{22} + 3\sigma_{12}^2\right]} > \sigma_{sep\_break}$$

Test principle



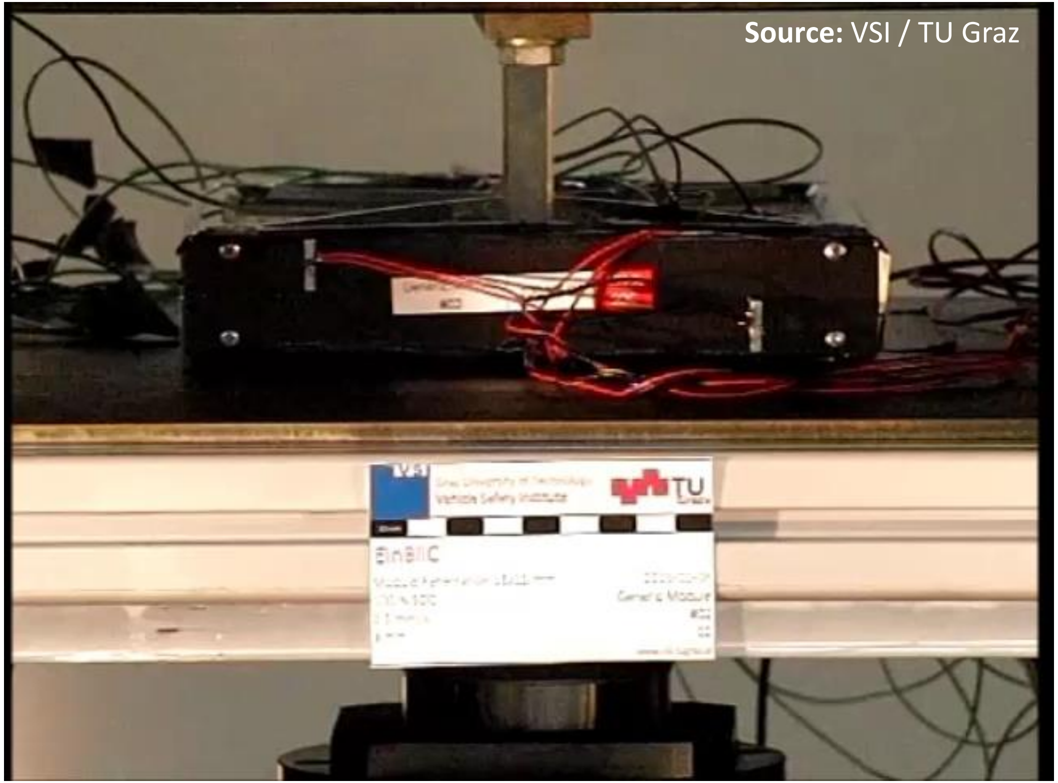
Experiment setup

CAD rendering



Source: VSI / TU Graz

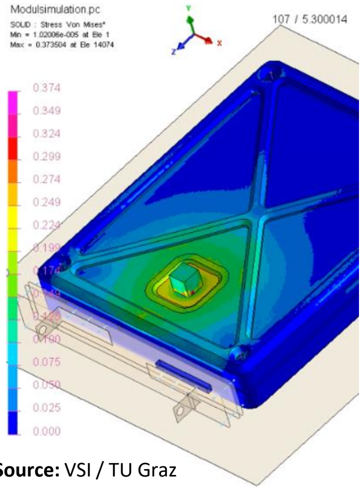
Proof-of-concept



Proof-of-concept

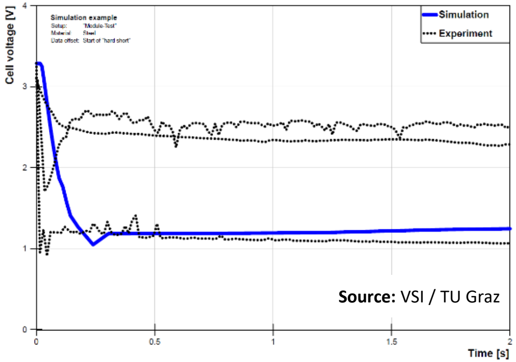
- PAM-CRASH calculates mechanical status
- Continuous check of failure criterion
- Separator failure ➔ Short-circuit mesh
- Short circuit simulation

Mechanical stress

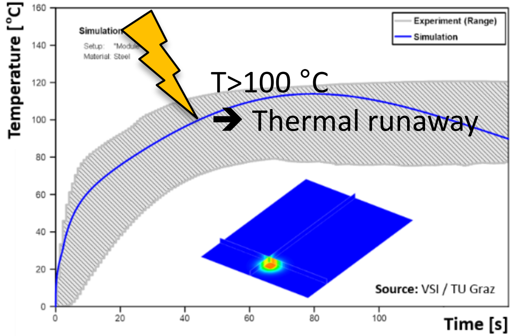


Source: VSI / TU Graz

Voltage drop



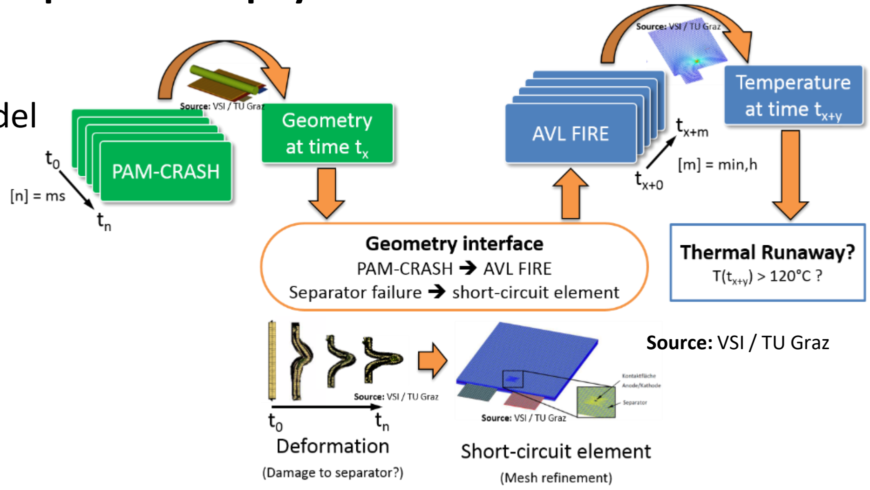
Temperature evolution



Conclusion

- Summary
  - Mechanical simulation of cell and module
  - Geometry interface with mechanical failure criterion
  - Electrical-thermal battery simulation + short-circuit model
- Fields of application
  - Estimate thermal runaway risk for a given load scenario
  - Predict the maximum allowable cell deformation
  - Assess design variants of battery cells, modules, packs
  - Assess thermal runaway avoidance and mitigation measures (e.g. cooling system)

Co-simulation of explicit FEA and implicit multi-physical solvers



➔ Our goal is to ensure safety of EES at a better level of energy density

Vehicle Safety Institute

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Related publications

„EinBliC“ project homepage. https://www2.ffg.at/verkehr/projekte.php?id=1115&lang=de&browse=programm

Breitfuß, C, et al. 2013. A ‘Microscopic’ Structural Mechanics FE Model of a Lithium-Ion Pouch Cell for Quasi-Static Load Cases. SAE international journal of passenger cars / Mechanical systems Volume 6. 2013, S. 1044-1054.

Feist, F, et al. 2013. Entwicklung eines mikroskopischen strukturmechanischen FE-Modells einer HV-Zelle fur den Crashlastfall. *VDI-Tagung Fahrzeugsicherheit.* 2013, S. 37-58.

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