Emanuele Michelini (Vehicle Safety Institute – TU Graz)

Wednesday, June 22, 2022

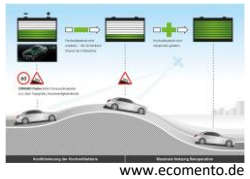
Mechanical and electrical test procedures to characterise the behaviour of lithium-ion batteries

Information Day Battery Simulation 2022, Stuttgart

Motivation

Ambient temperature

www.123rf.com



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Driving/recuperation

Calendric ageing

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Charging

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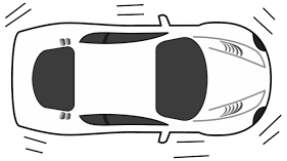
Shock events



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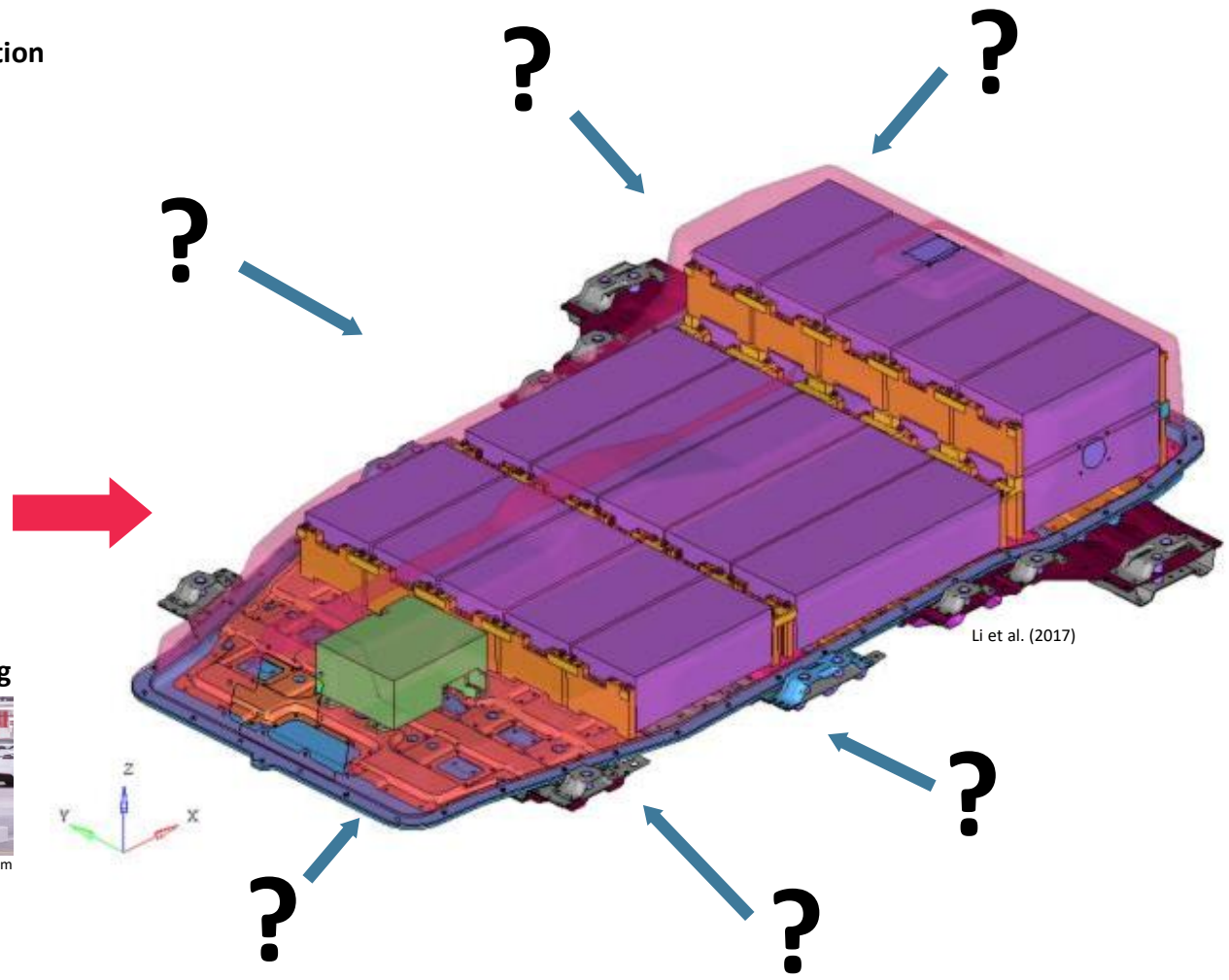
Road induced vibrations



Li et al. (2017)

Li, G., Fu, X., & Yang, Y. (2017). Anti-vibration safety performance research of battery pack based on finite element method in electric vehicle. 2017 36th Chinese Control Conference (CCC), 10281-10285.

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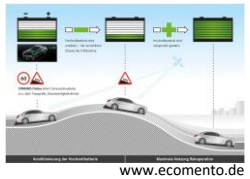

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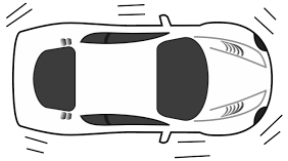

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Road induced vibrations

- Reduction of factors involved ➔ laboratory controlled environment
- Once the parameter to be measured and under which boundary conditions and loading has been identified, the test can be designed

- For simulation experiments is crucial:
  - Identify an appropriate measurement set-up (i.e. testbed)
  - Identify a mode of measurement of physical quantities for the determination of simulation parameters (i.e. sensors)
  - After testing, correctly interpret the results obtained

Experiments

- Challenges of test design:
  - Reproducibility of test design
  - Precise measurement and setting of loadings
  - Possibility of measuring several physical quantities simultaneously
  - High accuracy and sampling rate of sensors and measuring devices

- Different factors influence battery behavior:
  - Thermal ➔ Thermal tests
  - Electrical ➔ Electrical tests
  - Mechanical ➔ Mechanical tests

SafeLIB

CONDITIONING

THERMAL TEST

BATTERY-CONCEPT

ELECTRIC TEST

BEYOND STATE-OF-THE-ART
test bench technology

BSCG

BATTERY SAFETY CENTER GRAZ

- CALIBRATION
- VALIDATION

MECHANICAL TEST

DISASSEMBLING

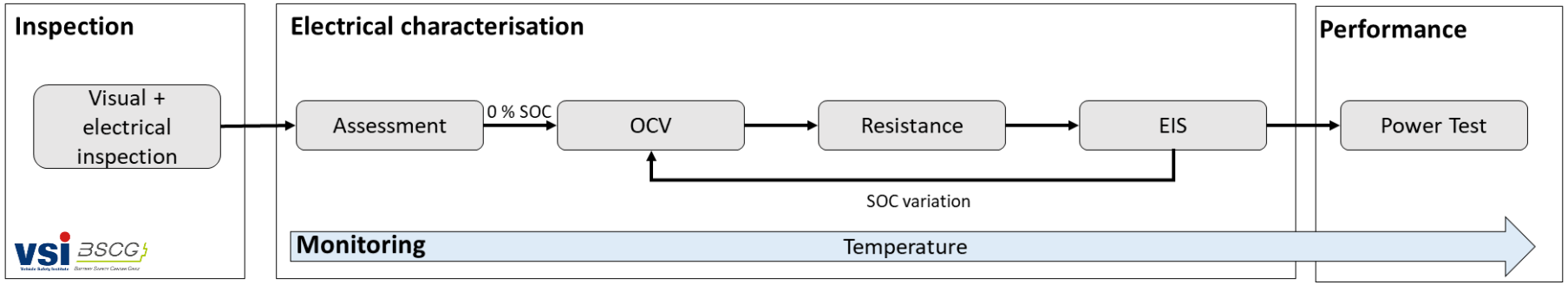
VSI

VEHICLE SAFETY INSTITUTE, GRAZ UNIVERSITY OF TECHNOLOGY, IN KOOPERATION MIT AVL LIST GMBH

AVL

Electric tests

- Electrical quantities are the loadings that are controlled
- The two quantities that are controlled by appropriate sensors are current and voltage
- Exemplary approach



- Multi-step test protocol ➔ a programmable cycling station is used

Determination of characteristic battery data:

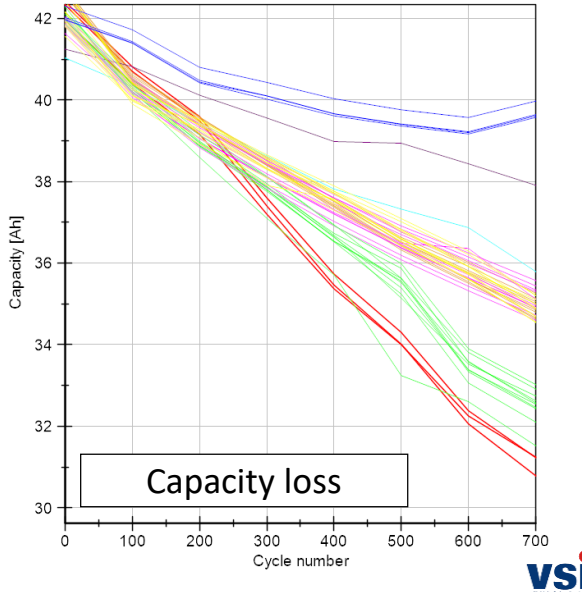
- Capacitance determination
- Open Circuit Voltage (OCV) curves
- Internal resistance determination
- Electrochemical Impedance Spectroscopy (EIS)
- Classification of battery performance and safety

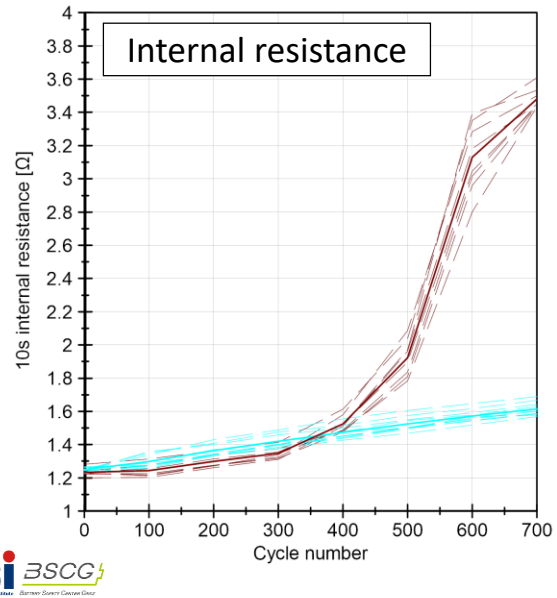
Electric test

- Which parameters to measure?

It depends

- For example: capacity loss and internal resistance increase can be used to validate electrochemical models of cell ageing



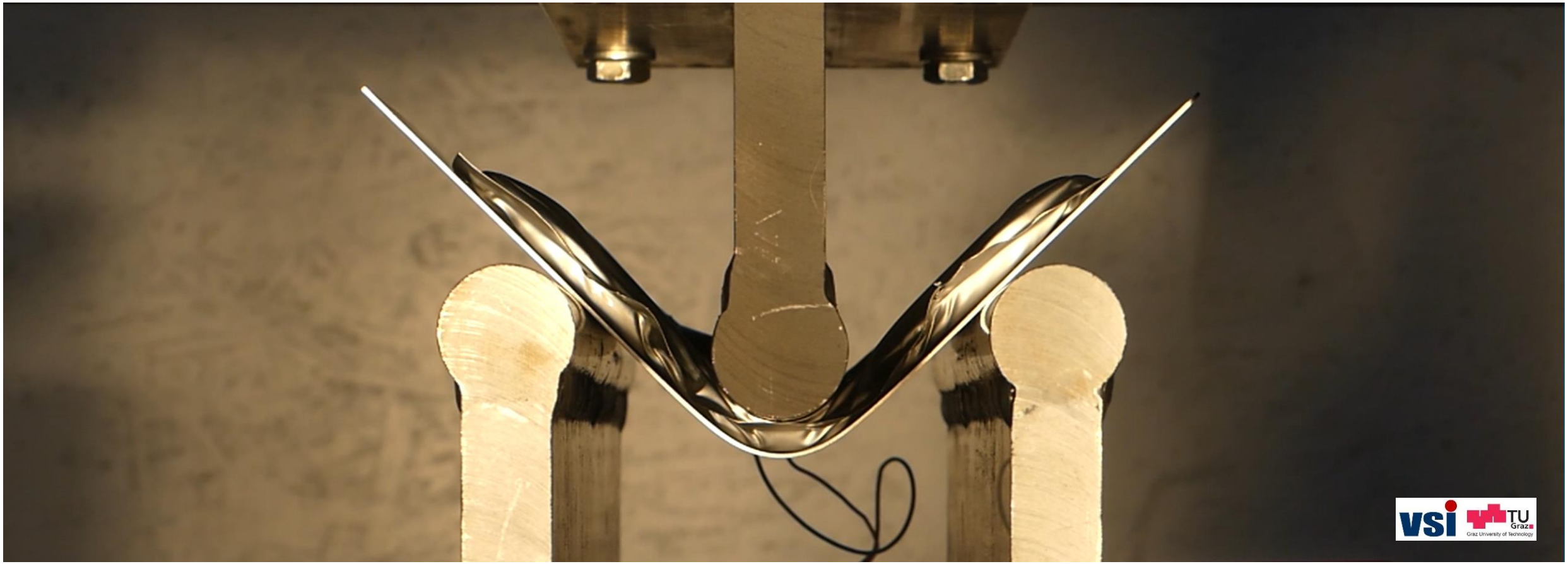


Mechanical test

- Mechanical quantities are the loadings that are controlled
- Examples of quantities that are monitored during testing are force, displacement, velocity, pressure

- Mechanical tests:
  - Various types of mechanical tests (e.g. compression, bending, indentation)
  - With impactor with different size and geometries (e.g. spherical, cylindrical, nail)
  - At different speed (quasi-static, dynamic)

Quasi-static mechanical test (Three-points bending)



Quasi-static mechanical test (Transverse compression)

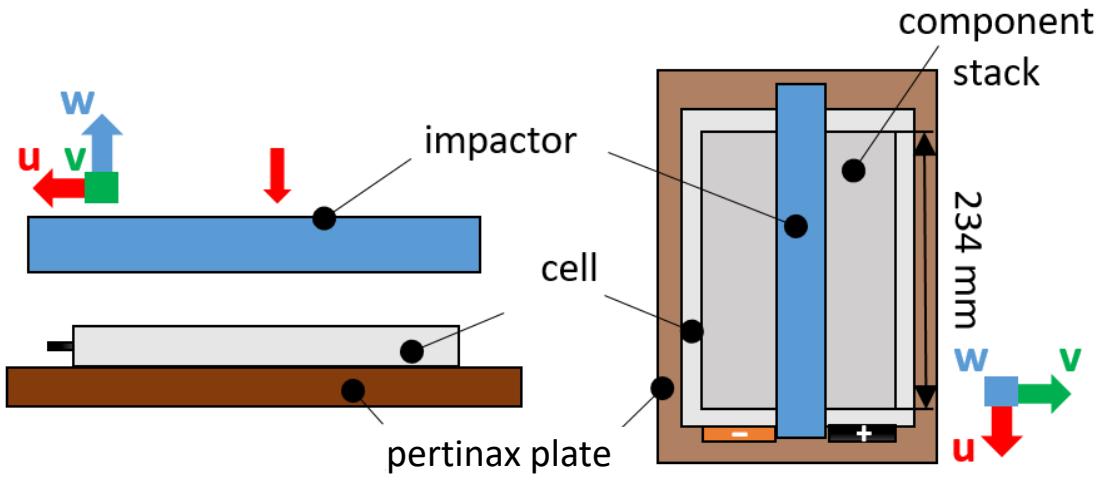
Quasi-static mechanical test

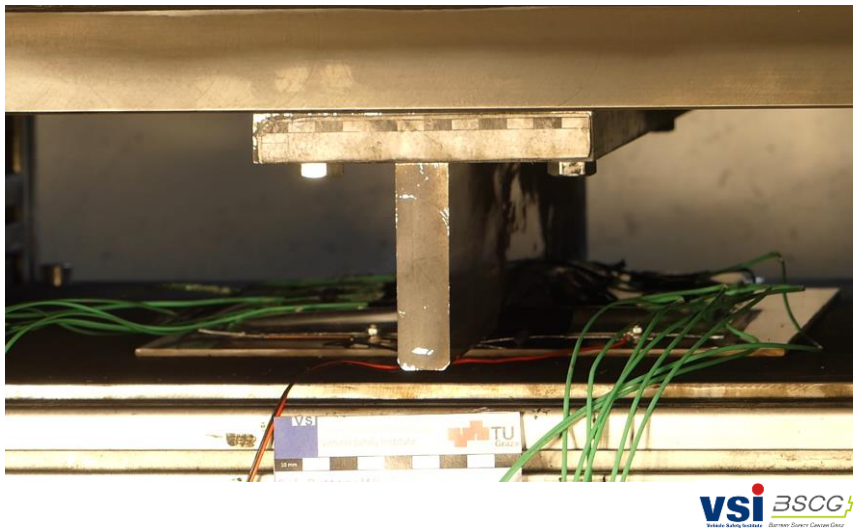
Exemplary approach:

- Indentation tests with rectangular impactor on fresh and aged cells

Comparison of:

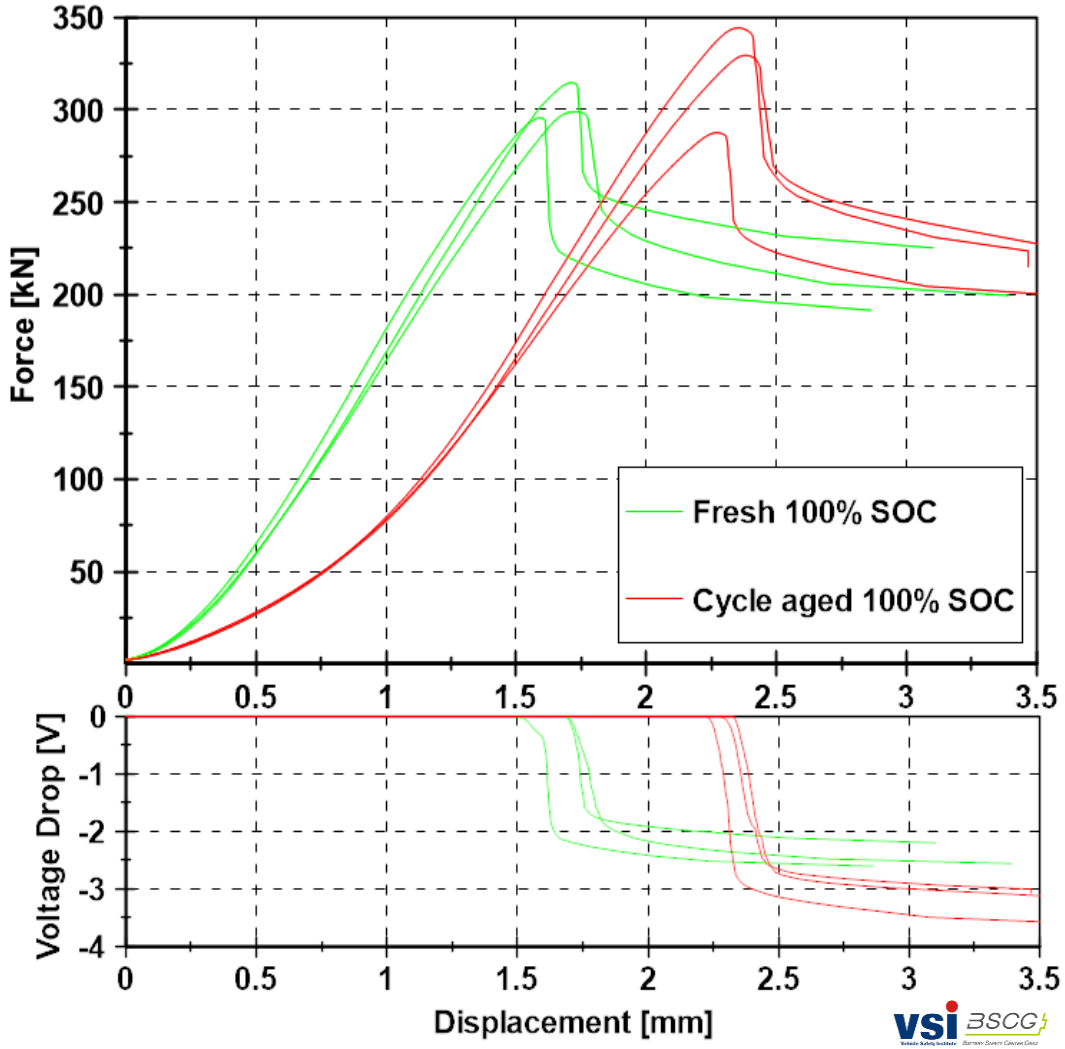
- Failure deformation
- Force increase
- Comparison of f-s curve
- Voltage drop





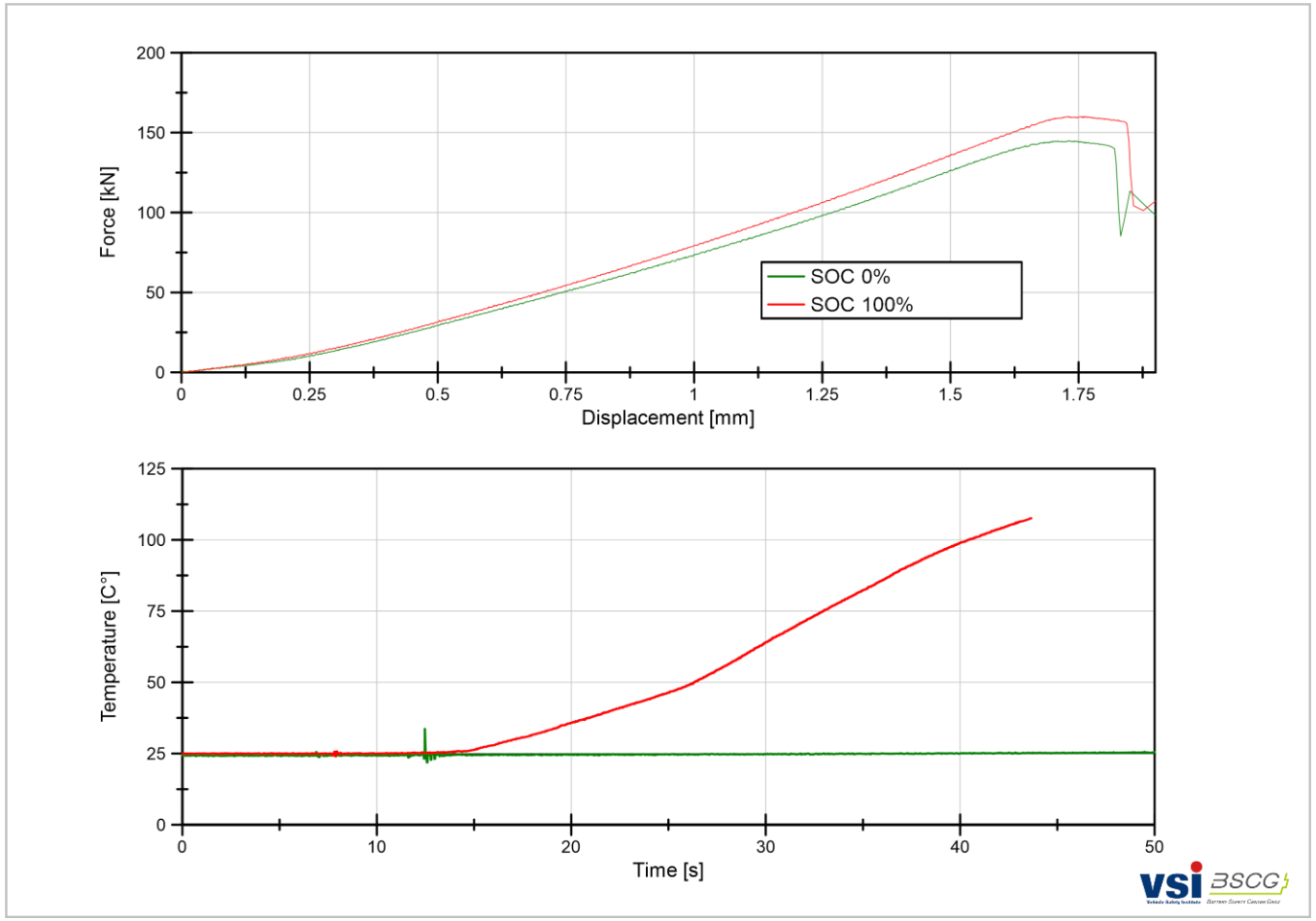
Quasi-static mechanical test

- Exemplary approach results aged compared to fresh:
  - Failure at higher deformations
  - Slight increase in average force at failure
  - Significant difference in onset of f-s curve
  - Deeper voltage drop



Quasi-static mechanical test

- Exemplary approach:
  - Indentation tests with cylindrical impactor on cell at different SOC
- Comparison of:
  - Failure deformation
  - Force increase
  - Comparison of thermal behaviour
- Results:
  - Failure for the fully charged cell required higher force and higher displacement
  - The fully charged cell goes into thermal runaway resulting in a high temperature increase



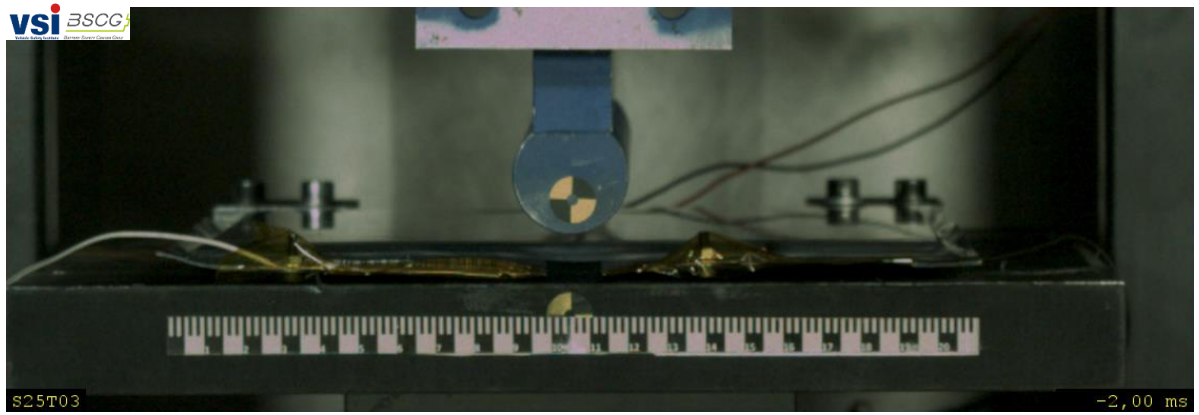
Dynamic mechanical test

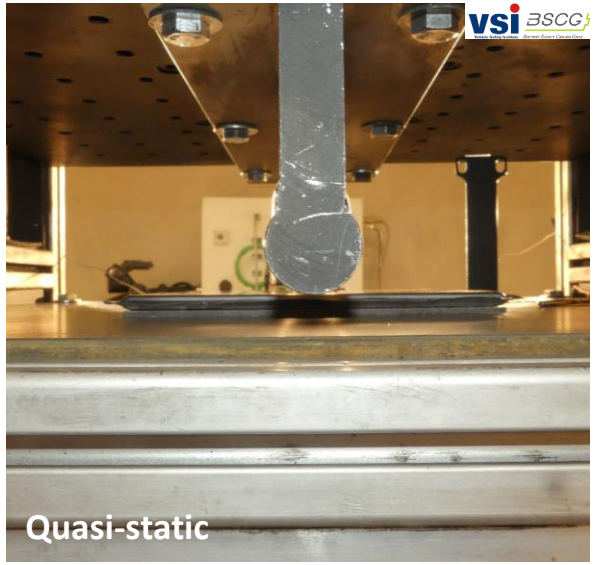
- Dynamic tests are close to the real behaviour of an automotive battery

Facts:

- Sled velocity: up to **30 m/s** (with 70 kg)
- (Sled deceleration: up to **300 g in 15 ms**)
- High-speed videos: more than **1000 fps HD**
- Precise testing and reproducibility due to guided sled

- Exemplary approach:
  - Quasi-static (1 mm/s) and dynamic (3000 mm/s) indentation tests with cylindrical impactor

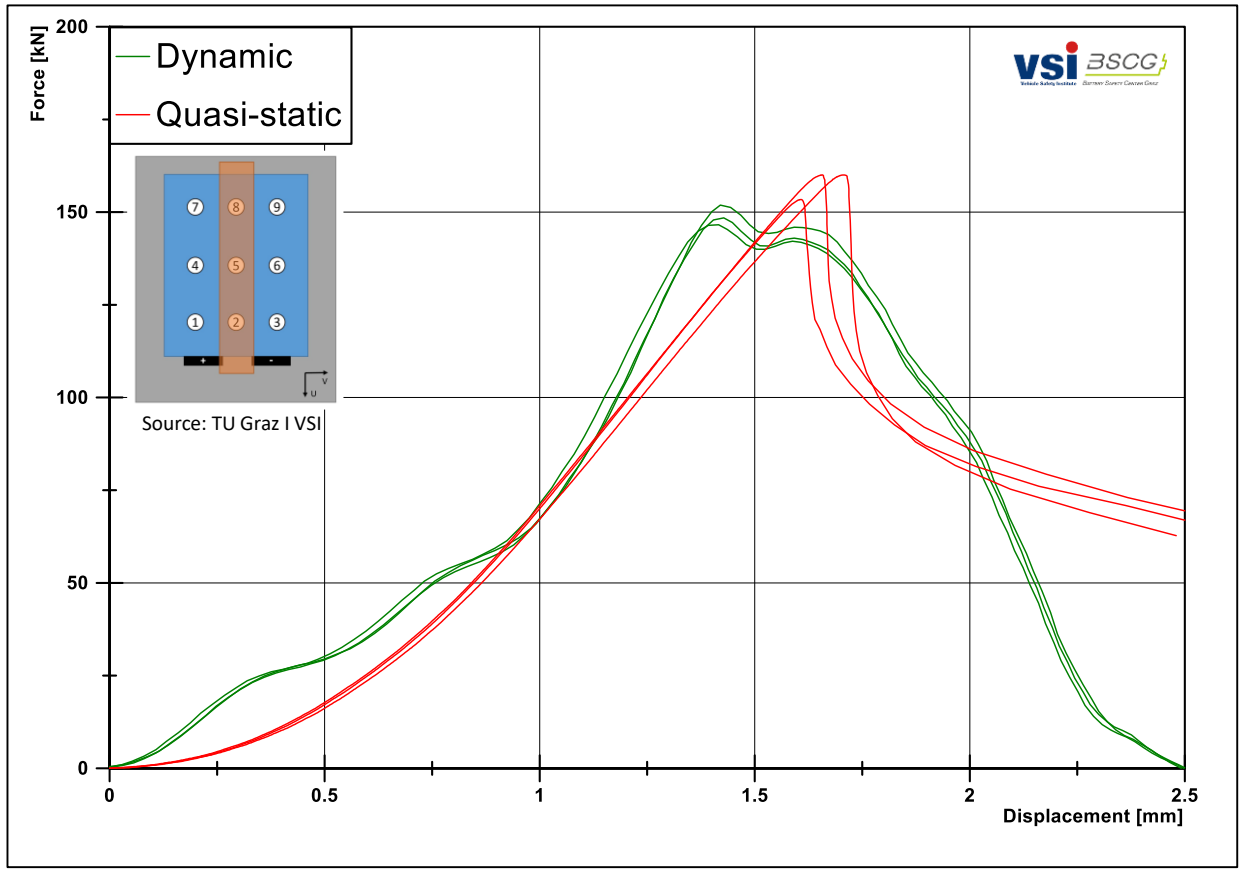




Results: Dynamic vs. Quasi static testing

- Comparison of:
  - Failure deformation
  - Force increase

- Exemplary approach results dynamic compared to quasi-static:
  - Lower peak force
  - Lower failure displacement



Summary & Conclusion

- Many different boundary conditions and loadings change the battery behavior

➔ In the laboratory, boundary conditions and loadings can be controlled and monitored

- Depending on the simulation parameter required, different types of test can be performed:
  - Thermal tests
  - Electric tests
  - Mechanical tests

- Further information can be gathered from post-mortem analysis or disassembly of cells not subjected to critical loadings

- Advanced test results are used for model validation (FEM, multi-physics, etc.) or calibration

Contact information

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Funding

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