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Analysis of the Mechanical Behaviour of Aged Li-Ion Batteries in Different Loading Conditions

21st AABC 2021, San Diego

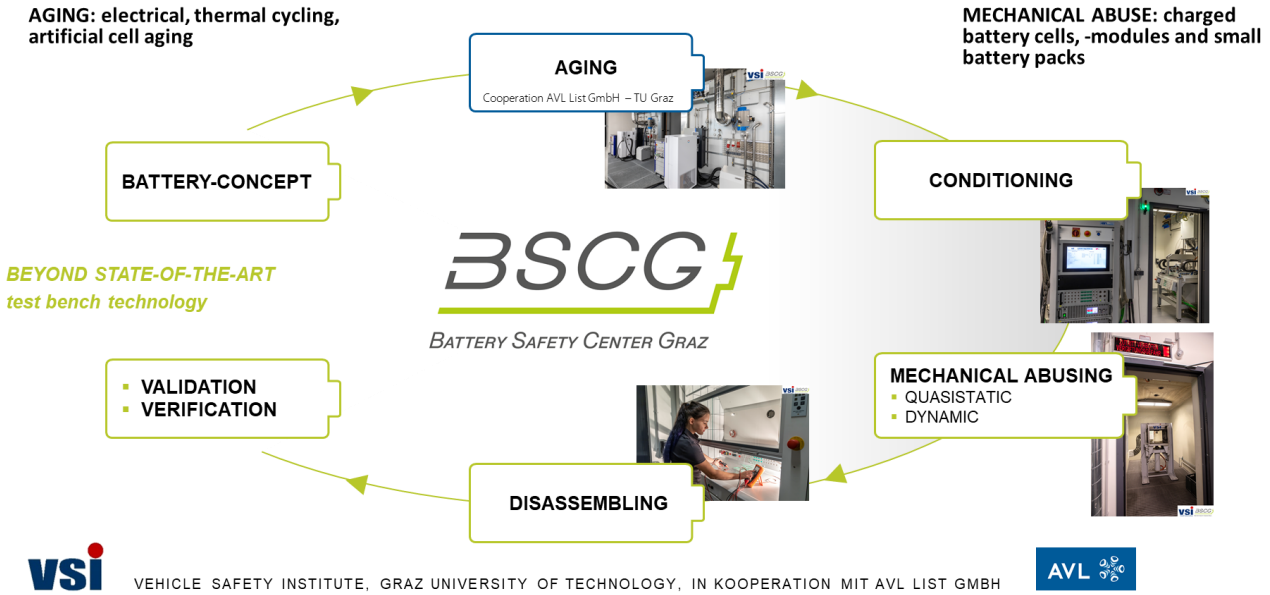
VSI, TU Graz

- Long term experience with testing and modelling of LIBs in mechanical abuse conditions
- New test lab (www.bscg.at) startet with 01/2021

- 1 recent and 1 ongoing international research project deal with influence of degradation effects on LIB properties

- SafeBattery – 2017-2021
- SafeLIB – 2021-2025
  - Modelling of LIB under crash loads
  - Ageing effects
  - Qualification of LIB for safe 2nd life applications

- Partners
  - OEMs: DAIMLER, PORSCHE, AUDI
  - SUPPLIERS: AVL, BOSCH, INFINEON
  - Further national Partners

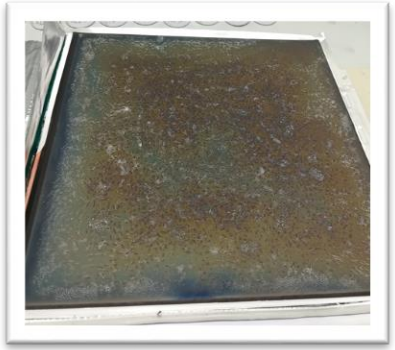


Goals

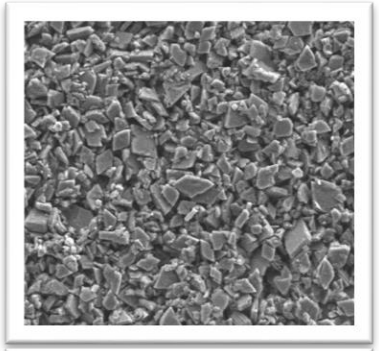
- To answer the following research questions:
  - Do electrically aged batteries experience **changes** to their **mechanical properties** and **safety behavior** under mechanical loadings?
  - Do aged cells experience a **change** in their **thermal runaway** behavior?

- Additional questions for in-depth analysis:
  - What are the **reasons** for the possible **changed behavior** (e.g. growth of additional layers, corrosion of current collectors)?
  - Which **degradation** mechanism/ degradation condition has the most severe **influence** on the **mechanical properties** of the batteries?

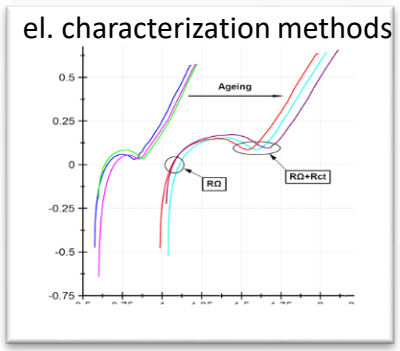
Visual inspection

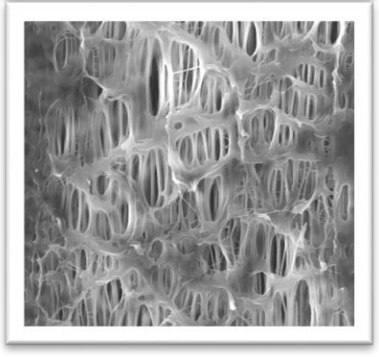


Microscopic imaging

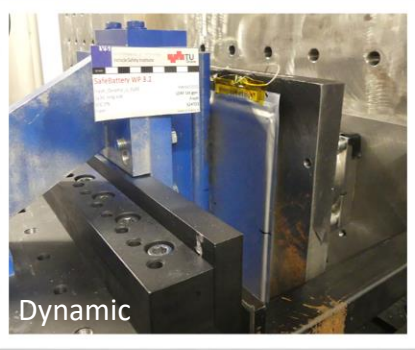


el. characterization methods

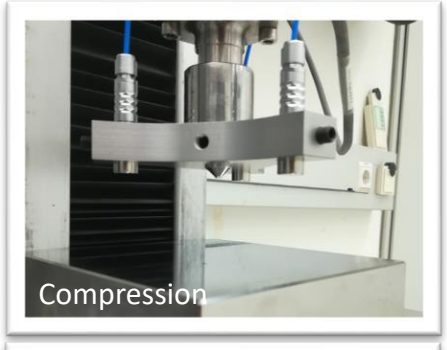


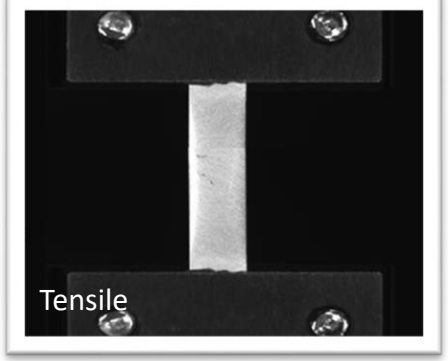


Cell level



Component level

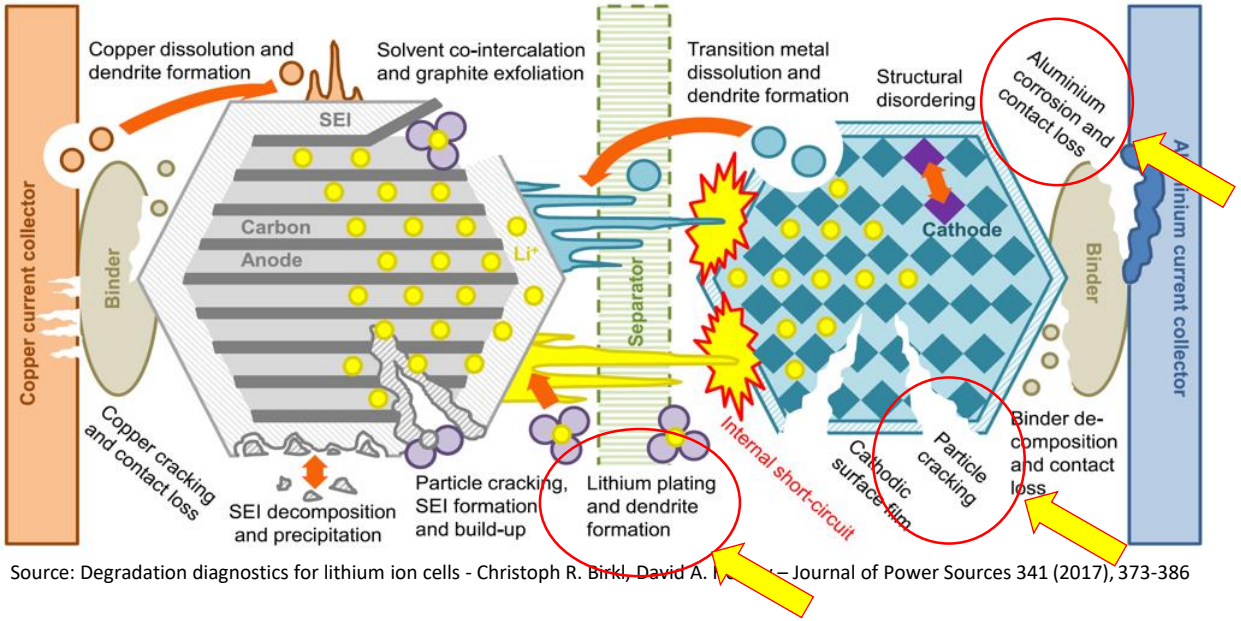




Degradation mechanisms and approach

- Many degradation effects described in literature (focus capacity fade, chemical stability, …)
  - Some are eligible for influence on mechanical properties

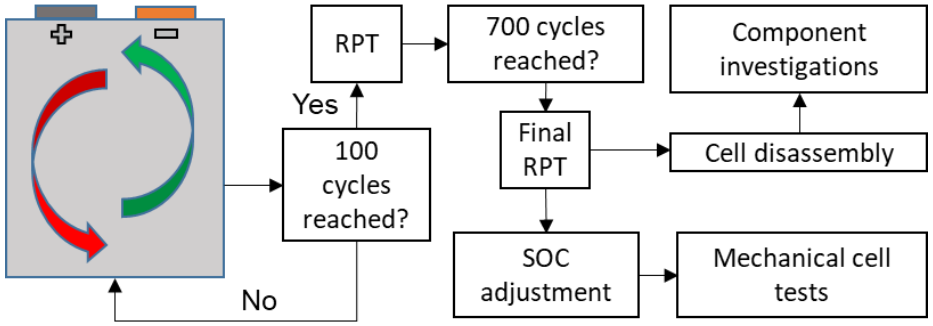
- Influencing factors
  - Temperature
  - SOC-Interval
  - C-Rate
  - Pretension



Source: Degradation diagnostics for lithium ion cells - Christoph R. Birkl, David A. [illegible] – Journal of Power Sources 341 (2017), 373-386

- Approach:
  - Analysis of current SoA commercial LIB
  - 41Ah, Pouch, NMC-LMO

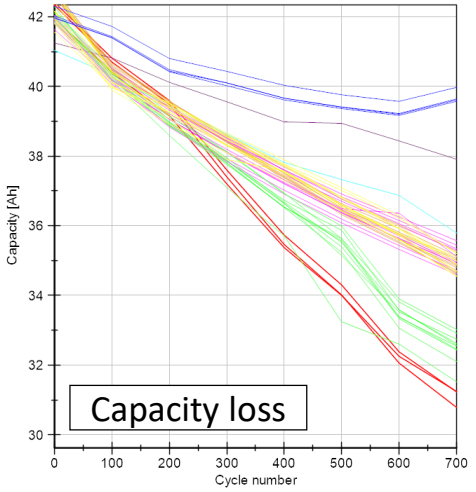
  - Artificial ageing of fresh cells to trigger degretation mechanisms
  - Comparison with fresh cells

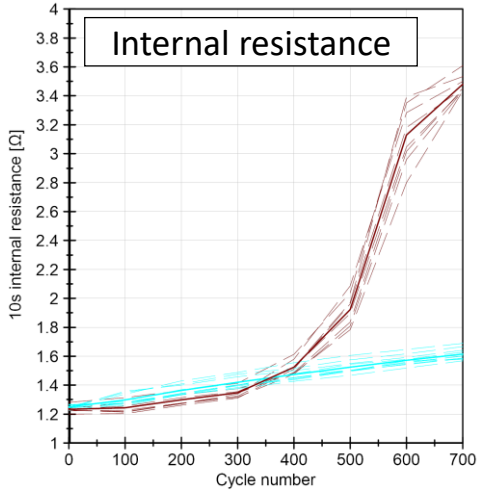


→8 differently aged groups of cells

→approx. 6-10 samples each

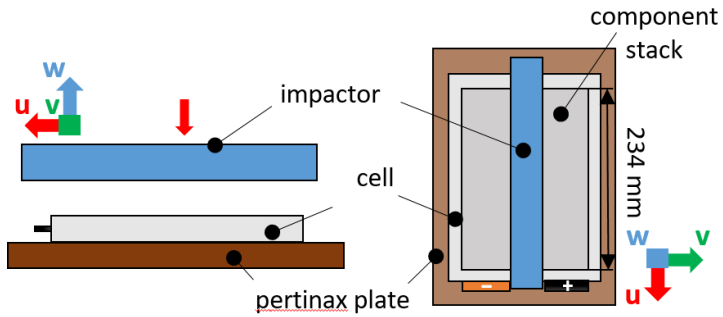
- Electrical Characterization (examples):

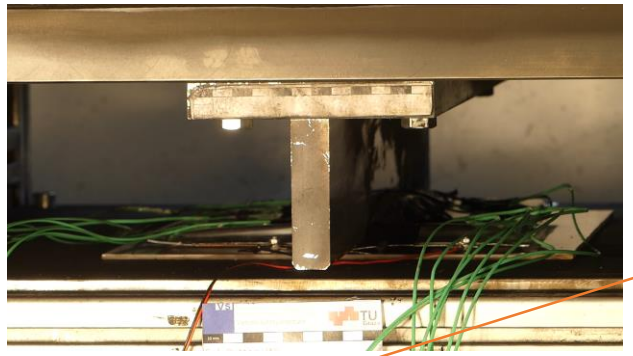




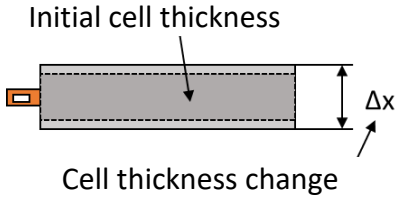
Results: Mechanical abuse testing - quasistatic

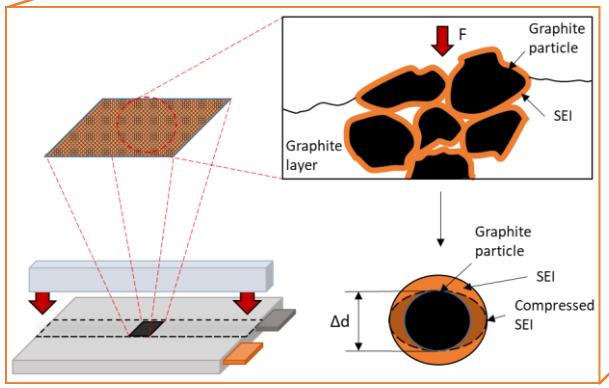
- Indentation tests with cylindrical impactor

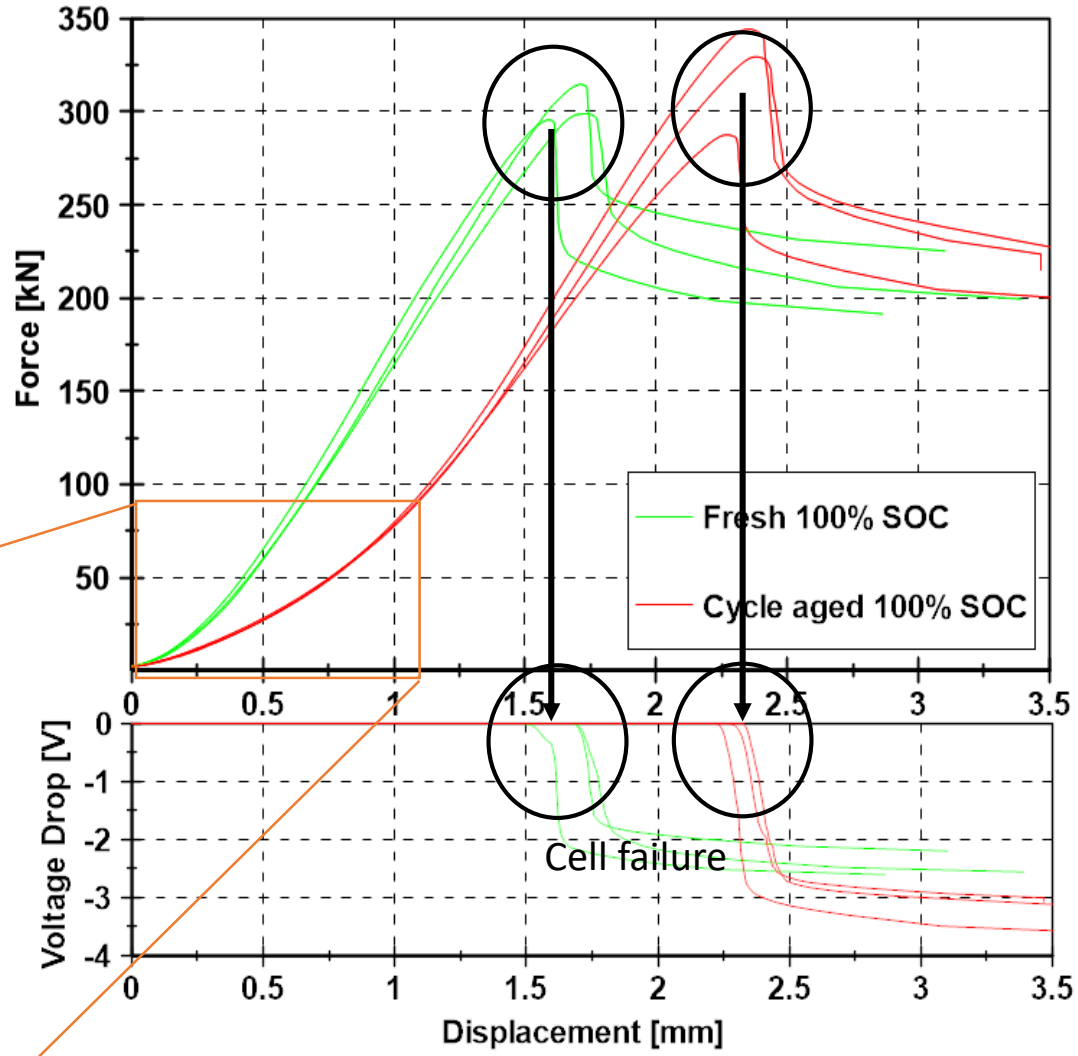




- Observed differences
  - Failure at higher deformations
  - Slight increase in average force at failure
  - Deeper voltage drop
  - Significant difference in onset of f-s curve

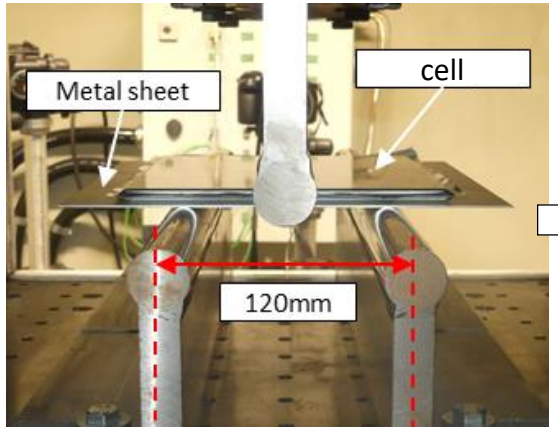


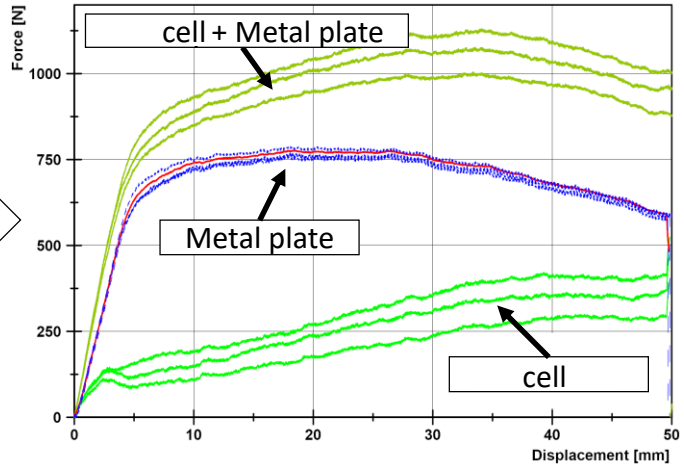


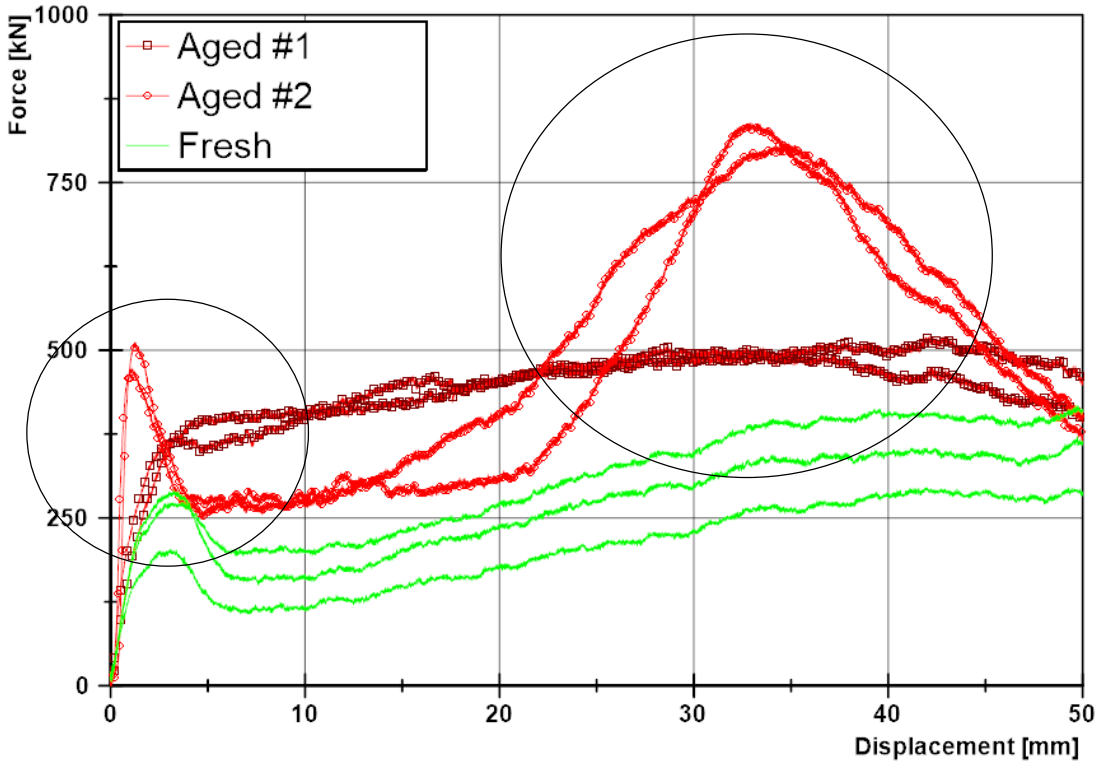


Results: Mechanical abuse testing - quasistatic

- 3-point bending test

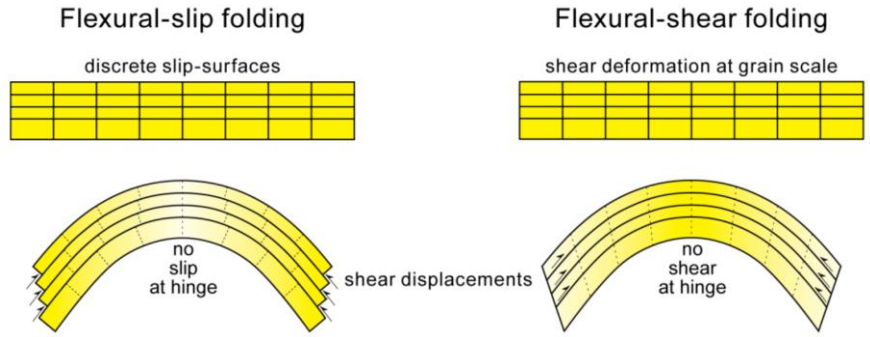






- Observed differences
  - Generally higher force level for aged cells
  - More/less pronounced discountinous f-s curve

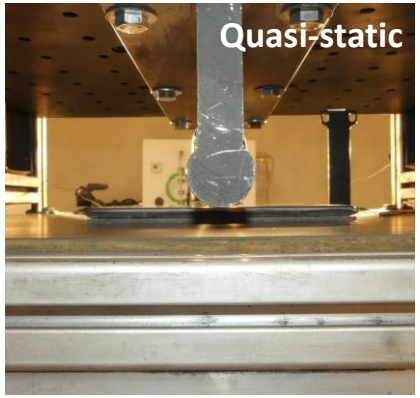
- Possible reasons for different behaviour
  - General increase of cell thickness due to swelling
  - Different interfacial behaviour between single layers
    - Ageing effects of the active material of anode and cathode
    - Binder ageing and cracking of the graphite surface
    - Binder ageing and cracking of the cathode AM particles
    - Electrolyte consumption during ageing

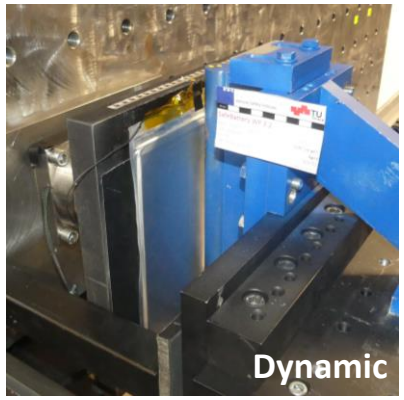


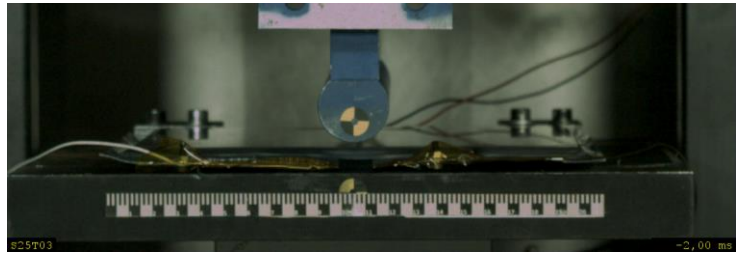
Source: Jean-Pierre Burg, ETH Zürich, Lecture Folding

Results: Dynamic vs. Quasistatic testing

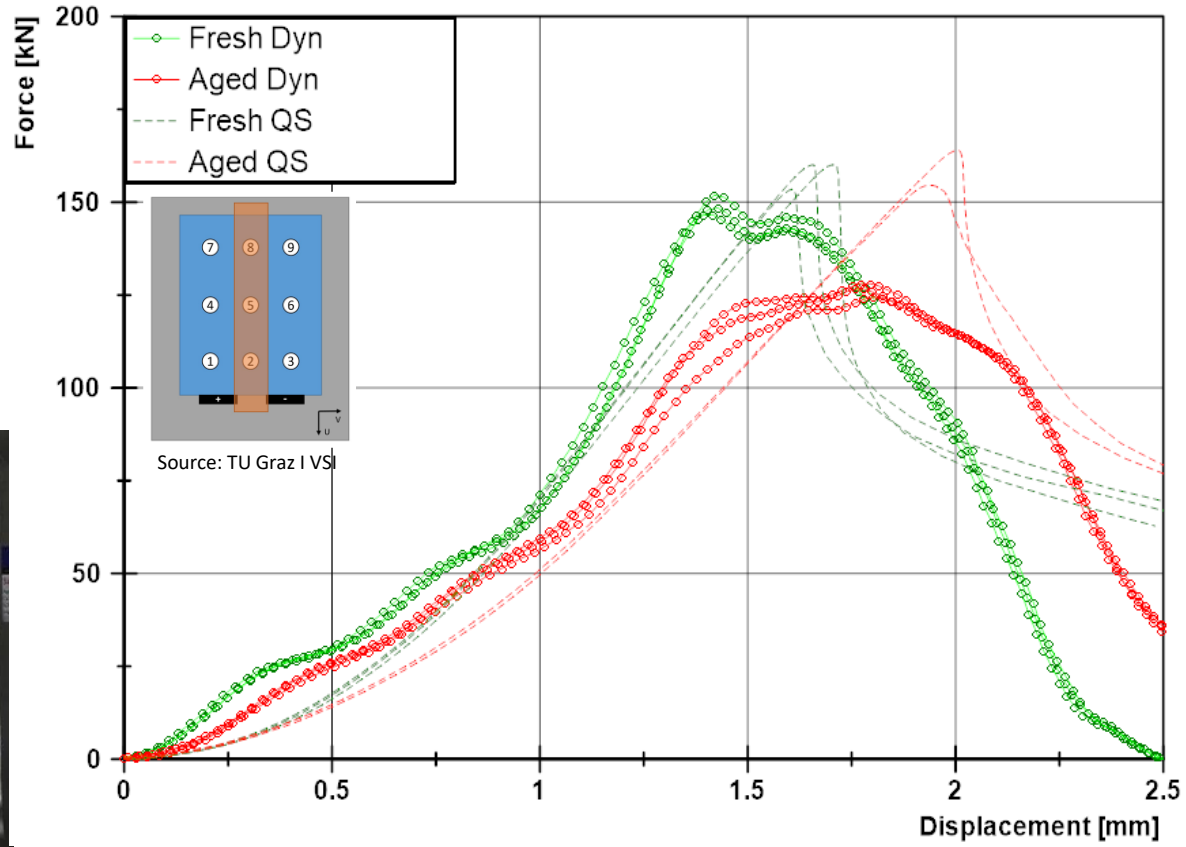
- Indentation test
  - Cylindrical impactor (Ø30mm)
  - v_1=1mm/s
  - v_2=3000mm/s







- Behavior of aged cells during dynamic loading:
  - Softer mechanical response compared to fresh cell
  - Failure at lower forces



- Possible reasons for different behaviour
  - Reduced amount of electrolyte in aged cells
  - liquid is pressed through porous structures in contact area – viscous behaviour

Summary and conclusions

- Influence of ageing on mechanical properties
  - A thicker SEI softens the mechanical response of aged cells in the initial compression
    - Thickness increase correlates with shift in the force/displacement curve under quasistatic indentation loads
    - Marginal increase in mechanical force at failure observed for aged cells
  - Degradation effects depend on pretension of battery during cycling
    - No pretension applied to batteries during charging/ discharging leads to a reduction of the mechanical strenght of batteries (i.p. tensile strength of anode)
  - Noticable reduction of peak force before failure at dynamic loads for aged batteries
  - During three point bending aged batteries showed a stiffer initial response and higher force levels
- Further findings:
  - High capacity losses lead to a less severe thermal runaway (reduced energy content)
  - Electrical ageing leads to reduced thermal conductivity in thickness direction
  - No change in chemical composition of exhaust gases

- Conclusions
  - Different behaviour of cells should be considered at design of battery systems
  - (for analysed battery) no indication for drastic increase of hazard over lifetime
  - Partly hard to draw a connex between component tests and cell tests
  - Partly contradicting results published in literature for other cells
- Next Steps:
  - Analysis for “non-intrusive” metrics to describe the SOH of a battery
  - Analysis of different cell chemistries
  - Comparison of artificially vs. real aged cells
  - Detailed analysis of specific degradation mechanisms

Talk to you in the Q/A-Session!

Warm wishes and best regards from snow-covered Graz!

Contact information

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