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Battery durability

Accelerated ageing test method

Battery performance degradation ”ageing”

- Four principal types of battery performance degradation
  - Capacity fade
    - Loss of cycleable Li
    - Loss of electroactive materials (anode, cathode, electrolyte)
  - Power fade
    - Loss of conductivity
    - Impedance increase – mainly contact resistance and Ohmic resistance in electrolyte
  - Reduced power efficiency
    - Associated with impedance increase – additional impedance components involved, e.g. charge transfer impedance
  - Irreversible swelling (change in physical cell dimensions)
- The ageing types do not have to proceed concurrently at the same rate
- Ageing is chemistry and cell/battery design specific
- Ageing is path dependent
- The relative importance of the different types of battery performance degradations varies between applications and system designs

Operating factors that influence battery ageing

- There are <u>at least</u> 5 operating conditions that have direct impact on battery life and durability
  - Discharge rate as determined by duty cycle as well as periods of activity or inactivity
  - Charge rate as determined by charge type and frequency
  - State of Charge (SOC) window of battery operation
  - Battery temperature during operation and idling
  - Time

Current battery ageing practice

- Typically involves two cell/battery degradation parameters
  - Electrical throughput (charge-discharge cycling)
  - Calendar ageing
- Acceleration of ageing processes achieved by
  - Cycling at higher current loads to shorten time of electrical throughput
  - Increasing the SOC window
  - Elevated temperatures (Arrhenius equation)

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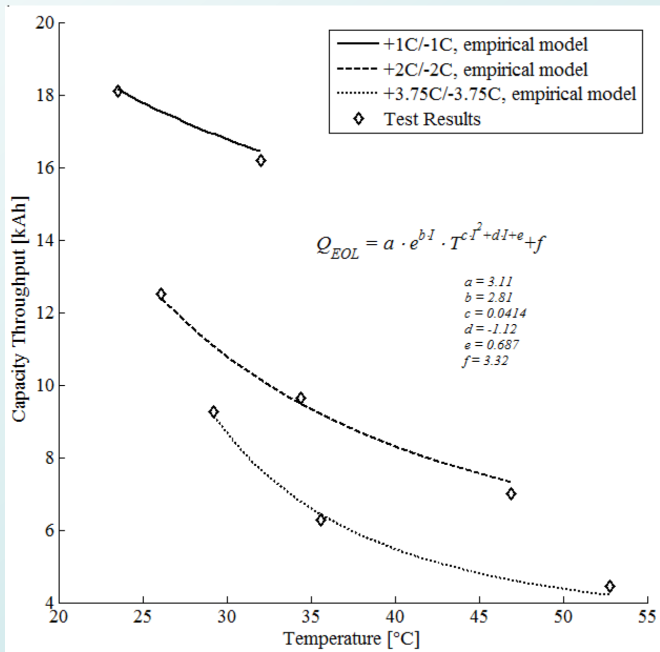
Example 1: LFP – dependence of duty cycle and temperature

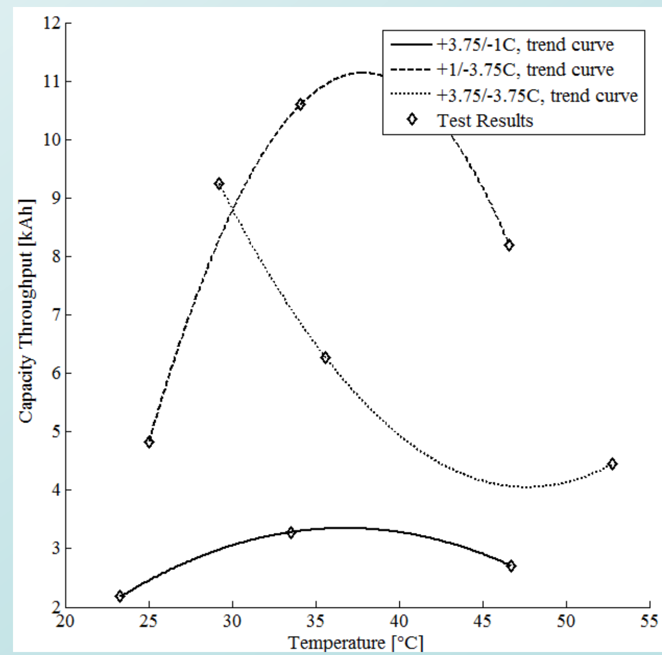
Path dependent

- Ageing mechanisms are non-linear and interdependent
- Previous experience is not transferreable:
  - Same cell type in a different application
  - Same application but with a different cell type
- Frequency and length of inactivity influences results

Symmetric constant current charge/discharge cycling



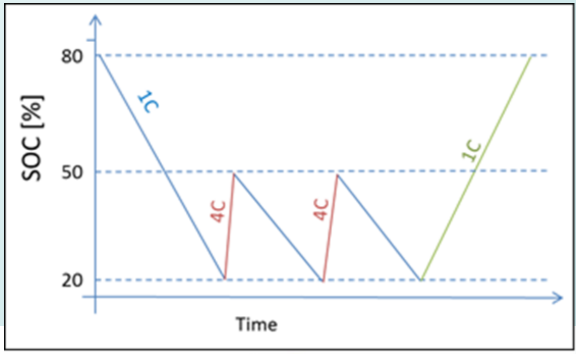
Assymmetric constant current charge/discharge cycling

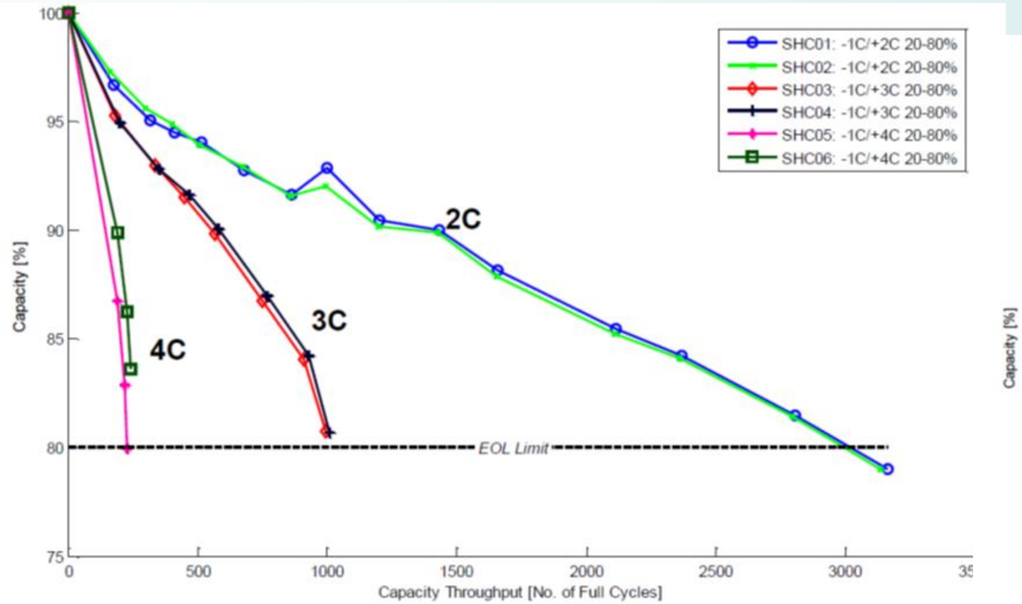


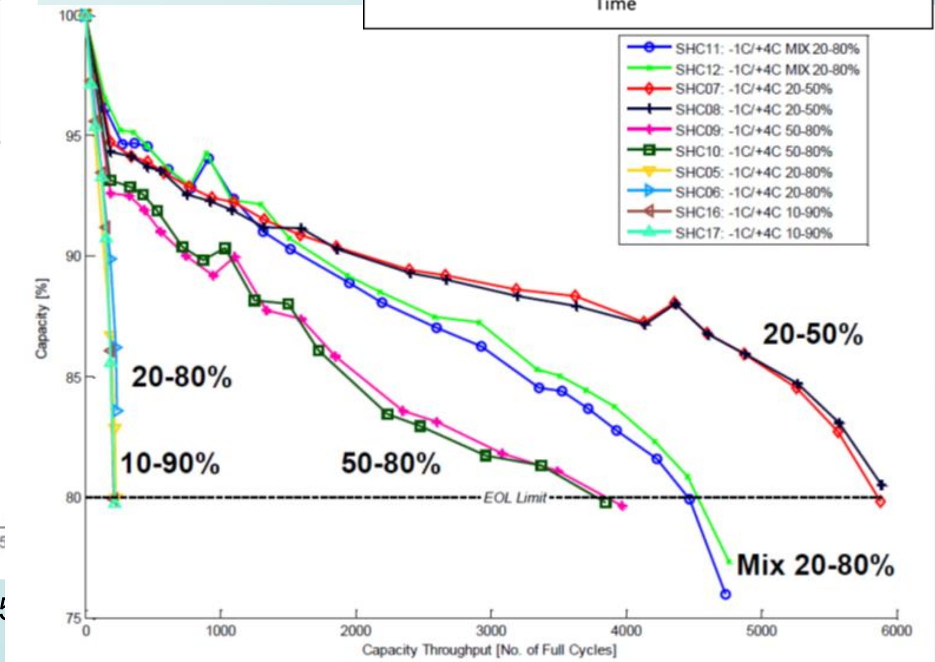
Source: J. Groot *et al.* (2015) J. Power Sources, 286, pp. 475-487.

Example 2 - NMC (26 Ah) – Dependence of charge current and SOC window

- Very fast ageing at high charge rate and wide operating SOC window
- Mixed SOC window has a mitigating effect on ageing rate
- Differences in ageing rate for the same cell and the same electric load but varying SOC window indicates activition of different ageing processes



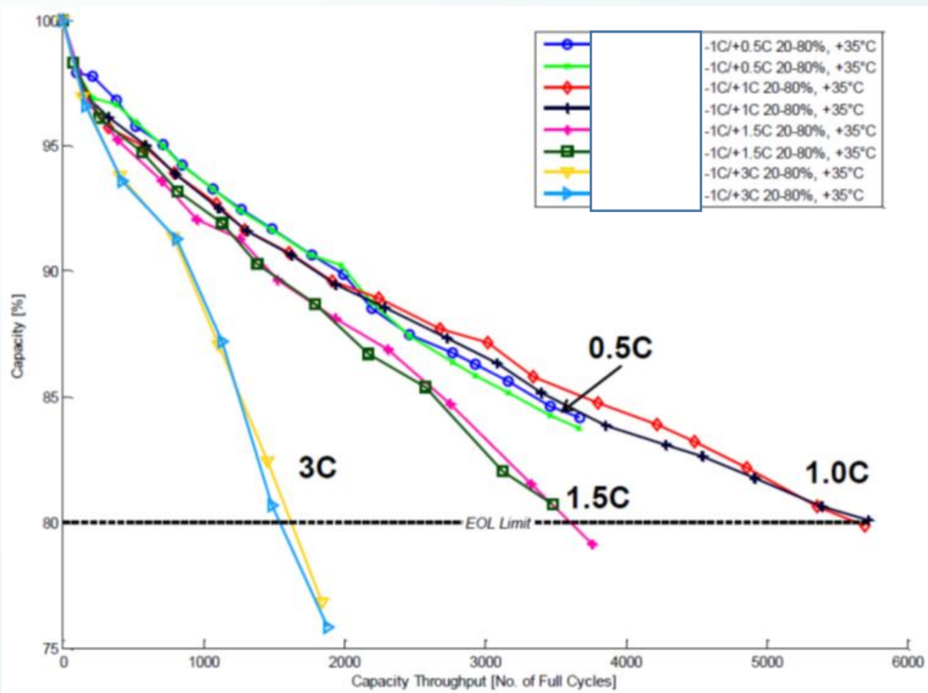


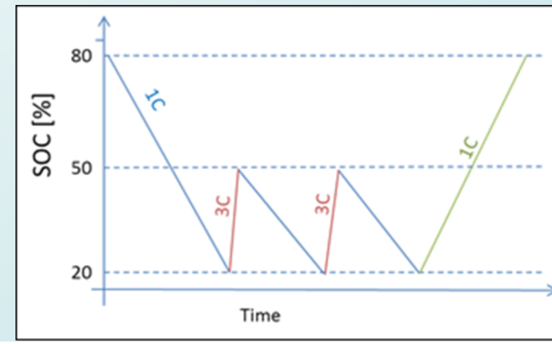


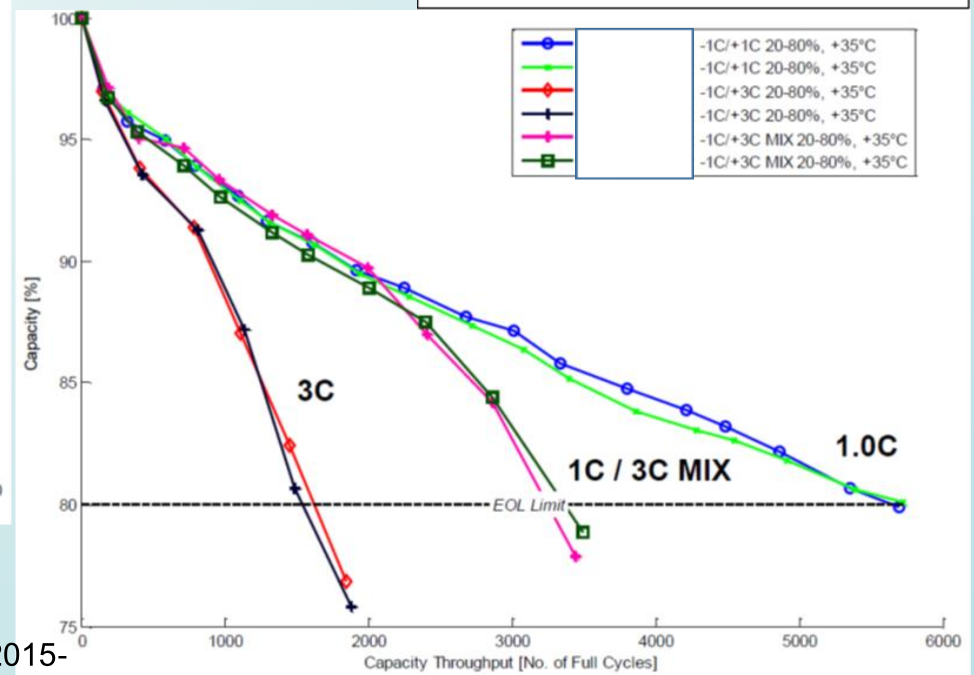
Source: Swedish Electromobility Center – "Fast Charge Project" 2015-2018 (J. Groot *et al.*)
Participants: Scania, AB Volvo, Volvo Cars, Uppsala Univ., KTH and CTH

Example 3: NMC (37 Ah) – Dependence of charge current and SOC window

- Similar ageing dependency for charge current and SOC window as for the 26 Ah NMC cell.



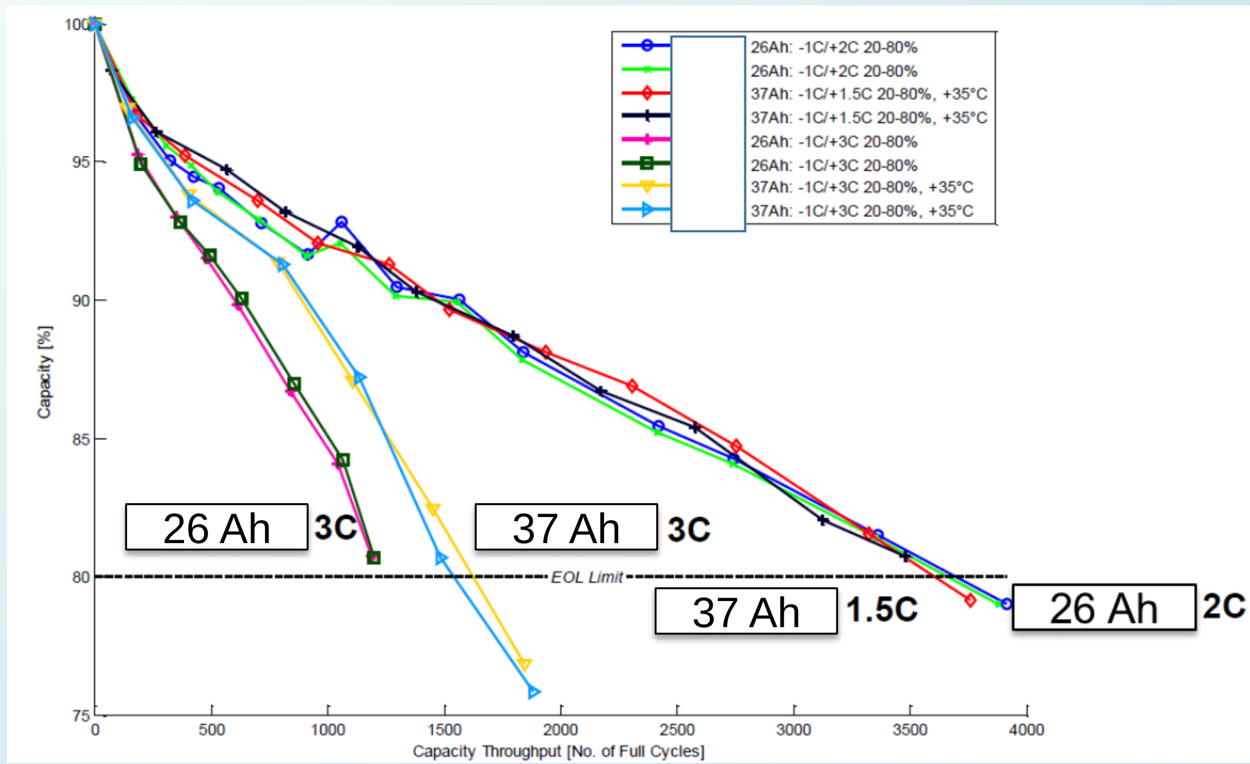




Source: Swedish Electromobility Center – "Fast Charge Project" 2015-2018 (J. Groot *et al.*)
Participants: Scania, AB Volvo, Volvo Cars, Uppsala Univ., KTH and CTH

NMC cell comparison: 26 Ah vs 37 Ah

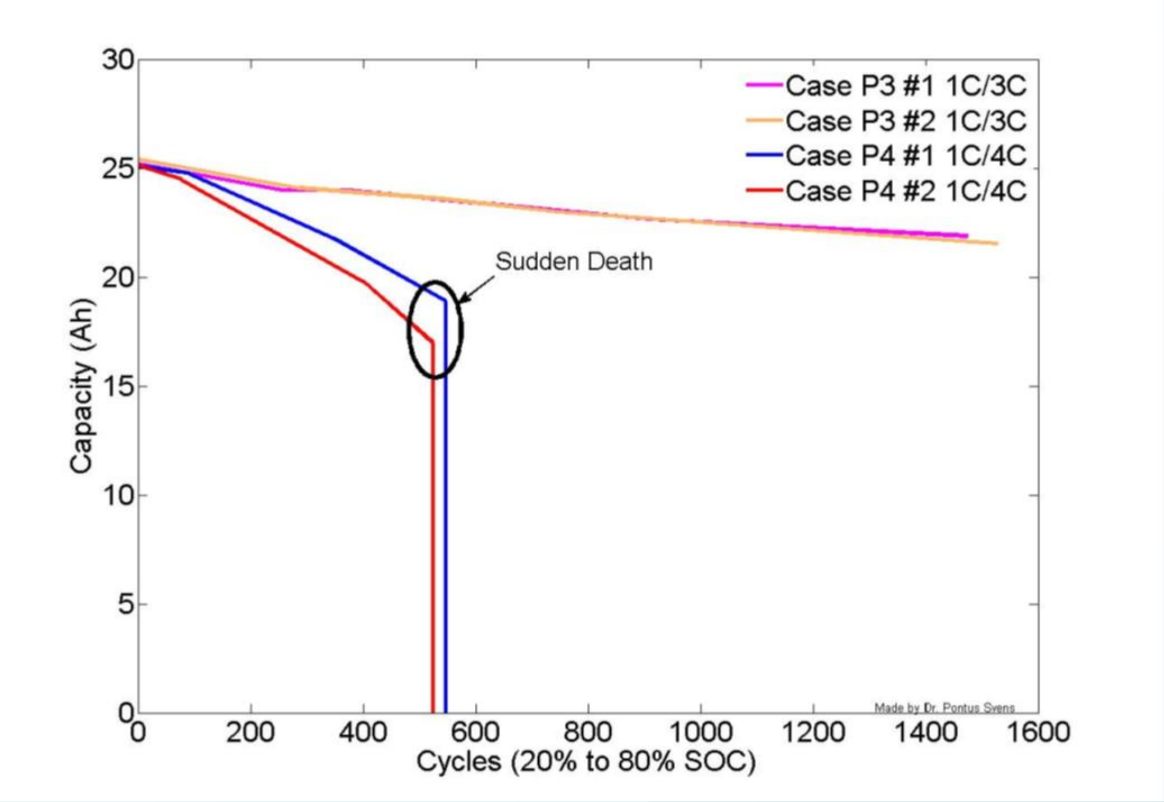
- Capacity fade with when charging with lower charging currents is about the same for both cell types
- When charging with 3C current, the 26 Ah cell has a faster capacity fade



Source: Swedish Electromobility Center – "Fast Charge Project" 2015-2018 (J. Groot *et al.*)
Participants: Scania, AB Volvo, Volvo Cars, Uppsala Univ., KTH and CTH

Example 4: Threshold effect – ”sudden death”

Small changes in test conditions can have a massive impact on durability performance as illustrated by the “sudden death” observed in cells when the charging current was changed from 3C (”20 min charging”) to 4C (”15 min charging”).



Source: Swedish Electromobility Center – “Fast Charge Project” 2015-2018 (P. Svens *et al.*)
Participants: Scania, AB Volvo, Volvo Cars, Uppsala Univ., KTH and CTH

Conclusions (1/2)

- Battery life testing limitations
  - Test cycles are typically highly simplified charge-discharge cycles
  - ”Fixed” SOC limits usually based on theoretical SOC window for accelerated tests
  - Test methods do not consider all parameters that contribute towards ageing
  - Inherent risk of activiting unrepresentative ageing mechanisms by acceleration
  - Ageing mechanisms are not simply additive due to complex interactions
- Practically impossible to engineer an accelerated bench test to a global fit
  - A general designed accelerated bench test will not correspond to the life performance of customers in all different electric vehicles
  - The battery usage stategies (represented by accelerated life tests) are designed for each specific project/vehicle and depend on
    - Customer assumptions
    - Expected Vehicle attributes
    - The specific performance characteristics of the battery cell used

Conclusions (2/2)

- Accelerating cell ageing by increasing typical test parameter values (current settings, temperatures, SOC window, etc), imposes a non-negligible risk of introducing unjustified bias, which can lead to unfair representation of the durability performance of a specific cell model.
- Significant tailoring of test method to a specific battery configuration is required to achieve equivalent ageing for fair durability comparisons between different battery systems
- If a physical regulatory durability test is required, then equivalent ageing across battery system technologies must be the objective of the test procedure, which raises a number of important questions, including but not limited to:
  - What is equivalent ageing?
  - How are different ageing processes taken into account?
  - How can equivalent ageing be realized in a test context?
  - How is equivalent ageing verified?
  - Is the outcome of the test relevant to field application operating and use conditions for a reasonable range of battery system designs?

OICA position summary

- Since the traction battery technology is still in a period of rapid development and change, a regulatory accelerated ageing test is premature
  - High risk of unjustified technology bias and unrepresentative ageing conditions
- Battery ageing and understanding the degradation mechanisms is extremely complex
- Life testing is very time and resource consuming
  - Large test matrixes and long test series (several years) are needed for confident results
- Life estimation models are under development but contain a number of uncertainties
  - Large variation in degradation due to customer usage and different applications make the models complex
  - It takes time to collect field data to verify the models
- New ageing models are needed for post Li ion cell technologies