Institute of Automotive Technology
Department of Mechanical Engineering
Technical University of Munich

Accelerated Aging Characterization of Lithium-Ion Cells in Automotive Applications

Development of an Appropriate Reference Cycle

Tanja Gewald[a,*], Alexander Hahn[b], Markus Lienkamp[a]

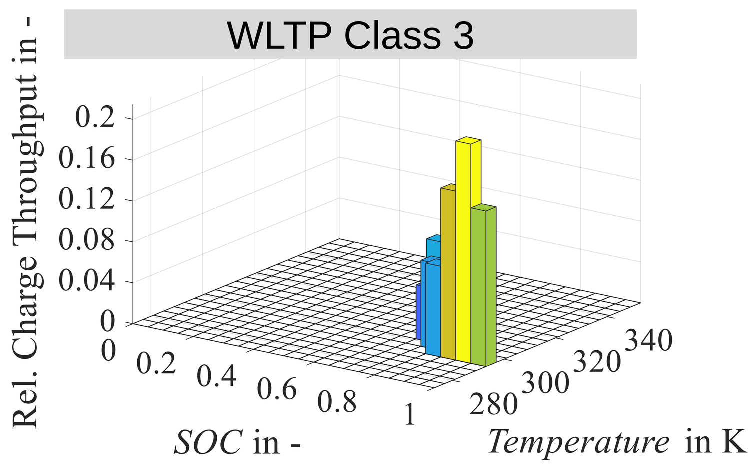
[a] Institute of Automotive Technology, Technical University of Munich, Boltzmannstr. 15, 85748 Garching, Germany
[b] DEE Dräxlmaier Electric and Electronic Systems GmbH, Bahnhofstr. 15-17, 84144 Geisenhausen
* *Corresponding author:* tanja.gewald@mytum.de, +49 (0)89 289 10333

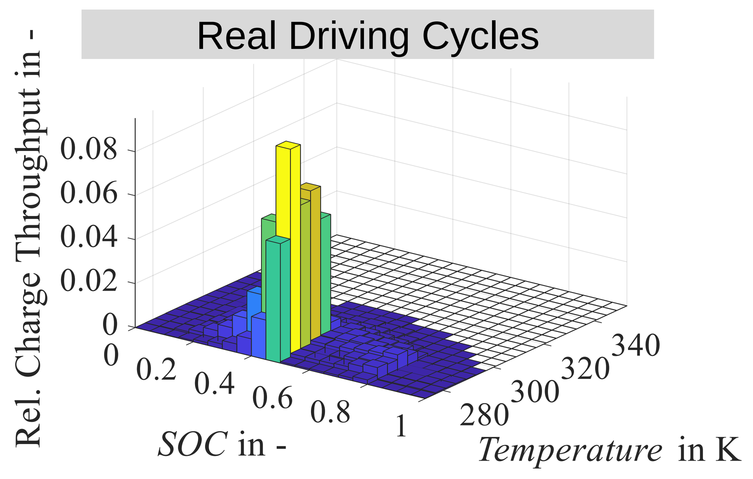
Abstract

An accelerated aging characterization is a prerequisite for the industrial process of battery design and thus for the promotion of electromobility in the market. For this issue, an appropriate reference cycle is essential. By using a Markov-Chain-Monte-Carlo method, a reference current profile (RCP) is developed that reproduces aging-relevant load conditions in automotive applications. In addition, a temperature-related approximation of this profile (RCP_{approx}) with a reduced load dynamic is developed that enhances the experimental implementation and reproducibility. Both profile candidates are investigated experimentally with a focus on the resulting effects and mechanisms of aging. The results show, that RCP and RCP_{approx} actuate a comparable aging on the investigated cell candidate on effect and mechanism level. The results for changing capacity (ΔC) or DC resistance ($\Delta R_{DC,10s}$) allow the assumption that by using RCP or RCP_{approx} an accelerated aging is initiated that maps the expectable cell aging under realistic automotive loads within a reduced test time.

Motivation

- In automotive applications, aging characterization is an important first step within the process of battery design, as an example for cell selection. An accelerated implementation of aging characterization is necessary due to limited time.
- The suitability of conventional reference cycles – such as the WLTP Class 3 – for aging characterization is questionable as different aging-relevant load regimes in comparison to real driving cycles are occupied as demonstrated by the shown load spectrum analysis [1].
- Therefore, an appropriate reference cycle is to be developed that maps real automotive battery loads and thus reproduces the expectable cell aging in automotive applications.





Method

1. Development of a Reference Cycle for Automotive Loads

- Development process:

Starting Point: 12,800 real driving cycles from fleet tests [2]

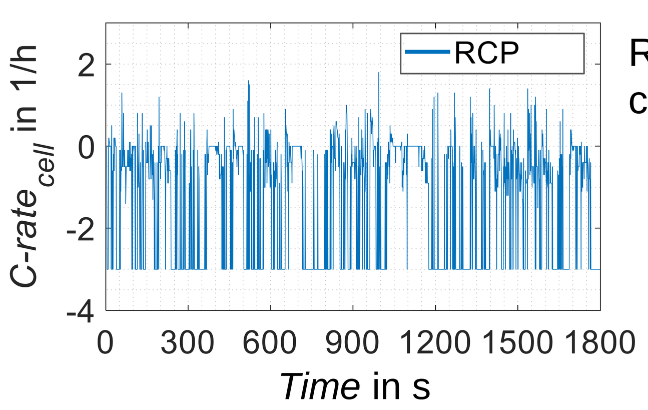
Computation of cell load profiles: Current, temperature, average state of charge (*ØSOC*), depth of discharge (*ΔDOD*)

Selection of profile candidates based on aging-relevance:

$$charge\ throughput\ rate = \frac{charge\ throughput\ per\ cycle}{cycle\ duration \cdot battery\ capacity}$$

Application of a Markov-Chain-Monte-Carlo method to the selected profile candidates [3]

Outcome: Reference Current Profile (RCP)

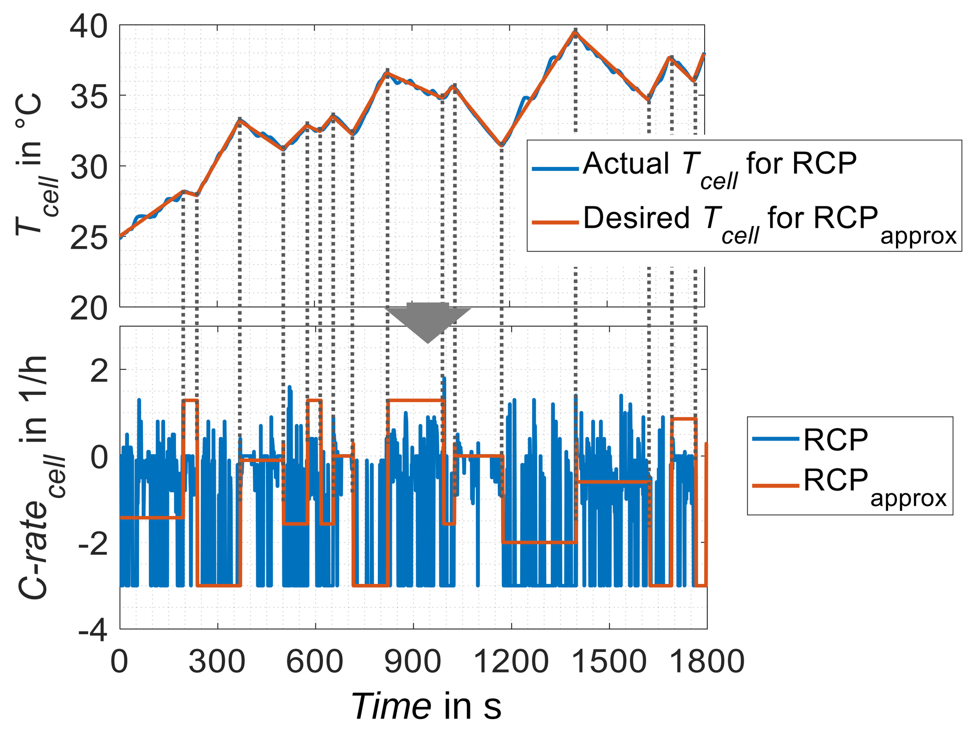


RCP with automotive load characteristics:

- highly dynamic loads
- discharge peak loads (starting processes)
- charge peak loads (regenerative braking)

2. Reduction of Dynamics – Developement of RCP_{approx}

- Motivation with respect to a facilitated experimental investigation: Programming effort, hardware-side limitation and reproducibility of test implementation.
- Approximation of RCP with the aim to reproduce its temperature profile, as temperature is crucial for aging:



- RCP_{approx} shows less *ΔDOD* than RCP (ΔDOD_{RCP} = 70 %, $\Delta DOD_{RCP,approx}$ = 63 %). Both show similar load characteristics (peaks, charge and discharge sequences).

3. Experimental Investigation

- Cell candidate: Sony (Murata) US18650VC7, a high-energy cell with NCA cathode and Si-doped anode, with a nominal capacity of 3.5 Ah and nominal voltage of 3.6 V.
- Aim of investigation: Comparison of RCP and RCP_{approx} regarding aging effects (ΔC, $\Delta R_{DC,10s}$) and mechanisms (investigated by differential voltage analysis, DVA).
- Test procedure:

Initial Cyclization for Setting and Activation

Initial Check-Up: ΔC, $\Delta R_{DC,10s}$, DVA — CU0

Charge and Profile (RCP or RCP_{approx}), 30 repetitions

Check-Up: ΔC, $\Delta R_{DC,10s}$ DVA — CU1

Charge and Profile (RCP or RCP_{approx}), 30 repetitions

Check-Up: : ΔC, $\Delta R_{DC,10s}$, DVA — CU2

16 days

- Statistics: three cells are tested for RCP and RCP_{approx}, respectively.

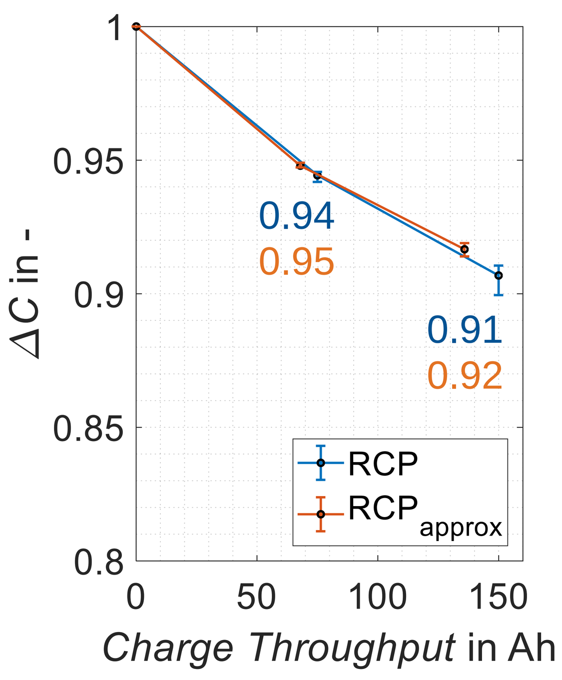
Results

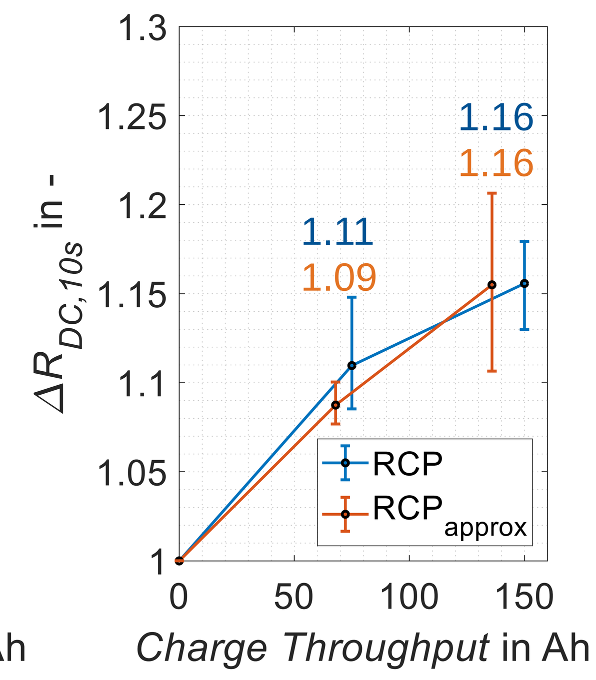
Findings on aging effects:

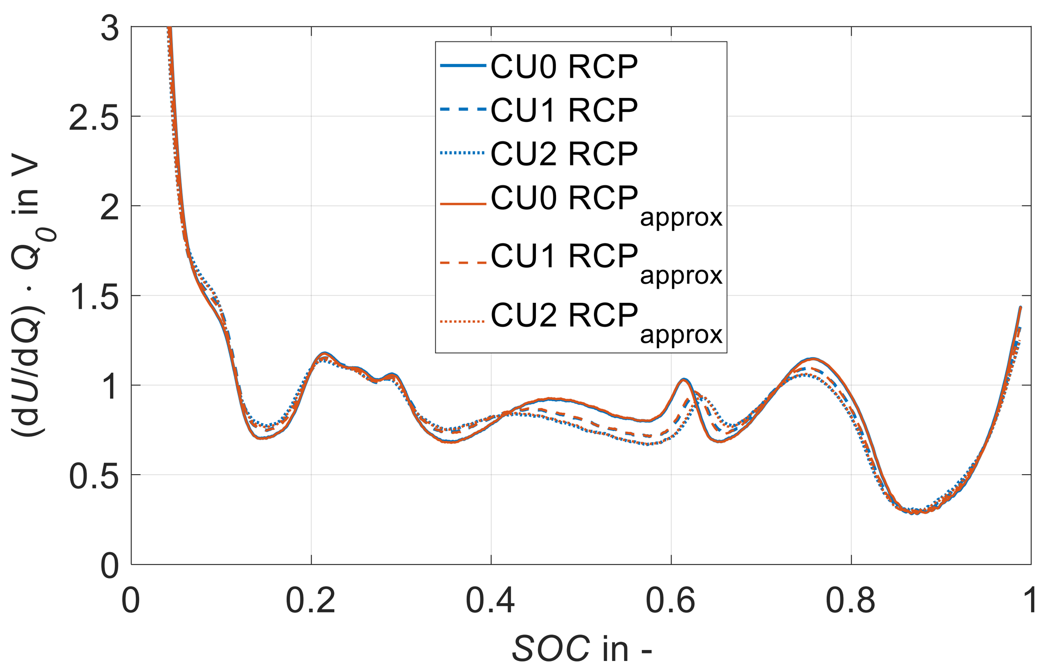
- For RCP and RCP_{approx}, a reduction of cell capacity by 8 – 9 % and an increase of resistance by 16 % during a charge throughput of approximately 150 Ah is measured.
- Thus, RCP and RCP_{approx} show similar results of cell aging on effect level.

Findings on aging mechanisms:

- For RCP and RCP_{approx}, the DVA spectra evolve similarly. They show a reduction of anodic and cathodic capacity as well as a shift in electrode balancing.
- Thus, RCP and RCP_{approx} also show similar results of cell aging on mechanism level.







Future Work

- As a next step, the acceleration potential of the described procedure needs evaluation regarding two aspects: The factor of aging acceleration and the consistency of aging mechanisms in comparison to the realistic, automotive cell aging.
- For this purpose, battery systems need to be retrieved from the automotive in-field usage, disassembled and the aged cell candidates need to be measured and evaluated regarding present aging effects as well as aging mechanisms.

References:
[1] T. Gewald et al., "Characterization and Concept Validation of Lithium-Ion Batteries in Automotive Applications by Load Spectrum Analysis", EVS 31 & EVTeC, Kobe (2018)
[2] M. Wittmann et al., "A Holistic Framework for Acquisition, Processing and Evaluation of Vehicle Fleet Test Data", ITSC, Yokohama (2017)
[3] M. Fries et al., "How to design a real-life driving cycle from fleet testing data with the Markov-Chain-Monte-Carlo Method" ITSC," Maui (2018)

Acknowledgement:
The authors gratefully acknowledge the basic funding by DEE Dräxlmaier Electric and Electronic Systems GmbH and the independent funding by the Institute of Automotive Technology at the Technical University of Munich.

DRÄXLMAIER