Effect of Fast-Charging and Cycling Window on Lithium-Ion Battery Performance and Aging

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Introduction

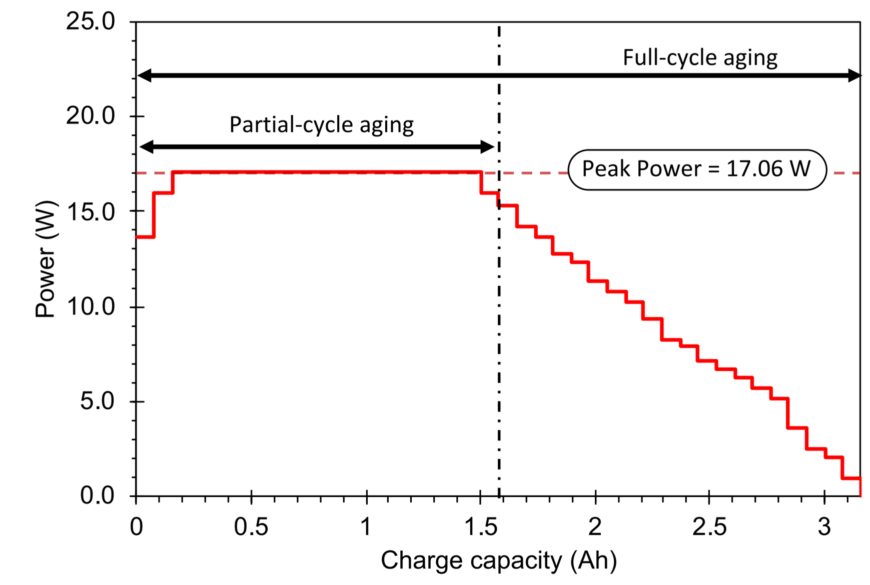
- Traditional fast-charge aging studies focus on conventional CC-CV fast-charging profiles with a **single C-rate rather than real-world profiles with varying C-rates**. This study aims to bridge that gap using a **scaled-down version of the 150kW EV charging profile.**
- EVs seldom operate across their full state-of-charge (SoC) range (0-100%). Investigating partial-cycle aging offers insights that better reflect actual EV usage patterns.
- In this work, the charging performance and degradation pathway of cells cycled under two different cycling conditions, **partial-cycle (0-50% SoC) and full-cycle (0-100% SoC), with the scaled-down real-world EV fast-charging profile,** have been investigated**.** Differential voltage and incremental capacity (DV and IC) analysis have been used to identify different degradation modes.

Cells and Equipment

Item	Specification
Manufacturer code	NCR18650GA
Positive electrode (PE)	$LiNiCoAlO_2$ (NCA)
Negative electrode (NE)	Carbon/graphite
Nominal capacity	3.35 Ah
Nominal voltage	3.60 V
Upper Cut-off Voltage (V_{UCV})	4.20 V
Lower Cut-off Voltage (V_{LCV})	2.50 V

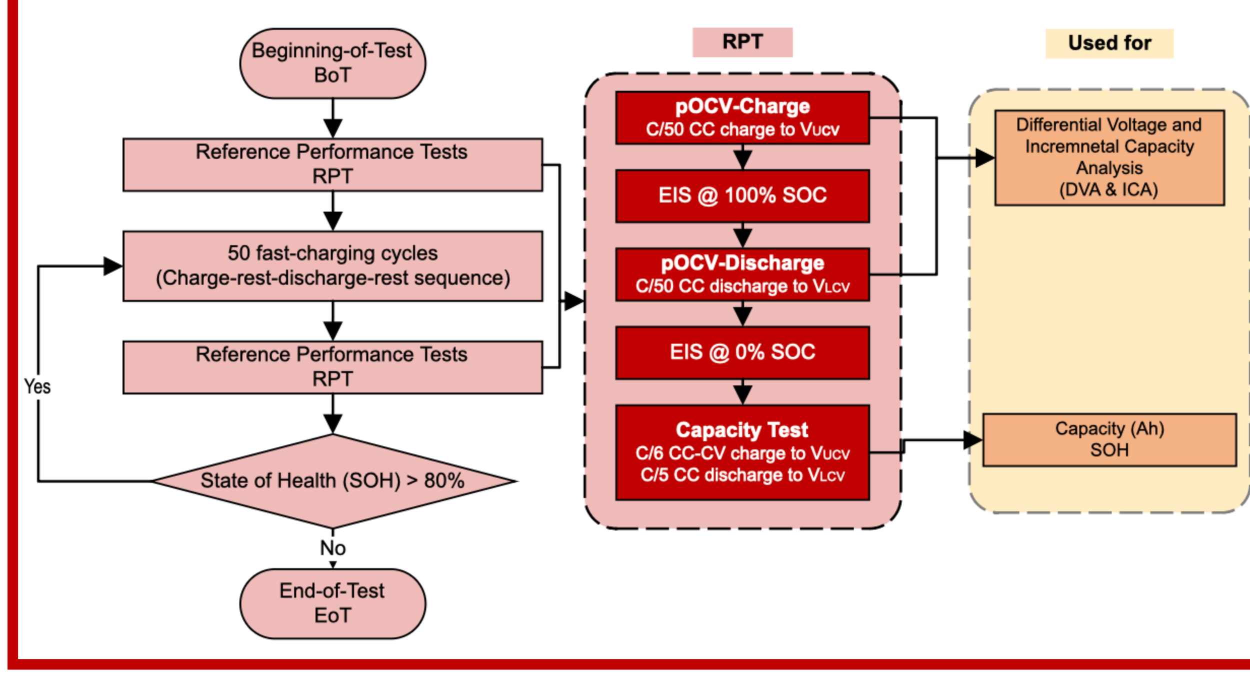
The cycling experiments were conducted using an Arbin Instruments MSTAT multi-channel battery tester.

Fast-charging Profile

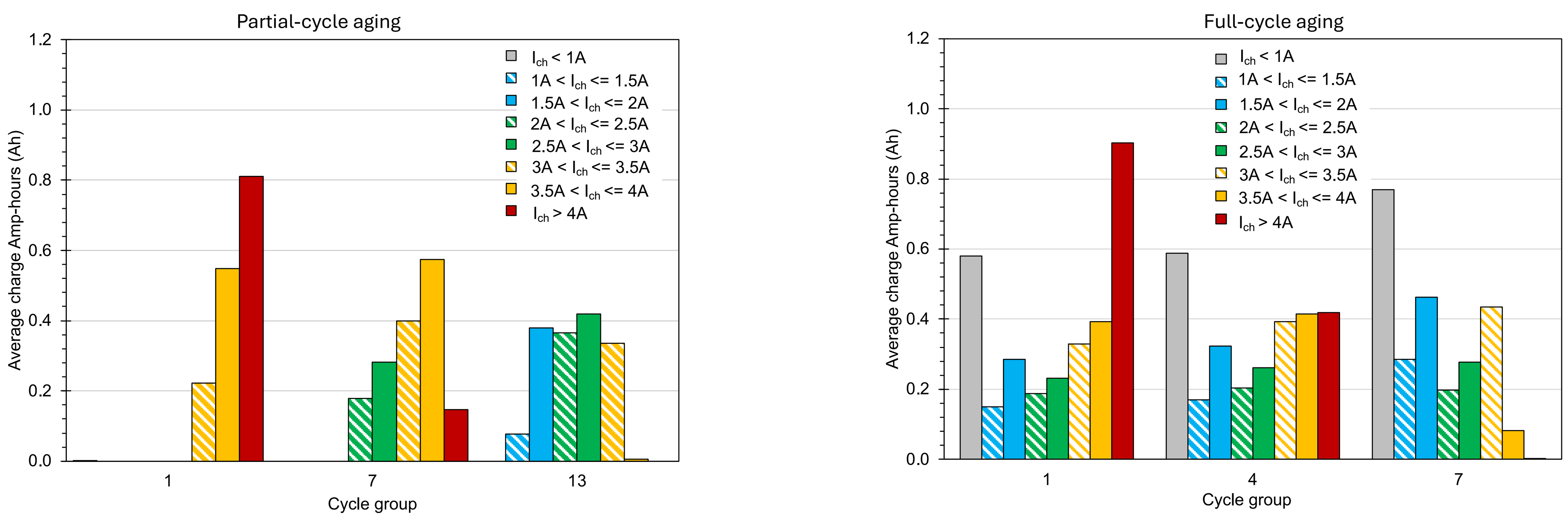


Multi-stage Constant Power (MSCP) charging profile:
A scaled-down 150 kW EV charging profile

Cycling Procedure

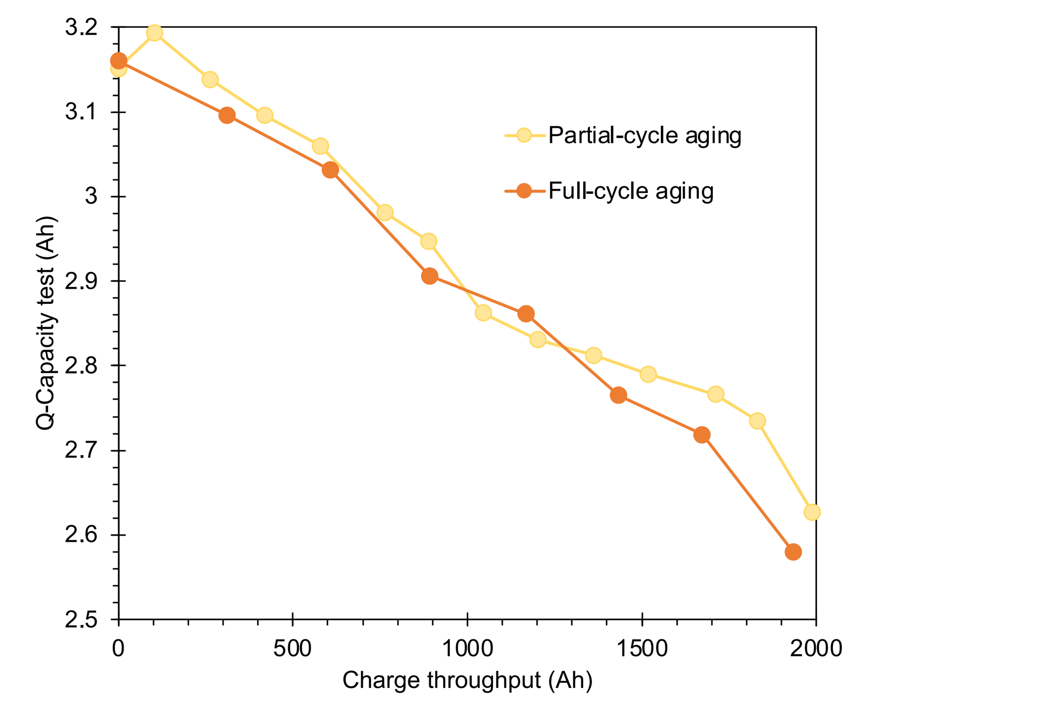


Charging Performance



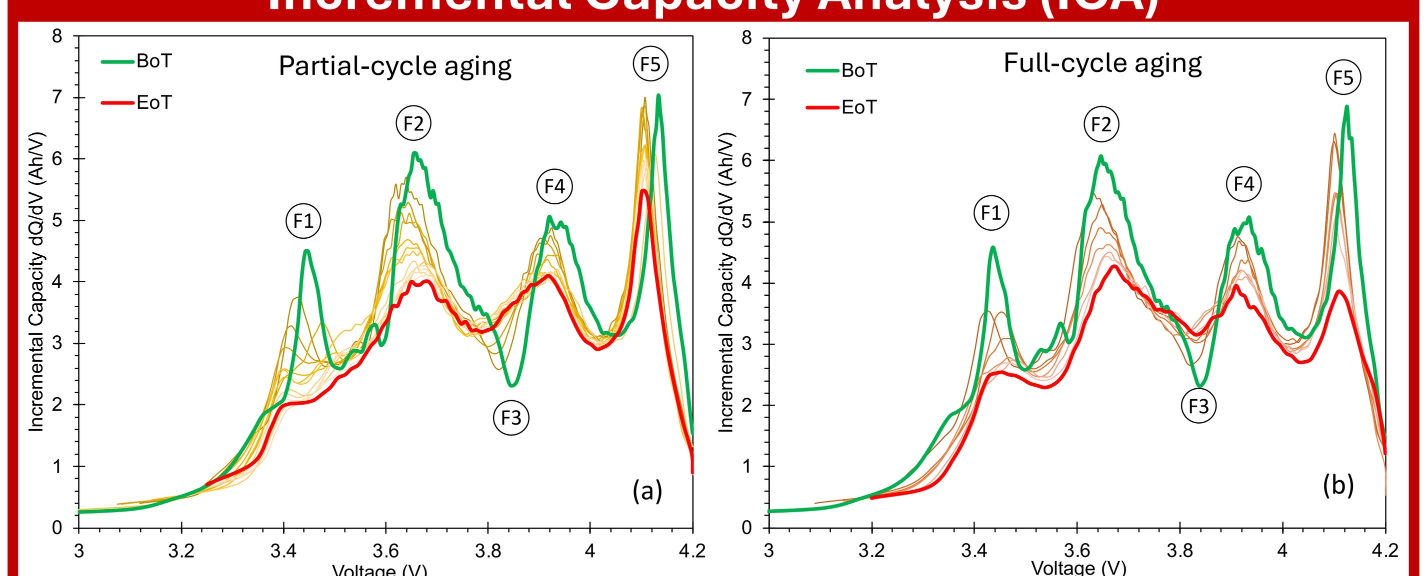
- For both cycling conditions, the charging time increased as the cells aged. Both the cycling conditions showed similar charging performance in the 0 to 1.58 Ah range. Over 60% of the full-cycle aging charging time was spent from 80% to 100% SoC.
- As the cells aged, their voltages hit V_{UCV} before reaching the target charge capacity for the respective MSCP charging steps, shifting most charging duties either to the subsequent steps or the CV phase in case of partial-cycle aging.

Capacity Degradation



- The cells used for partial-cycle and full-cycle aging completed 650 (288 FEC) and 353 (296 FEC) cycles, respectively, before reaching EoT.

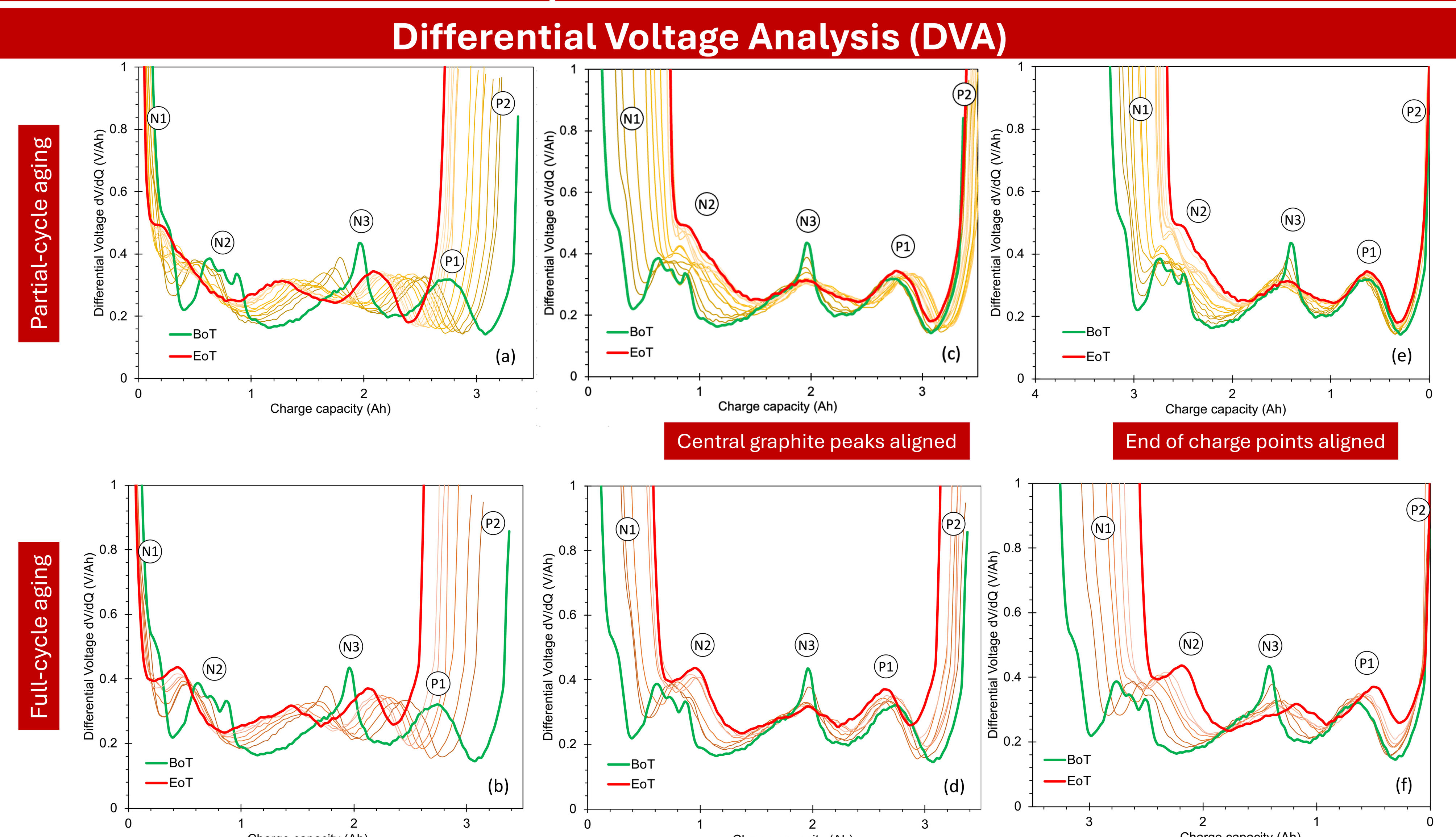
Incremental Capacity Analysis (ICA)



IC curves highlight phase transformations, with peaks corresponding to voltage plateaus

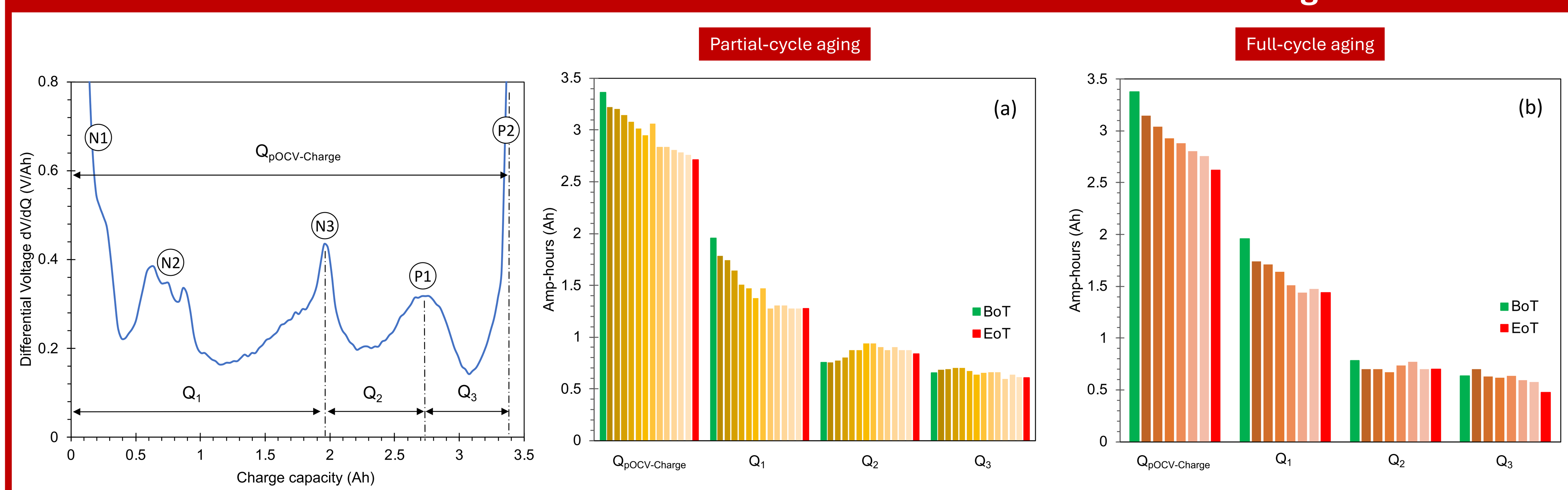
- **Partial-cycle aging**:
  - F1 decreased in height and eventually disappeared.
  - Arch F3 decreased in intensity and shifted to lower voltages, indicating rate degradation of NE (RDF_{NE}).
  - F5 remained unchanged initially but decreased in height during later stages, suggesting loss of active material of PE (LAM_{PE}) towards EoT.
- **Full-cycle aging**:
  - F1 decreased in height but did not disappear.
  - F5 consistently decreased throughout the cycling, indicating LAM_{PE} was present throughout the test.

Differential Voltage Analysis (DVA)



- The peak N3 broadened, while N2 either smeared into a single peak (full-cycle aging) or disappeared (partial-cycle aging). This broadening and disappearance of peaks are attributed to the heterogeneity of lithium distribution.
- The DVA spectra to the left of N3 appear compressed, indicating a loss in capacity at lower SOCs. The DVA spectra to the right of N3 remain stable in partial-cycle aging but appear compressed in full-cycle aging.
- The dV/dQ values increased more drastically to the left of N3 than to the right, suggesting increased polarization of the NE, which is likely due to higher local resistance.

DVA – Peak Tracking



- Q_1 and Q_3: Degradation indicator capacity for NE and PE, respectively; Q_2 offers insights into electrode balance
- For both cycling conditions, the trends of Q_1 largely resemble $Q_{pOCV\text{-}charge}$, indicating the LAM_{NE} as a significant contributor to cell degradation.
- For full-cycle aging, the decreasing trend of Q_3 is not as prominent as Q_1 but persists until the end of the tests, suggesting LAM_{PE} from the very early stages of cycling.

Conclusion

- Both cycling experiments exhibited similar overall capacity fade trends, but the underlying causes differed.
- The DV-IC analysis revealed that LAM_{NE} was pivotal in capacity fade for both cycling experiments.
- LAM_{PE} was observed alongside LAM_{NE} throughout the cycling experiment for full-cycle aging, but it was only observed towards the EoT in partial-cycle aging.
- Additionally, a decrease in the homogeneity of lithium distribution within the negative electrode and kinetic rate degradation of the negative electrode (in the case of partial-cycle aging) were evident.