READ ME: UofM Pouch Cell Voltage and Expansion Cyclic Aging Dataset

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Research Overview

The focus of this research effort is to systematically study the capability of aging diagnostics using cell expansion under variety of aging conditions and states. The data collection campaign is very important to cover various degradation modes to extract the degradation features that will be used to inform, parameterize, and validate the models developed earlier. In the data collection campaign, we are documenting the evolution of the electrical and mechanical characteristics and especially the reversible mechanical measurement. It is important to note that we collect data using newly developed fixtures that enables the simultaneous measurement of mechanical and electrical response under pseudo-constant pressure.

Citations related to this material:

- P. Mohtat, et al., *"Reversible and Irreversible Expansion of Lithium-Ion Batteries Under a Wide Range of Stress Factors."* J. Electrochem. Soc. 168 100520 (2021)

The research team consists of Jason B. Siegel (PI), Anna G. Stefanopoulou (co-PI), Peyman Mohtat (PhD student). The research was conducted at the University of Michigan's powertrain battery lab starting summer of 2018.

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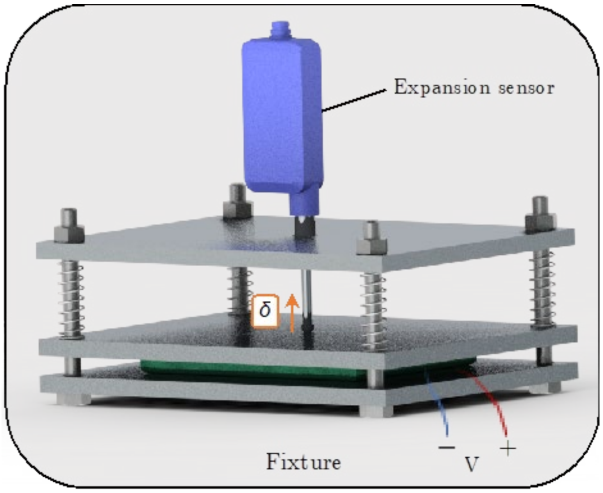
Methods

The research conducted was using a pouch cell built at the University of Michigan Battery Lab (UMBL) and a newly developed fixture. The fixture was designed such that the top and bottom plates are fixed in place while the middle plate is free moving. For pouch cells, added pressure is needed to ensure the optimal performance of the battery. Hence, the fixture was designed to apply a uniform pressure on the pouch cell. This was achieved by using compression springs and polymer poron sheets (Rogers, USA). The target applied pressure of 5 psi was achieved by adjusting the spring compression to a fixed displacement using the threaded rods. The expansion was measured using a displacement sensor (Keyence, Japan) mounted on the top plate. The dynamic testing was carried using a battery cycler (Biologic, France). The temperature was measured using a K-type thermocouple (Omega, USA) placed on the surface of the battery.



The fixture was installed inside a climate chamber.

The summary of all the testing conditions is shown in Table 1.

- **Cycling procedure:** Before starting the cycling tests, the chamber temperature was set to the target temperature of the cycling test, and the cells were held at rest for 3 hours to ensure thermal equilibrium. The cycling consists of a constant current (CC) charge until reaching 4.2 V, followed by a constant voltage (CV) phase at 4.2 V until (I<C/50). Then a CC discharge until reaching 3.0 V for the full range conditions. For partial DOD, the discharge time is with respect to the nominal capacity at all times (i.e., to obtain 50% DOD, 2.5 Ah are discharged from a completely charged state). During all the tests, in addition to the traditional signals of voltage, current, and temperature, the thickness changes (expansion) of the cell are also recorded. All the cells were cycled to at least 70\% capacity retention, and characterization tests were performed periodically.

- **Characterization procedure:** Initial characterization was done for all the cells before the start of the aging experiment. The subsequent characterization tests were performed after a certain number of cycles corresponding to an expected 5% capacity loss for cyclic aging tests. Before starting the tests, the cells were brought back to room temperature and held at rest for 3 hours to ensure thermal equilibrium. The characterization tests are as the following:
    1. A C/20 charge-discharge cycle consists of an initial C/5 discharge until reaching 3.0 V, followed by a CV phase at 3.0 V until (|I|<C/50) and 1 hour rest to ensure the cell is fully discharged. Then a C/20 charge until reaching 4.2 V, followed by a

CV phase at 4.2 V until (I<C/50) and 1 hour rest. Then a C/20 discharge until reaching 3.0 V.

2. Hybrid pulse power characterization (HPPC) and electrochemical impedance spectroscopy (EIS) measurements at 10% SOC intervals. First the cells are charged using C/2 CC until 4.2 V, followed by a CV at 4.2 V until (I<C/50) and 1/2 hour rest. Then a C/2 CC discharge for an equivalent of 10% SOC discharge, where the discharge time was adjusted based on the prior capacity measurement (C/20) test. Followed by a 1/2 hour rest. Then the HPPC profile was done which consists of a 1C CC discharge for 10 s, a 10 min rest, a 1C CC discharge for 10 s. Followed by a 10 min rest. Then the EIS measurement was done over frequency range of 10 mHz - 10 kHz. The above steps were repeated until the end of discharge 3.0 V was reached.
3. The C-rate dependency test consists of charging the cell at different rates for characterizing the rate capabilities of the cell. Before each charge, the cell was fully discharged to 3.0 V by a C/3 discharge current until reaching 3.0 V, followed by a CV phase at 3.0 V until (|I|<C/50). Then the cell was charged using CC (C/10, C/5, C/2, and 1C) until 4.2 V.

The Biologic BTS-815 battery cycler was connected to a computer over the LAN network connection to transfer the voltage, current, and temperature data. BT-Lab software was used for collecting and storing this data at 10 sec intervals. The expansion data was transferred to the same computer over the serial port. A custom LabView program was used to collect and store the expansion data at 10 sec intervals.

Table 1 Cyclic aging conditions

Cyclic aging conditions			
Cell number - Temperature (R/C/H)	**Depth of discharge**	**Charge**	**Discharge**
01 (R) | 02 (C) | 03 (H)	0-100%	C/5	C/5
04 (R) | 05 (C) | 06 (H)	0-100%	1.5C	1.5C
07 (R) | 08 (C) | 09 (H)	0-100%	2C	2C
10 (R) | 11 (C) | 12 (H)	0-100%	C/5	1.5C
13 (R) | 14 (C) | 15 (H)	0-50%	C/5	C/5
16 (R) | 17 (C) | 18 (H)	0-50%	C/5	1.5C
19 (R) | 20 (C) | 21 (H)	0-50%	1.5C	Drive cycle

File Inventory

The raw data for each cell is available as CSV files. For each cell there are four CSV files that are described in the following table:

File Name	Type	Description
cycling_wExpansion.csv	Data file	Contains all the cycling tests data
OCV_wExpansion.csv	Data file	Contains all the C/20 charge-discharge tests data
Crate_wExpansion.csv	Data file	Contains all the C-rate dependency tests data
Resistance.csv	Data file	Contains all the HPPC and EIS tests data

The following files contain some starter code to load the datasets in MATLAB.

File Name	Type	Description
import_cycling_data_example.m	Code	Imports the cycling data
import_OCV_data_example.m	Code	Imports the C/20 charge-discharge data
import_Crate_data_example.m	Code	Imports the C-rate dependency data
import_resistance_data_example.m	Code	Imports the HPPC and EIS data

Software requirements

MATLAB® software is required for using the sample starter codes to import the dataset in this repository.
The code has been tested on the following Operating Systems (OS) and software versions:

- Windows 10 (version 2004) | macOS (10.15.6)
- MATLAB® 2019

Definition of Terms and Variables

A glossary of the variables and their definition in the data set:
Time [s]: the measured time
Current [mA]: the measured current
Voltage [V]: the measured voltage
Expansion [mu m]: the measured expansion
Temperature [C]: the measured temperature
Q [Ah]: the measured running coulomb counting
Capacity [Ah]: the measured coulomb counting per charge and discharge
Cycle number: the cycle number
Total Ah throughput [Ah]: the total Ah throughput
Frequency [Hz]: the measured frequency
Magnitude [Ohm]: the measured EIS magnitude
Phase [deg]: the measured EIS phase
Re [Ohm]: the measured real part of EIS
-Im [Ohm]: the measured negative of imaginary part of EIS