Sandia National Laboratories
SNL Energy Storage Technology and Systems – Energy Storage Safety
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Risk Analysis and Database Development of Large-format Li-ion Cells Through Thermal Runaway Testing

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Introduction

- Thermal runaway is a safety risk inherent to all Li-ion batteries
  - Effects of thermal runaway include high temperatures, release of hazardous pressure, toxic gas and chemical particulate
  - Results of thermal runaway can cause surrounding structural damage, personal injury, and environmental pollution
- Results of testing from SNL and ORNL are used to analyze thermal runaway severity and will be incorporated into a database available to the battery community
  - Thermal runaway analysis uses observed hazard severity (OHS) and calculated hazard severity (CHS) for optimized battery comparison
  - Benefit to battery designers, manufacturers, first responders and end users

ORNL-Sandia data-based hazard severity levels for single-side indentation*

Hazard Severity Level	Description
1 (VL, 0-10)	Very low, instant local Joule heating, detectable voltage drops
2 (L, 10-25)	Low, localized heating, small voltage drops and recovery
3 (M, 25-75)	Moderate, localized heating spread, significant voltage drops, continued discharge after recovery
4 (H,75-90)	High, heating due to chemical reactions, cell puff and gas release, voltage drop to close to zero
5 (VH, 90-100)	Very high, heating spread to the cell, heavy smoke and possible fire, voltage drops to zero

*L.S. Lin, J.L. Li, I.M. Fishman, L. Torres-Castro, Y. Preger, V. De Angelis, J. Lamb, X.Q. Zhu, S. Allu, H. Wang, Mechanically induced thermal runaway severity analysis for Li-ion batteries, Journal of Energy Storage, Volume 61, 2023

Methodology

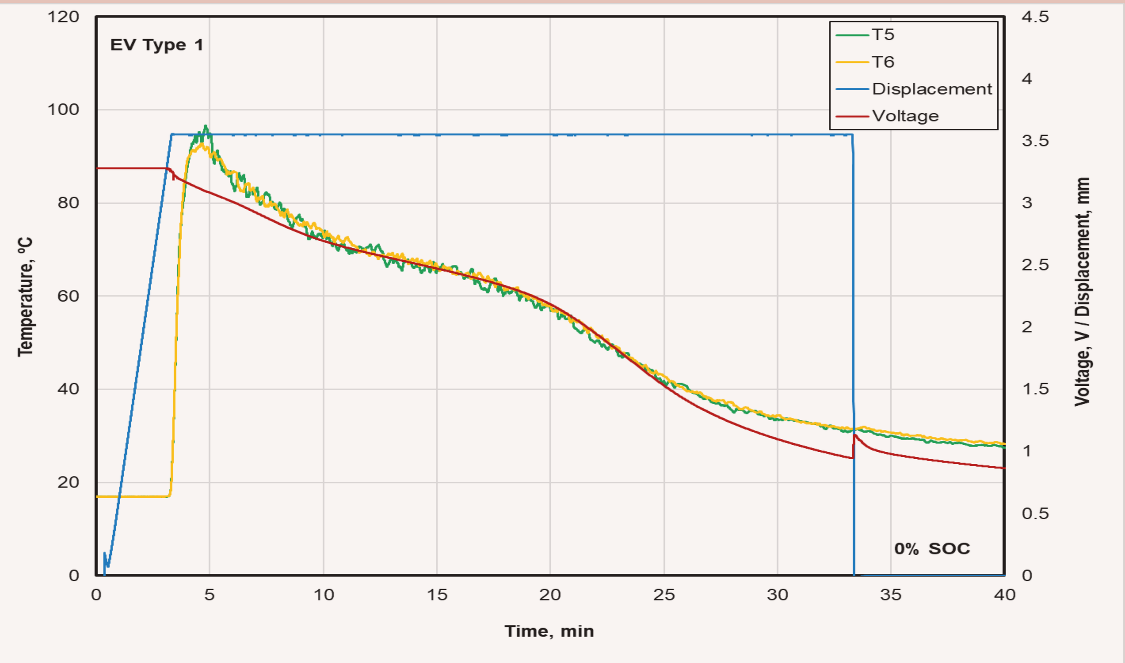
- Single cells were obtained from 2 types of EV modules at ORNL and shipped to SNL
- Testing in duplicate at ORNL and SNL at 0%, 50%, 70%, 90% and 100% SOC

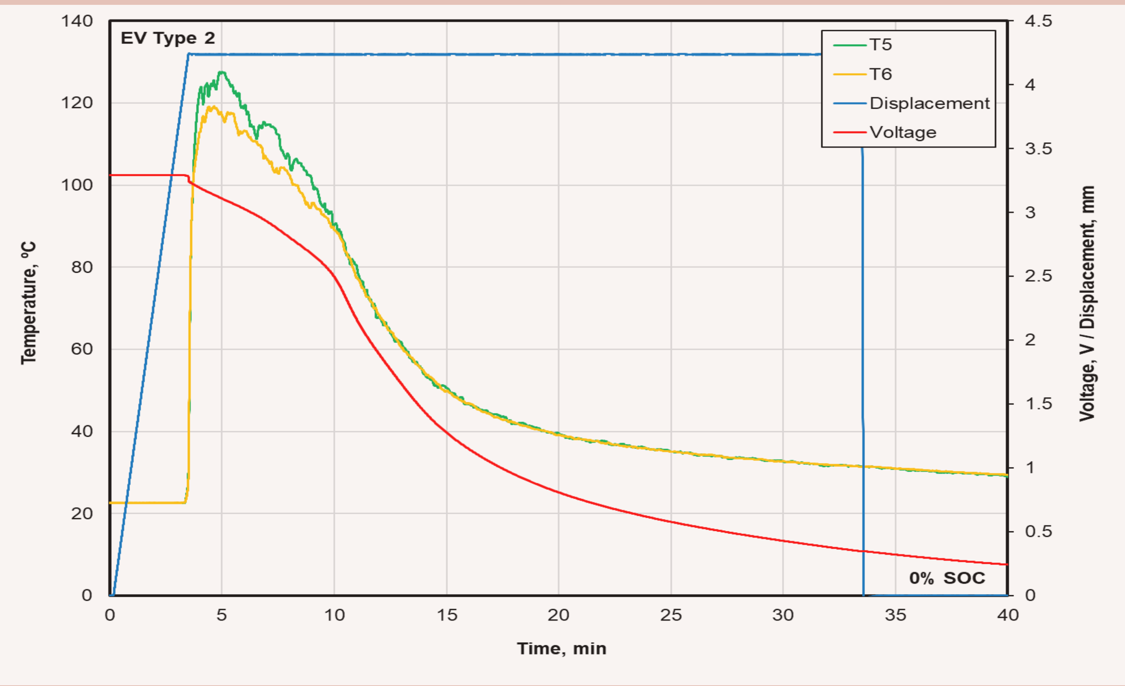
Hydraulic equipment with 6mm indenter

- Test protocol for failure initiation:
  - 6mm diameter blunt indenter
  - Indentation speed of 0.05 in/min
  - Indent until ≥ 25 mV voltage drop or cell failure
  - Temperature monitoring within 5mm of indentation location (TC5, TC6 below)
  - SOC based on measured capacity

Single cell prepped for testing with voltage sense leads and thermocouples

0% SOC



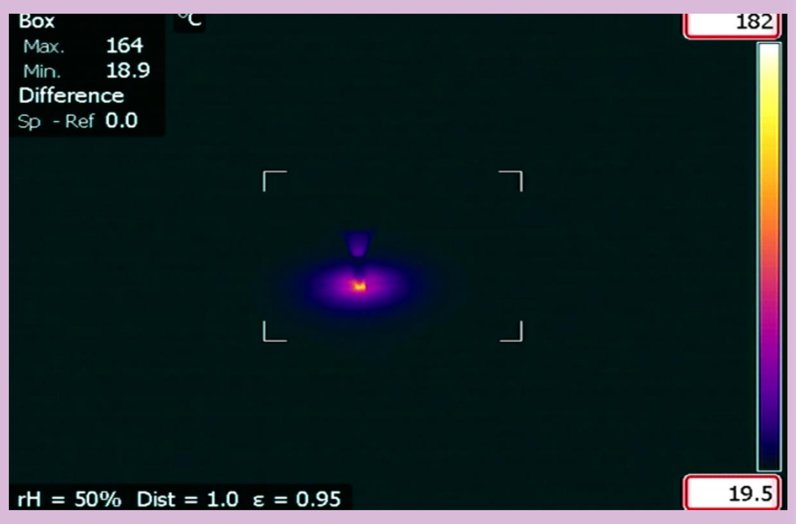


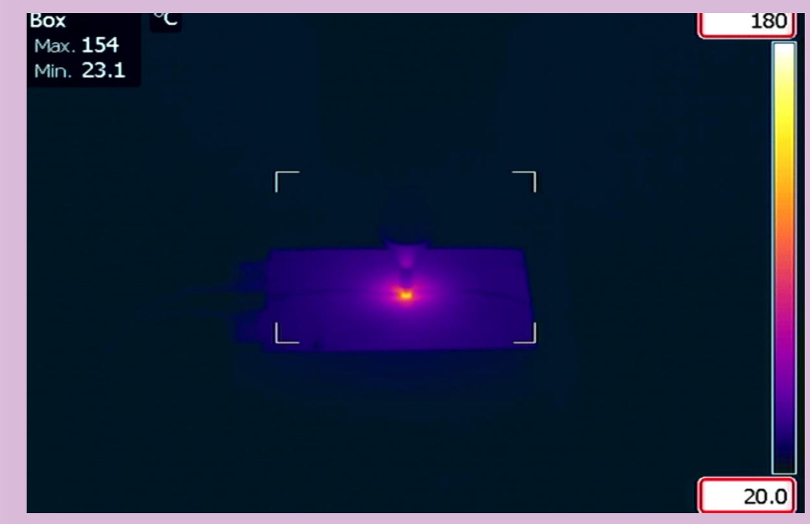
	EV 1 Cell 1	EV 1 Cell 2	EV 2 Cell 1	EV 2 Cell 2
Max Displacement	3.94 mm	3.56 mm	4.25 mm	4.18 mm
Max Force	2046 N	2039 N	2081 N	2257 N
Max Temperature	97 ˚C	97 ˚C	128 ˚C	110 ˚C
30min V drop	1.178 V	2.178 V	2.862 V	2.872 V
Max Increase Rate*	132 ˚C/min	124 ˚C/min	725 ˚C/min	495 ˚C/min

*T5/T6 Avg

IR Thermal Imaging

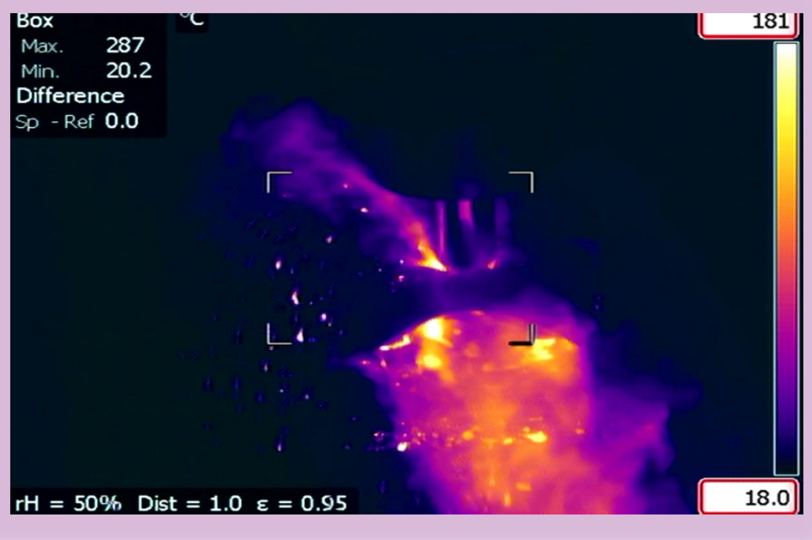
Right: Initial thermal response to mechanical indenter at 25mV loss in cell voltage with no runaway



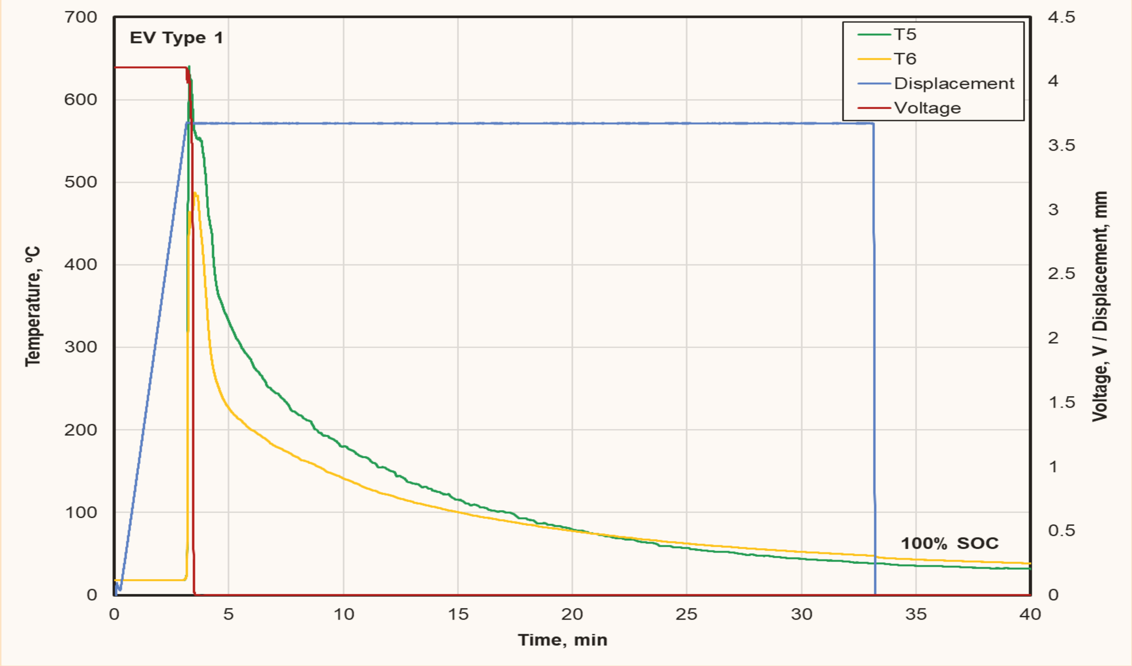


Left: Thermal response at t = 30 minutes post 25mV loss in cell voltage with no runaway

Right: Initial thermal response to mechanical indenter at 25mV loss in cell voltage with immediate runaway



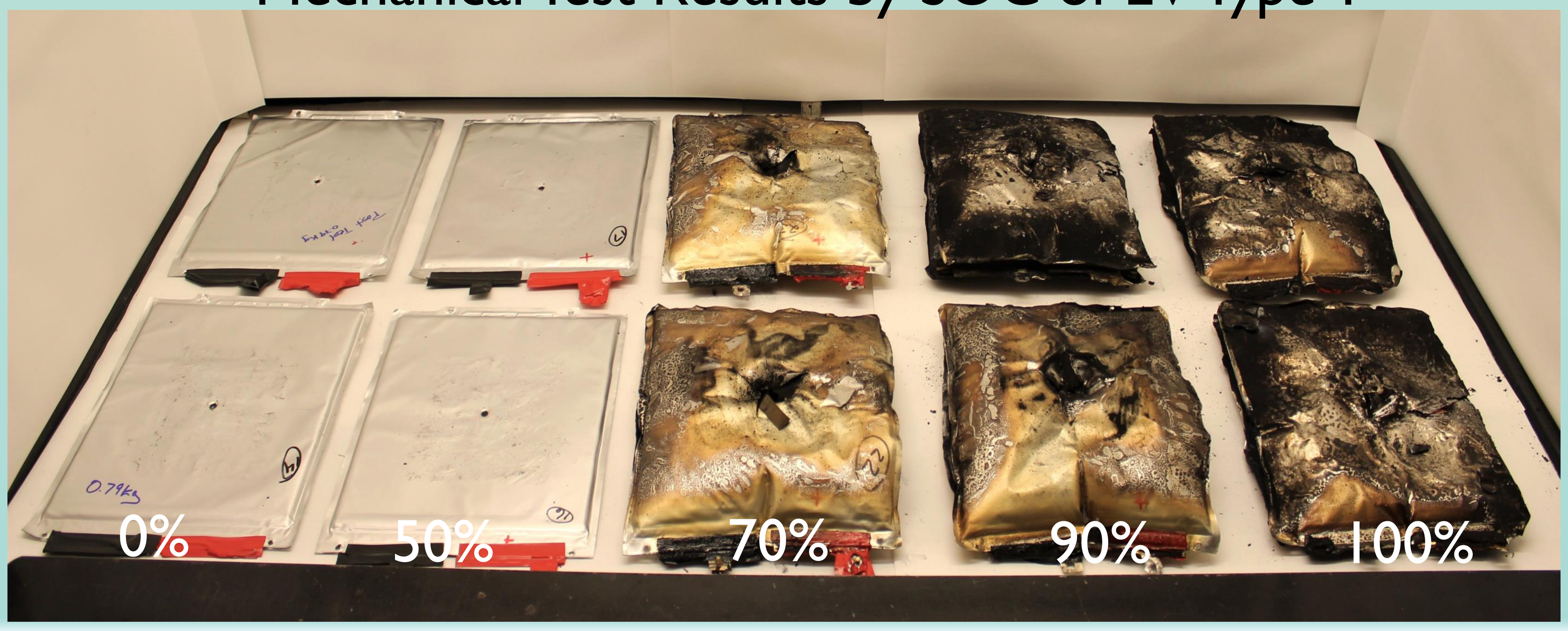
100% SOC



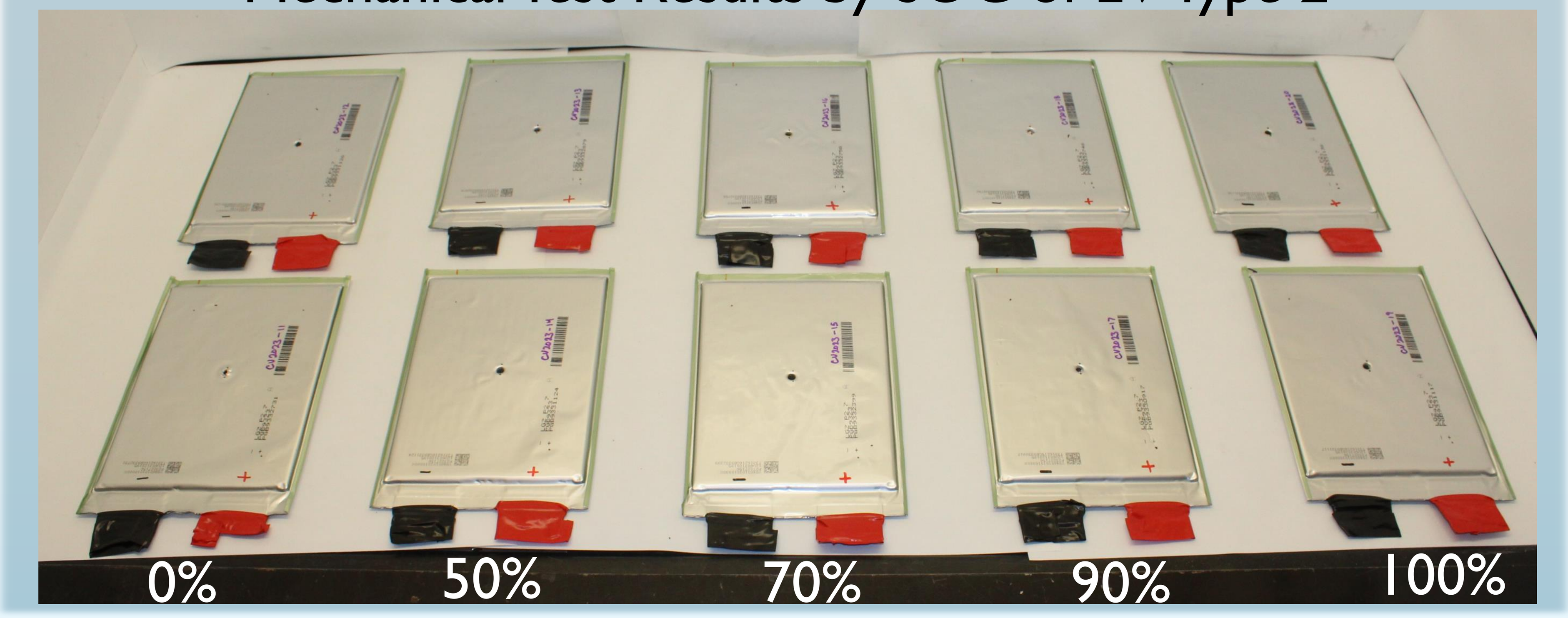
	EV 1 Cell 1	EV 1 Cell 2	EV 2 Cell 1	EV 2 Cell 2
Max Displacement	3.68 mm	3.55 mm	3.64 mm	4.06 mm
Max Force	2526 N	2370 N	2744 N	2652 N
Max Temperature	640 ˚C	513 ˚C	136 ˚C	174 ˚C
30min V drop	4.105V	4.105 V	0.123 V	0.141 V
Max Increase Rate*	13,805˚C/min	8,775 ˚C/min	252 ˚C/min	466 ˚C/min

*T5/T6 Avg

Mechanical Test Results by SOC of EV Type 1



Mechanical Test Results by SOC of EV Type 2



Future Work:

- Acquire large-format Li-ion single cells from stationary energy storage applications
- Perform indenter abuse tests on these large-format cells at same SOCs and submit data to ORNL for severity risk analysis

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