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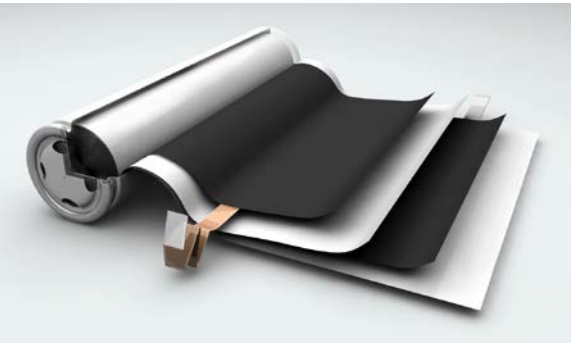

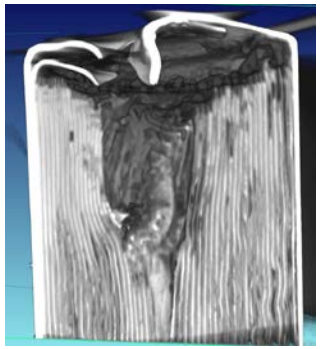

Battery Safety Testing

SAND2018-4903 C

Joshua Lamb*, Mohan Karulkar, Chris Grosso,, Loraine Torres-Castro, June Stanley

Sandia National Laboratories

BAT203

2018 Energy Storage Annual Merit Review

Washington, D. C. June 2017

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Overview

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TIMELINE

- **Start Date: Oct. 2017**
- **End Date: Oct. 2018**
- **Percent Complete: >75%**

BUDGET

- **FY18 Funding: $500k**
- **FY17 Funding: $1.3M**
- **FY16 Funding: $1.3M**
- **FY15 Funding: $1.3M**

PARTNERS

- **NREL, INL, ANL, ORNL**
- **USABC Contractors, USCAR, CAEBAT**

BARRIERS

- **Safety continues to be a barrier to widespread adoption**
- **Understanding abuse response for a variety of cell and battery chemistries and designs**
- **Understanding abuse response changes due to high rate charging**
- **Issues related to cell safety represent significant challenges to scaling up to li-ion for transportation applications**

Relevance and Objectives

Abuse tolerance evaluation of cells, batteries, and systems

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- **Provide independent abuse testing support for DOE and USABC**
- **Abuse testing of all deliverables in accordance with the USABC testing procedures**
- **Evaluate single point failure propagation and short circuit current in batteries**
- **Alternative approaches to induce battery failures**
- **Provide testing data to support failure propagation model (NREL)**
- **Provide testing support for ABR Post Test program (INL/ANL)**

Milestones

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Demonstrate improved abuse tolerant cells and report to DOE and the battery community

Completed USABC deliverables (Zenlabs)	Q1
Internal short circuit tool development	Q1
Final version of SNL abuse testing procedures published	Q1
Completed USASBC deliverables (NOHMS, Amprius, 24M):	Q2
Impact of high rate charging on abusive battery failure	Q2/Q3
Impact of cell energy on thermal runaway	Q2/Q3
Completion of USABC Deliverables (Amprius, Farasis, XALT, Zenlabs)	Q3/Q4
Dynamic drop tower commssioning	Q3/Q4

Approach and Capabilities

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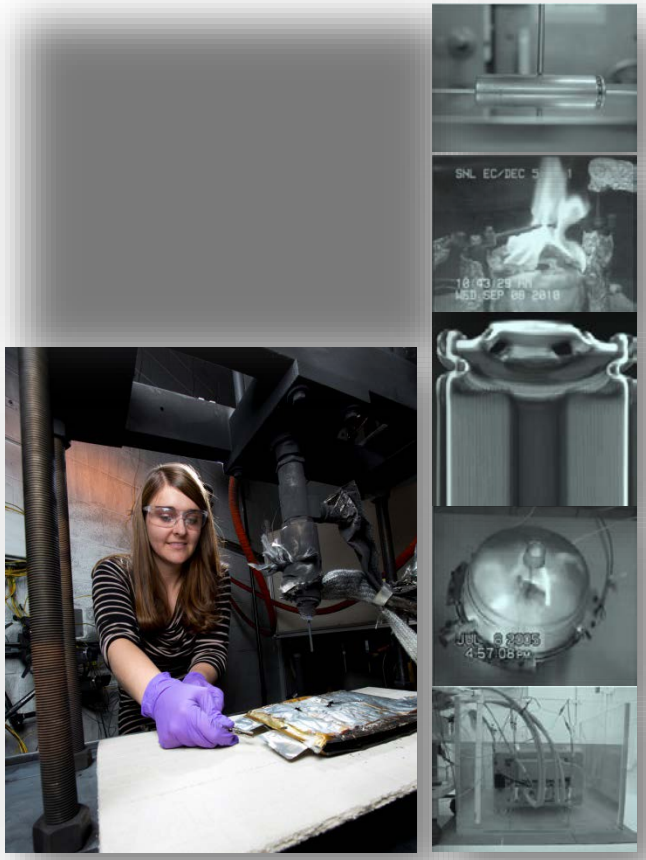
Cell and Module Testing
Battery Abuse Testing Laboratory (BATLab)



Battery Pack/System Testing
Thermal Test Complex (TTC) and Burnsite

Battery Calorimetry

Technical Accomplishments/Progress/Results

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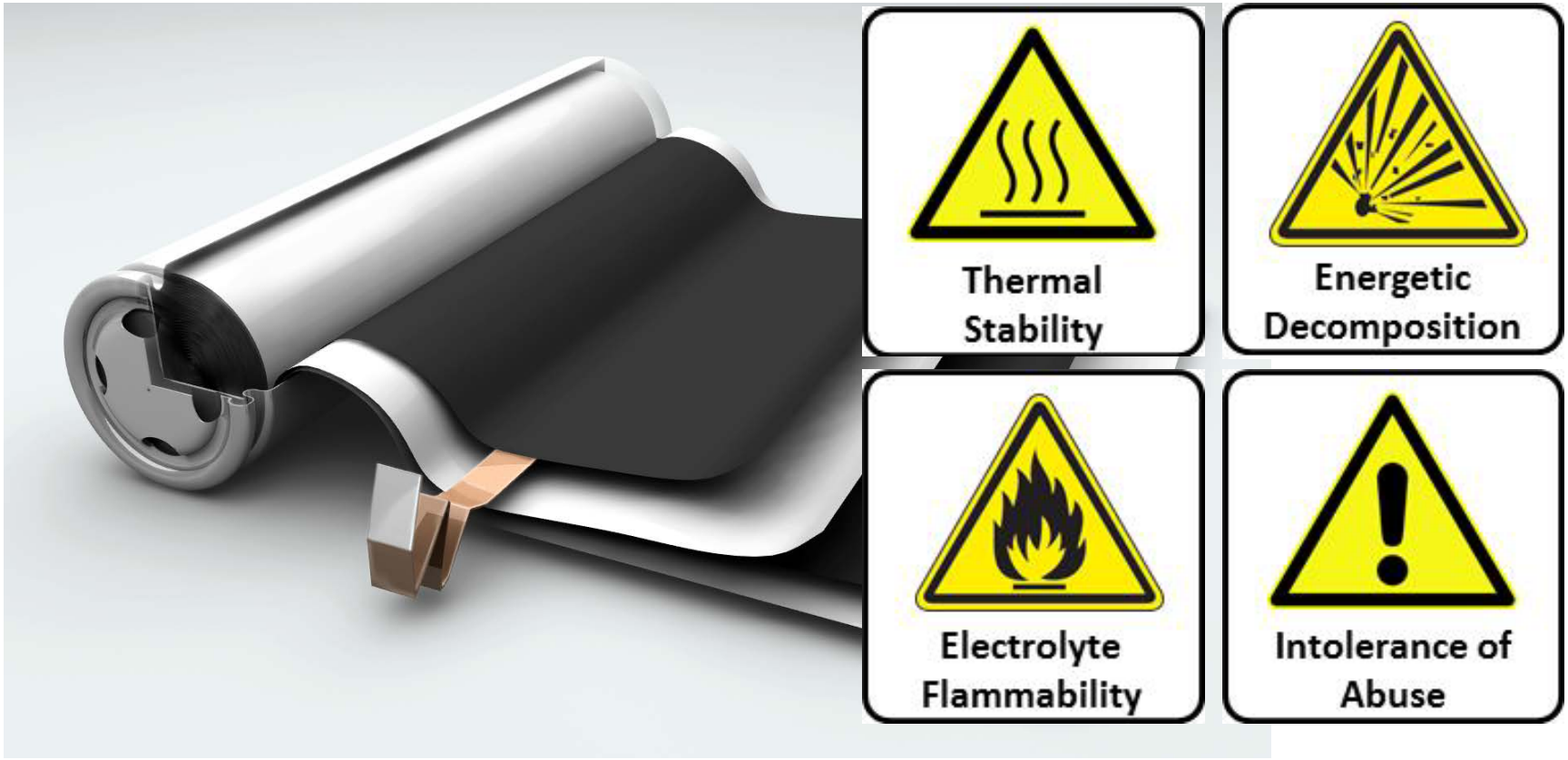
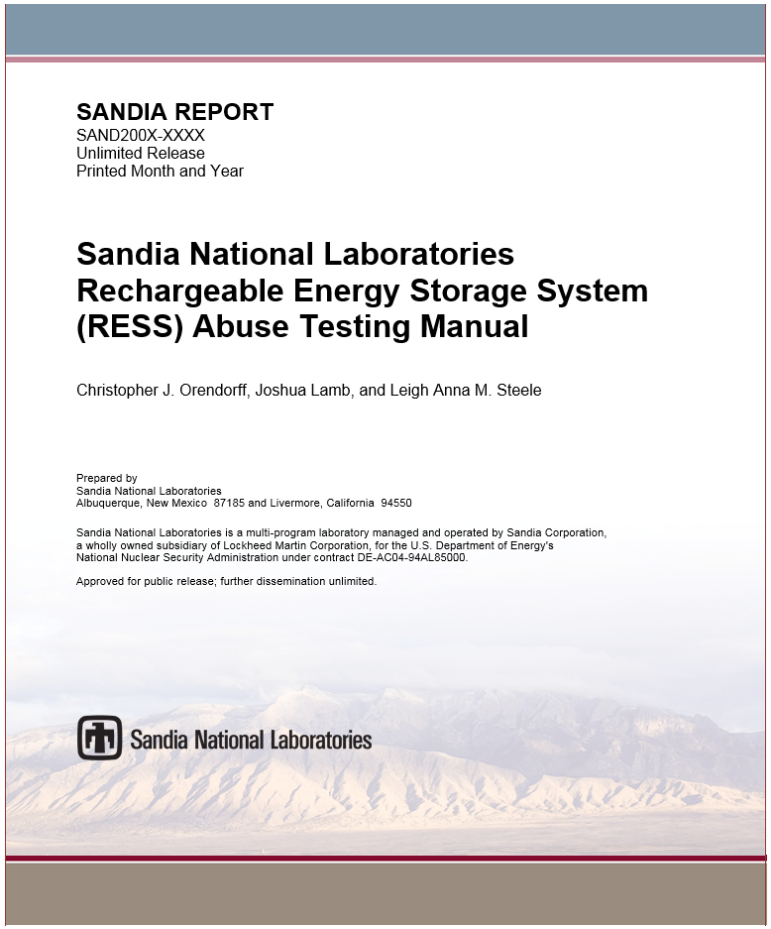
- Completed testing of all USABC deliverables to date and reported results to the USABC TAC
- Current abuse testing procedures published as a Sandia report SAND
- Developed method to use a laser to induce a short within cells
- Investigated propagation effects with alternative cell designs
- Testing support for CAEBAT activities
- Extended failure propagation modeling efforts with NREL using testing data
- Provided testing support for several cell chemistry types (NMC, LFP, and Si) to varied levels of overcharge in support of the ABR post test program (ORNL, SNL, and ANL)
- Evaluated impact of extended high rate charging on abuse response of pouch format cells
- Impact of cell scale and state of charge on Accelerating Rate Calorimetry results examined

Lithium-ion Safety Issues



Testing program aimed at understanding and improving abuse tolerance of energy storage systems

SNL Abuse Testing Procedures



SANDIA REPORT
SAND200X-XXXX
Unlimited Release
Printed Month and Year

Sandia National Laboratories Rechargeable Energy Storage System (RESS) Abuse Testing Manual

Christopher J. Orendorff, Joshua Lamb, and Leigh Anna M. Steele

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Approved for public release; further dissemination unlimited.

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Notable changes:

-Revision 2005 SNL Sandia Report (SAND2005-3123)

-Enhanced safety basis

-Updated to testing procedures according to current testing methods/capabilities

-Use of empirical data to support test conditions

-Failure propagation test

-Draft vetted within the broader community

-Final version published and available (SAND2017-6925)

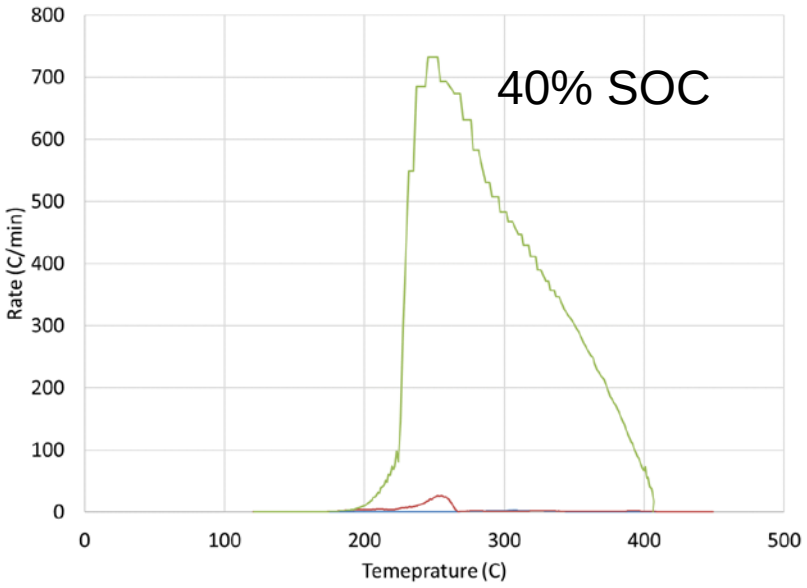
- ***Final version has been published and is available as report SAND2017-6925***

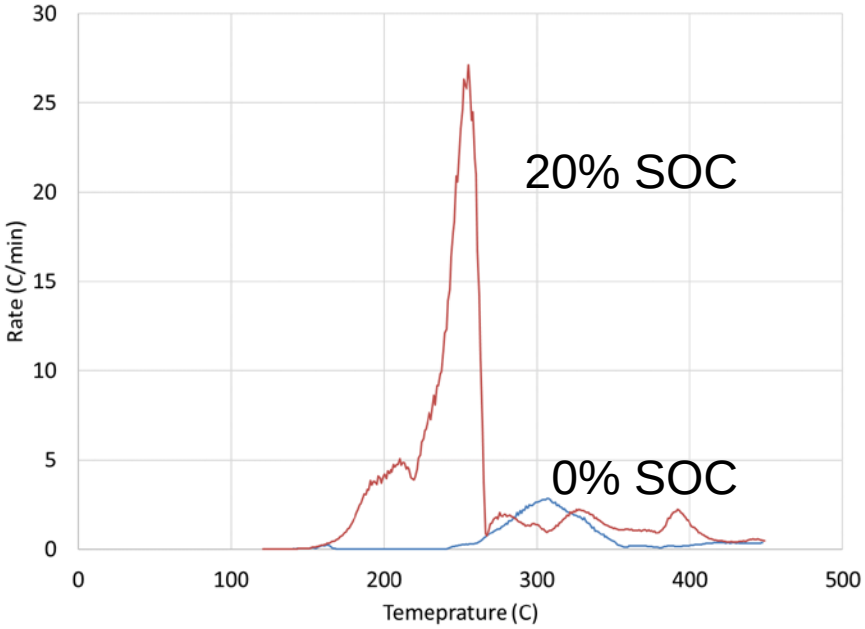
Abuse Testing

Representative thermal abuse test of multi-cell COTS lithium-ion pouches (non-USABC)- 1kWh

- ***Testing performed according to USABC Abuse Test Manual (heat 5°C/min to 250°C or failure)***
- ***Usage of Burnsite for larger scale testing at SNL***
- ***Complete propagation through 12 cell pack with burn time of ~ 5 min and peak temps of 800°C***

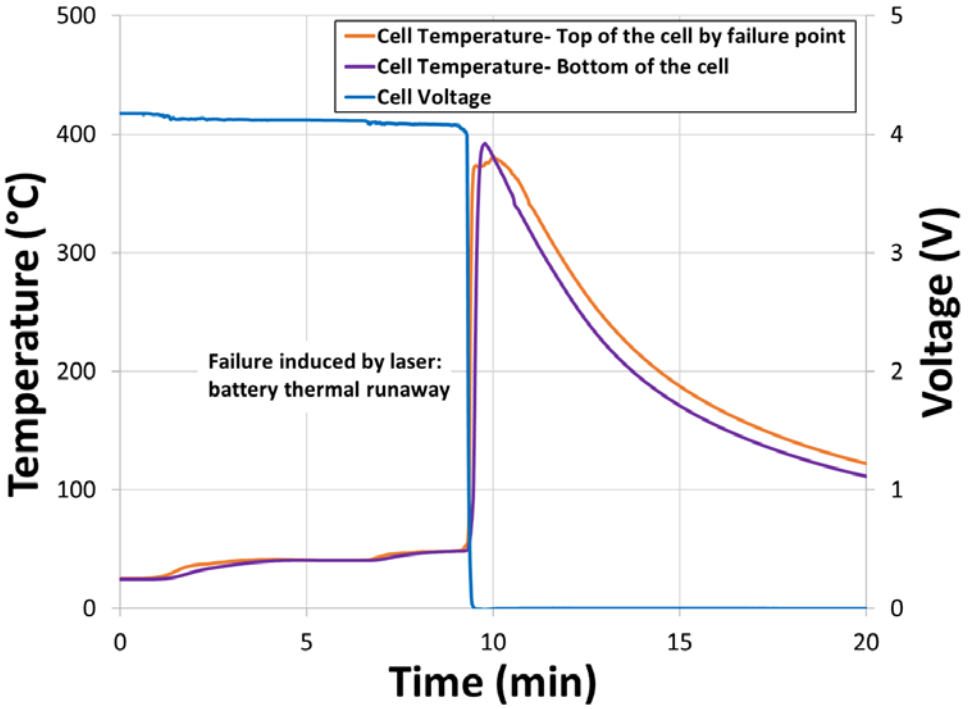
Impact of State of Charge on Thermal Failure

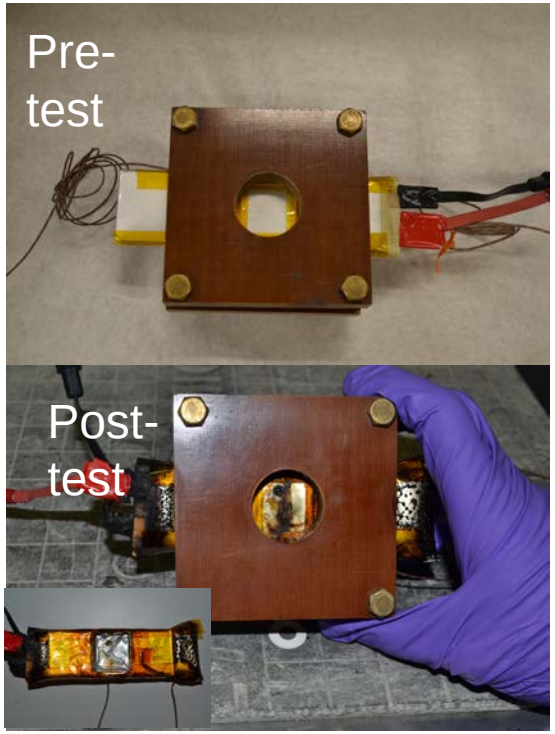




- Studied the impact of state of charge on the thermal runaway of commercial off the shelf NMC cells
- 0% Shows energetics of electrolyte breakdown at elevated temepratures
- 20% SOC shows some higher rate decomposition
- By 40% SOC high rate thermal runaway becomes observable
- Higher SOC testing ongoing

Laser Initiated Battery Failure Refinement





- Able to induce failure using laser through silica slide
- Final power setting of 350V, 20ms, 1Hz to induce thermal runaway
- More energy needed to induce runaway through silica slide
- Maintained seal between silica and pouch cell until full runaway

High Rate Cycling and Abuse Response

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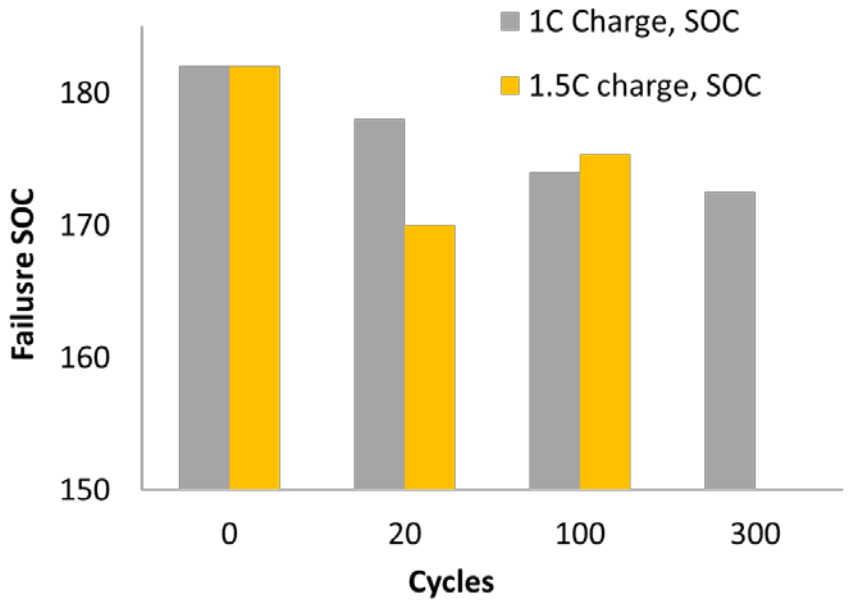
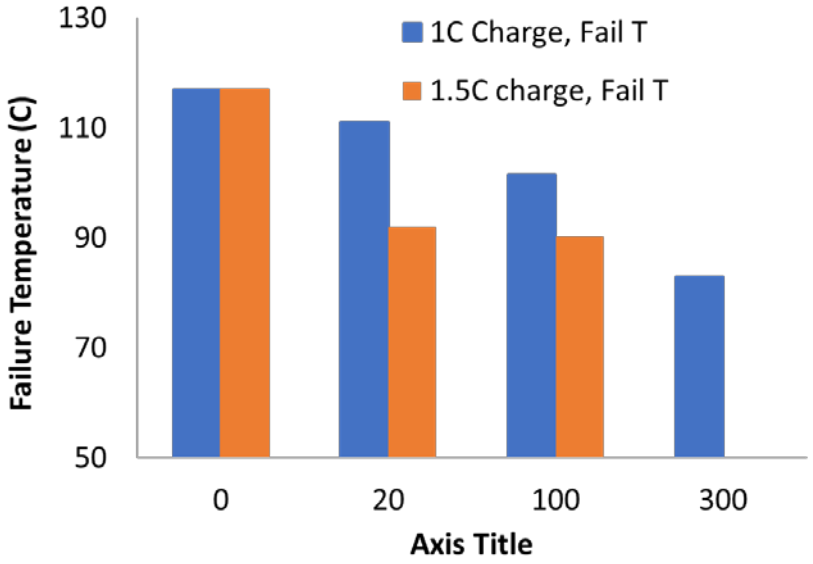
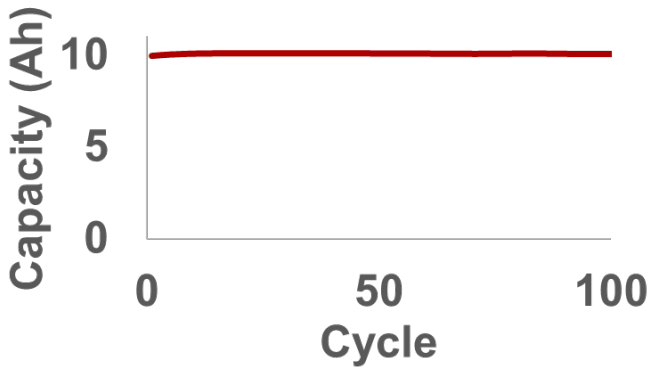
Overcharge Failure SOC



Overcharge Failure Temperature





Cycling did not affect capacity – only abuse response.

High rate Cycling and Abuse Response

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- COTS 10Ah cells were cycled at 1C discharge and either 1C (max spec) or 1.5C (over-spec) charge, for up to 300 cycles.
- Both cases decreased failure SOC and failure temperature in overcharge tests; effect increased with cycles.
    - SOC change was relatively small, but temperature drop was 30% after 300 cycles, with higher drops at 1.5C charge.
- Meanwhile, 300 cycles with either charge rate did not affect cell capacity. Only *abuse response* was affected.

COTS cells are designed for low cost, with commodity materials and techniques. Automotive cells optimize volume and weight, with thinner inerts, more compressed electrodes, and tighter windings. Thus, ***effects seen in COTS cells could be worse in automotive fast charge cells.***

➔ **Results indicate a need to evaluate effect of fast charge on abuse response of automotive cells.**

CAEBAT Support

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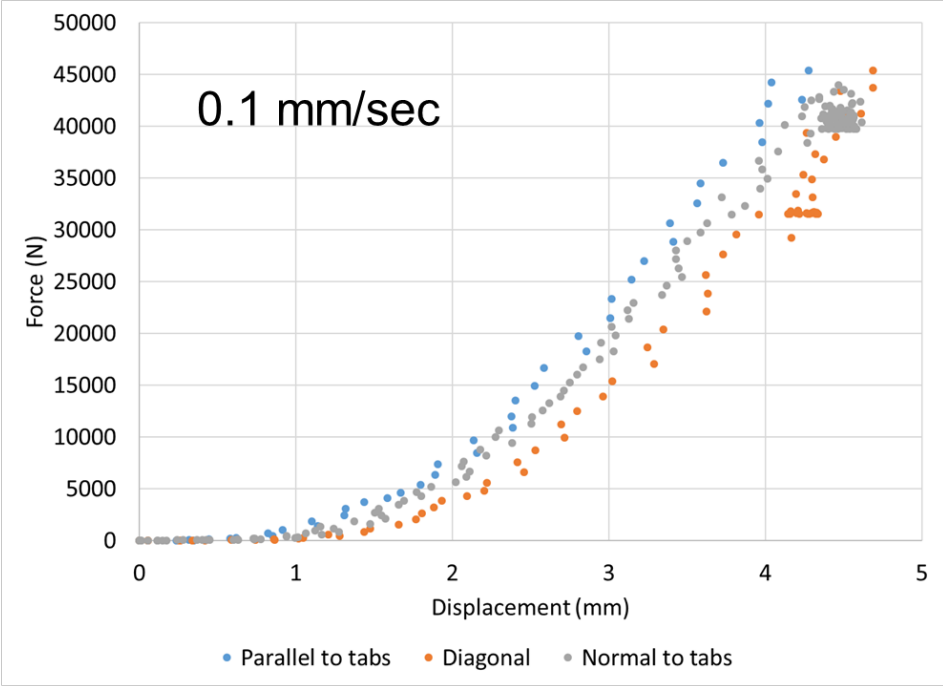
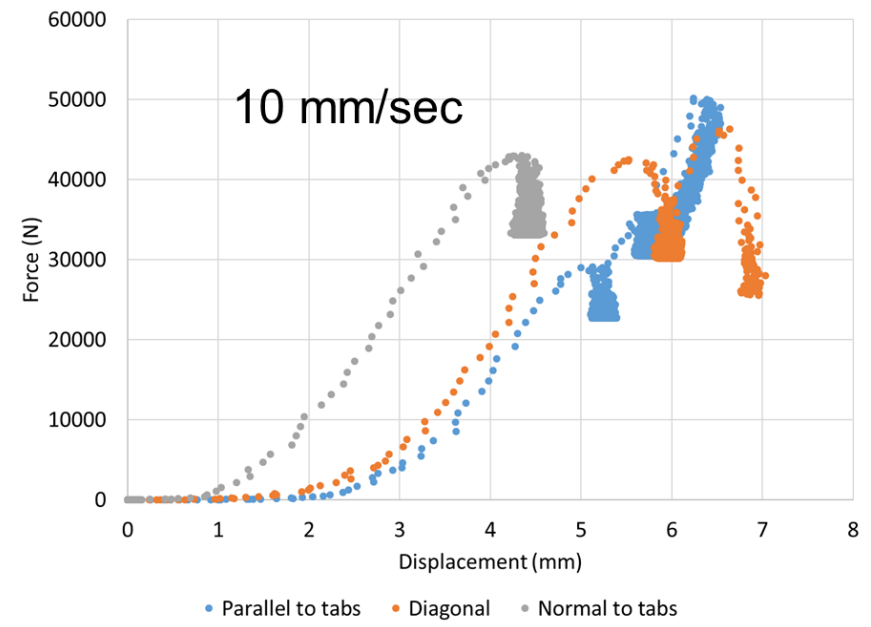
Crush testing and dynamic drop tower /impact tester development

Comparison of orientations





- Variation observed at higher rates – lower rates show little meaningful difference
- At higher rates some differences in both low rate data, some evidence of fracturing was observed in two of the three cases

Collaboration and Coordination with Other Institutions

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- **Propagation and mechanical modeling through CAEBAT:NREL**
- **Post test analysis supporting ABR: ORNL and ANL**
- **USABC: INL, NREL, ANL, ORNL**
- **USABC Technical Advisory Committee (TAC)**
- **USABC Contractors**
- **USCAR Crash Safety Working Group (CSWG)**

Proposed Future Work

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- Abuse testing cells and batteries for upcoming USABC deliverables and new contracts
- Exploration on the impact of high rate charging on abusive battery failure
  - Will extreme charging rates introduce new failure modes?
- Development of test methods to fully evaluate new high capacity chemistries
  - Special emphasis on development of ARC and test fixtures for containing high energy anode materials
- Working with NREL refining a predictive failure propagation model
- Leverage system scale battery modeling effort at SNL to increase data for VTO portfolio
- Dynamic mechanical testing (implement new drop tester) and model validation to demonstrate battery crashworthiness (USCAR, NREL, CAEBAT)
- Support testing for post test analysis of cells to determine degradation

Summary

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- Fielding the most inherently safe chemistries and designs can help address the challenges in scaling up lithium-ion
- Materials choices can be made to improve the inherent safety of lithium-ion cells
- Completed abuse testing support for all USABC deliverables to date and on track to complete all work by the end of FY17
- Developed a method to induce a battery short using a laser: TA filed on methodology/results
- Examining impact of total cell energy on thermal runaway behavior
- High rate charge cycling was shown to impact the onset SOC during overcharge testing. This presents a new potential hazard if this could lower the tolerance of overcharge to more moderate SOCs.
- Results for the mechanical testing of batteries will be used as input parameters for a crash worthiness model developed by NREL/MIT supported by CAEBAT. SNL will also provide validation test support
- Testing support for post mortem materials analysis of 3 cell types completed in collaboration with ORNL/ANL

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