Mitigation of Thermal Runaway Propagation in Lithium-ion Cell Shipping Packages

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Agenda

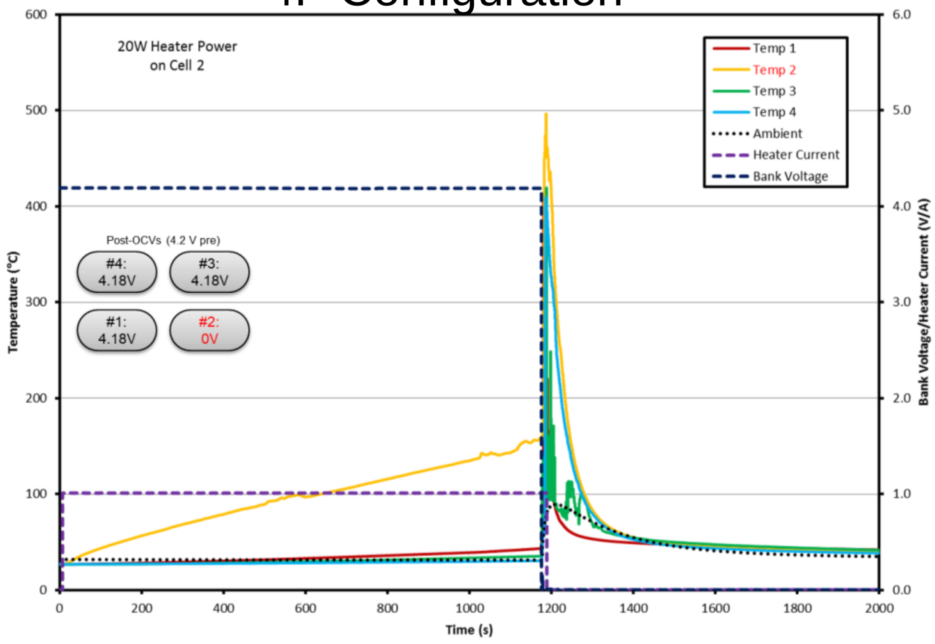
I. Introduction
II. Test Plan and Test Article Configuration
III. Test Results
IV. Summary and Future Work

Introduction

- Thermal runaway in lithium-ion cells and batteries has been an area of significant concern in the past few decades.
  - Recalls of commercial lithium-ion cells and batteries has been common with this battery chemistry with some of them being recalled even two years after their entry into the commercial market.
- Another area of great concern has been in the transportation of these cells and batteries by various modes which include ground, air and sea.
- Catastrophic events during transportation had led to restrictions being placed on the state of charge (SOC) of the lithium-ion cells and batteries during transport.
- Other in-field events such as the Boeing 787 incident, the grid energy storage system battery fires, automotive battery fires and fires during ground testing have also led to institution of regulations that require that single cell thermal runaway does not propagate to the other cells in the battery or that the fire be contained within the battery.
- Given the numerous cell and battery models, the various combinations of electrodes, separator and electrolytes, as well as the innumerable applications that these provide power for, it is not an easy task to have a modular battery where everything is so safe that there will not be a thermal runaway propagation event, no matter how they are arranged in a final battery configuration.
- Our team has been involved in studying thermal runaway and its propagation in a variety of cell and battery designs and at various SOCs.
- The goal of this work is to study the efficacy of various materials that would prevent thermal runaway propagation or contain it within the shipping container.

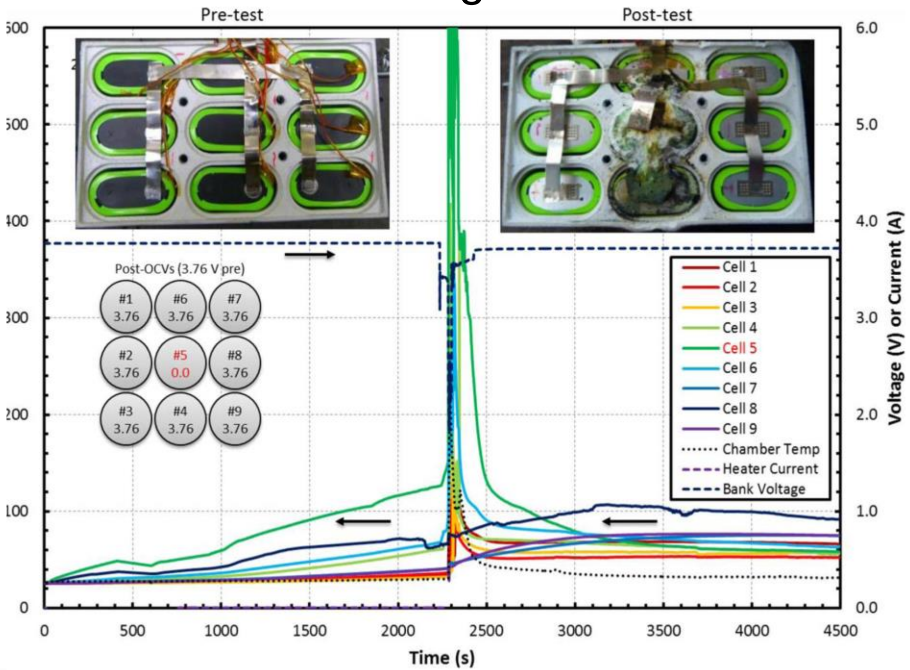
Past Work

4P Configuration



Radiant barrier

9P Configuration



Intumescent Mold

Propagation was not observed

Lopez, Jeevarajan, Mukherjee, JECS, A1905-1915, 2015

Work Plan and Test Variables

The test articles are 18650 Li-ion cells

Configuration: 25P (25 cells in parallel)

SOC: 100% (all cells)

Trigger cell location: center

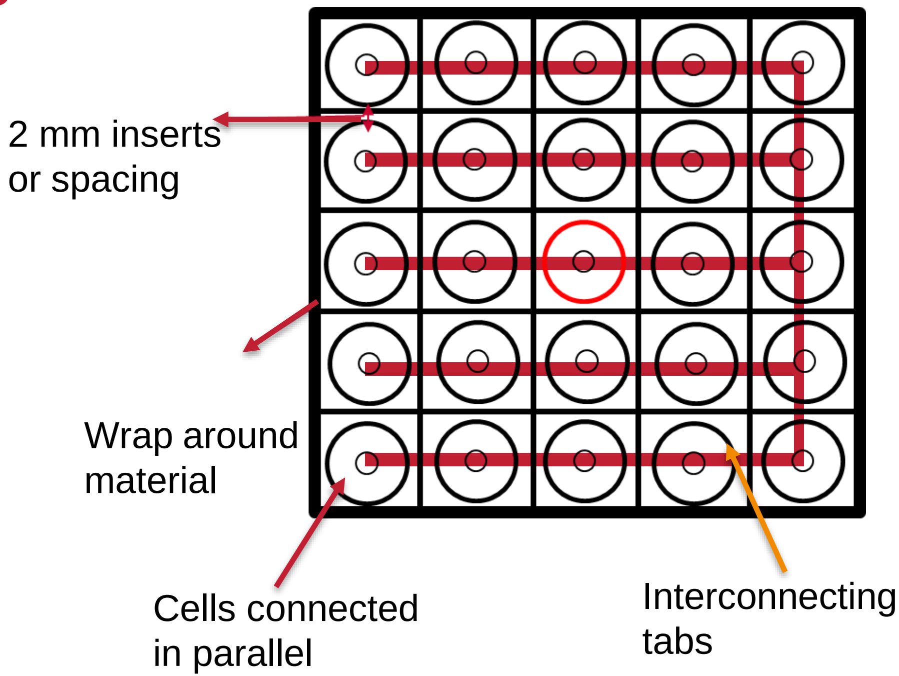
Materials to study Propagation Mitigation: Four manufacturers (A, B, C, D)

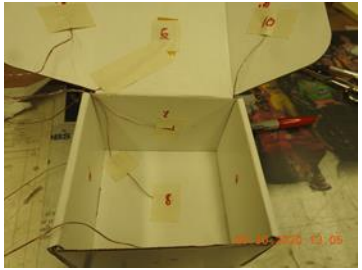
Container Manufacturer : E

Target heating rate for trigger cell: 10 °C/min

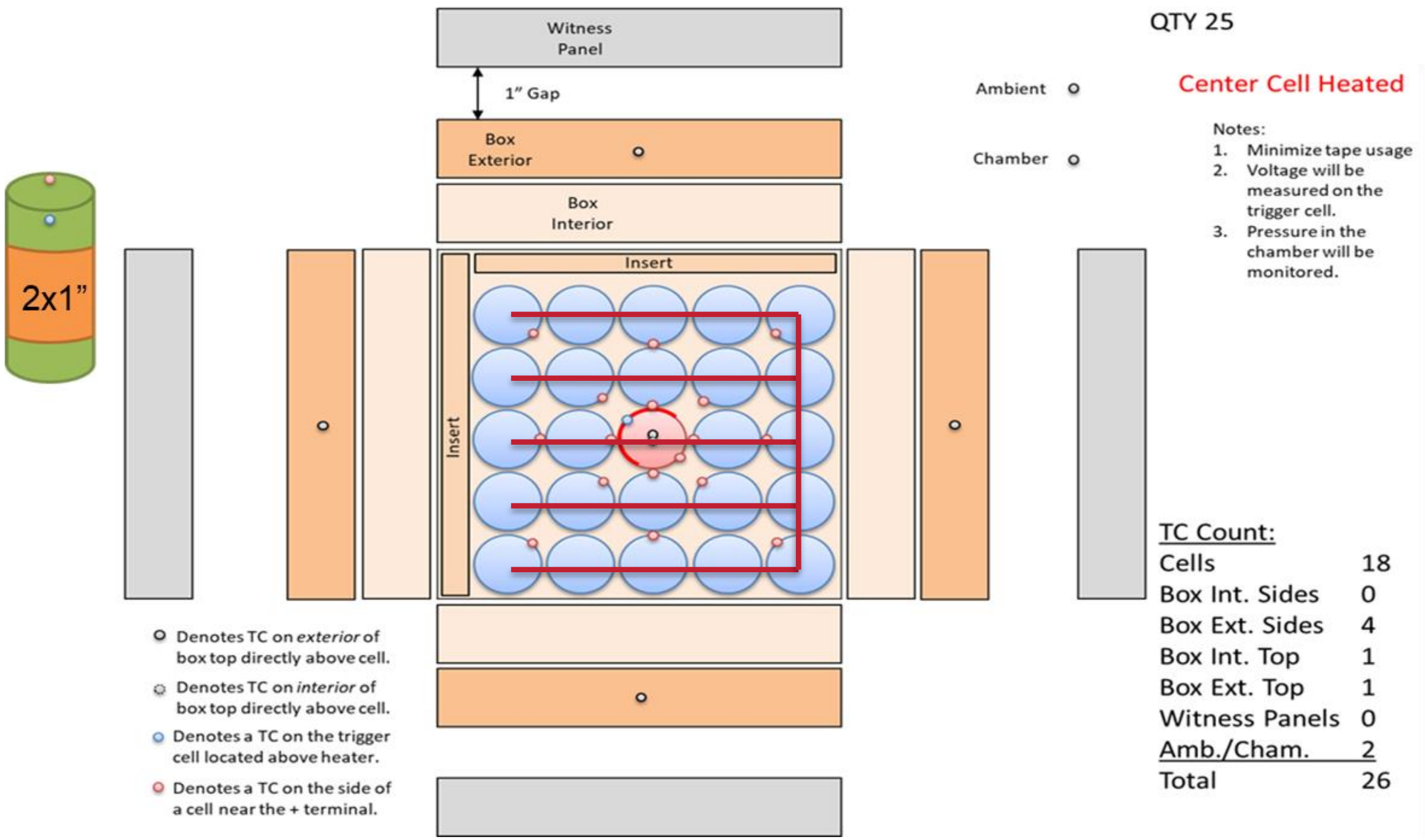
Corrugated generic packaging box and in one case UN-rated box

Test Article Configuration



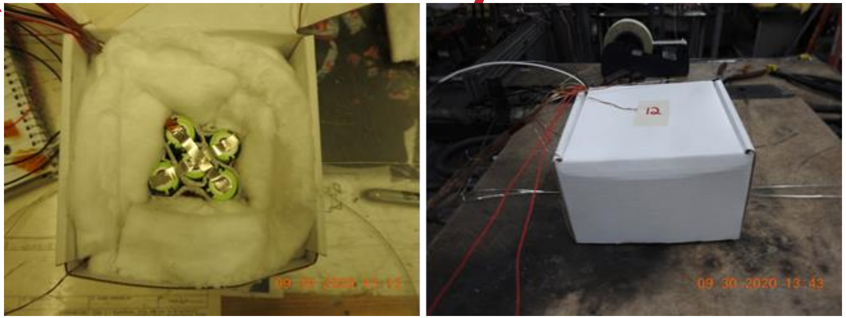


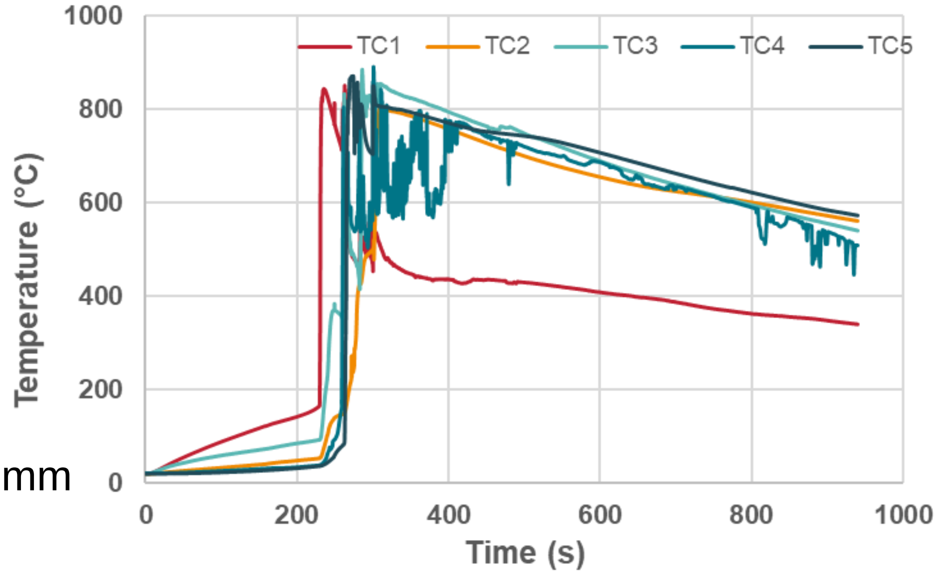
Test Article Configuration Showing Typical Thermocouple locations



Drawing Courtesy: Stress Engineering Services Inc.

Thermal Runaway Mitigation Test: 5P Cell Configuration (Manufacturer A)





5P Electrically connected

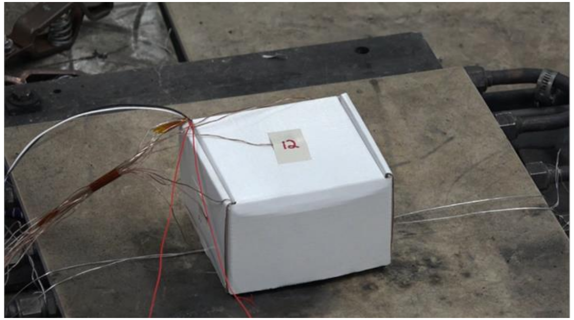
Cell-to-cell separator: Kaowool 333-E paper 2 mm thickness

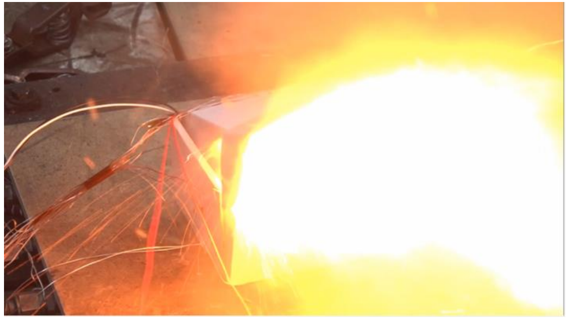
Wrap around 5P cell group: Cerablanket (1/2”)

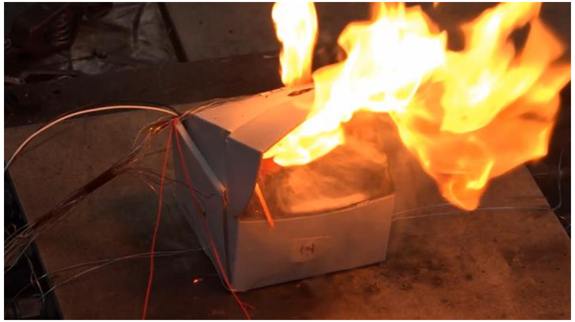
Full propagation of thermal runaway, fire

(Note: This material was chosen by our team; manufacturer does not claim that it will prevent thermal runaway propagation)

Thermal Runaway Mitigation Test - Manufacturer A
5P Cell Configuration





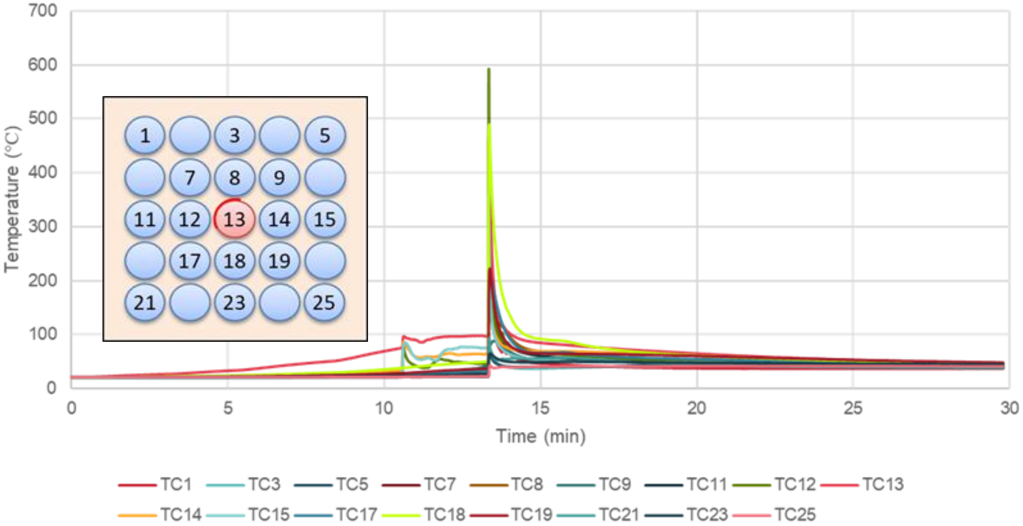


Fire and Thermal Runaway with full propagation

Cell-to-cell separator: Kaowool 333-E paper 2 mm thickness
Wrap around 5P cell group: Cerablanket (1/2”)

Thermal Runaway Mitigation Test - Manufacturer B

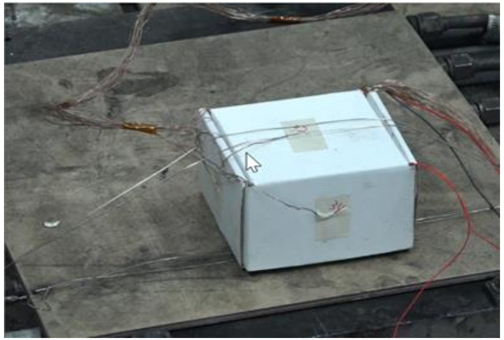
25P Cell Configuration

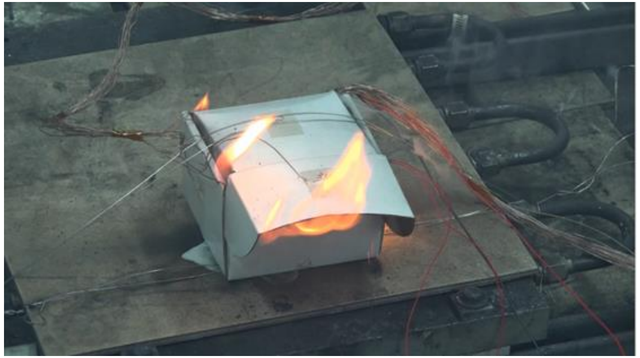


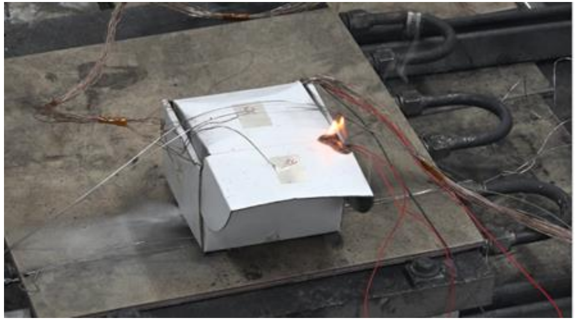
No propagation of thermal runaway
Post-test V: Trigger cell = 0V;
Cell 14 = 3.45 V; All cells = 4.15 V

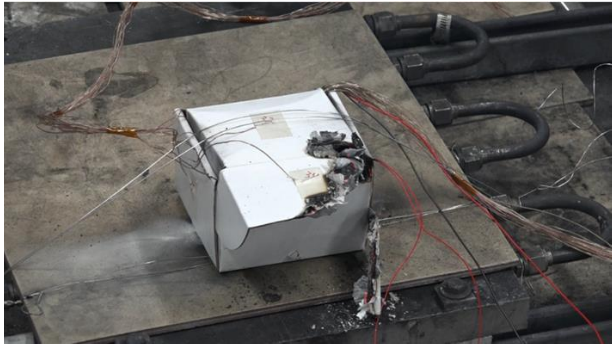
Block/Mold with 2mm wall between cells
Ejecta-control pouch on top of cells

Thermal Runaway Mitigation Test - Manufacturer B
25P Cell Configuration





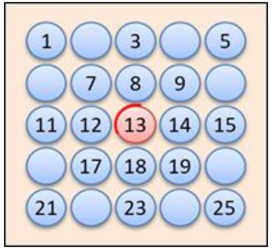


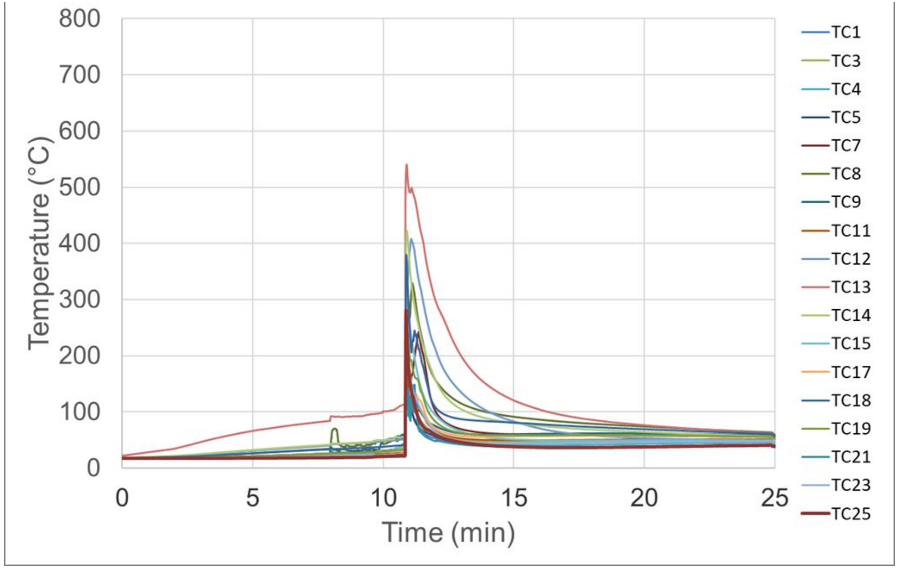


Initial burst of flame dies down and container burns a little and the fire dies down completely; No thermal runaway propagation to neighboring cells

Block/Mold with 2mm wall between cells
Ejecta-control pouch on top of cells

Thermal Runaway Mitigation Test - Manufacturer B
25P Cell Configuration



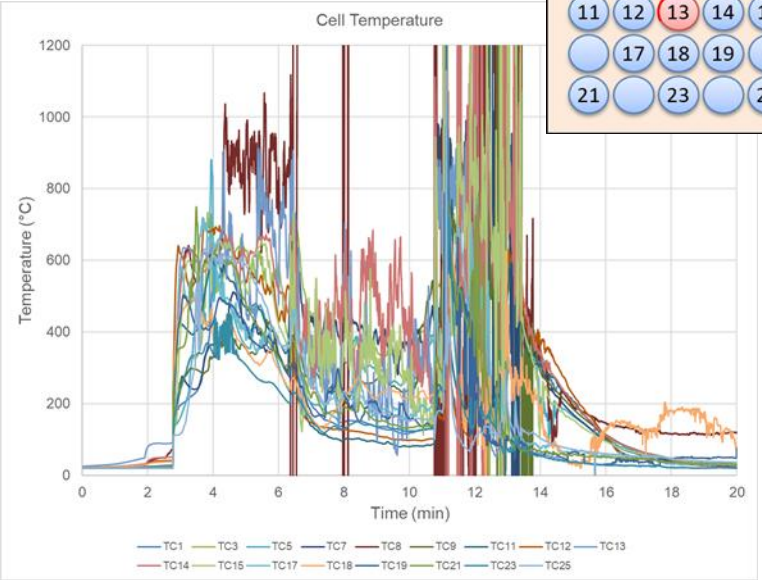


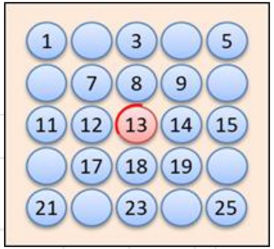
No propagation of thermal runaway

Post-test V: Trigger cell = 0V; All cells = 4.15 V

Block/Mold configuration; 2mm wall between cells; No ejecta-control pouch on top of cells

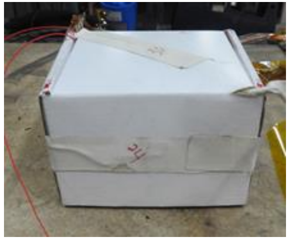
Thermal Runaway Mitigation Test - Manufacturer C
25P Cell Configuration

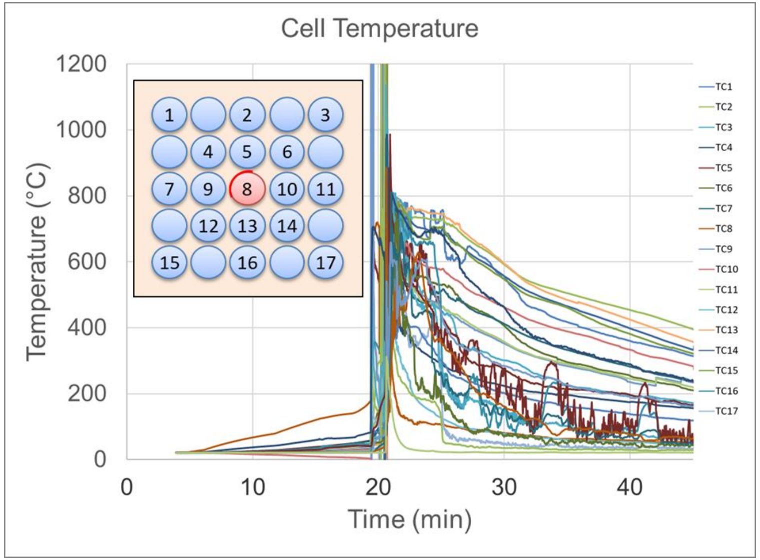




Flexible mica type tubes on each cell
Mica plates on sides and top of cells
Full propagation of thermal runaway, fire

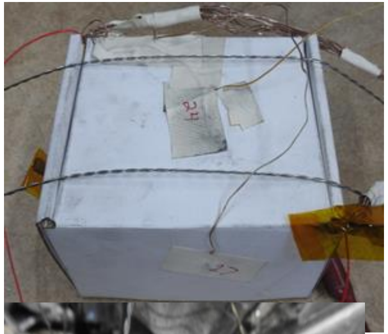
Thermal Runaway Mitigation Test - Manufacturer C
25P Cell Configuration

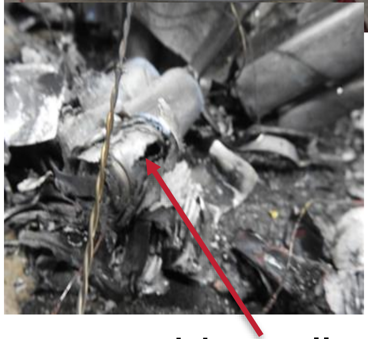




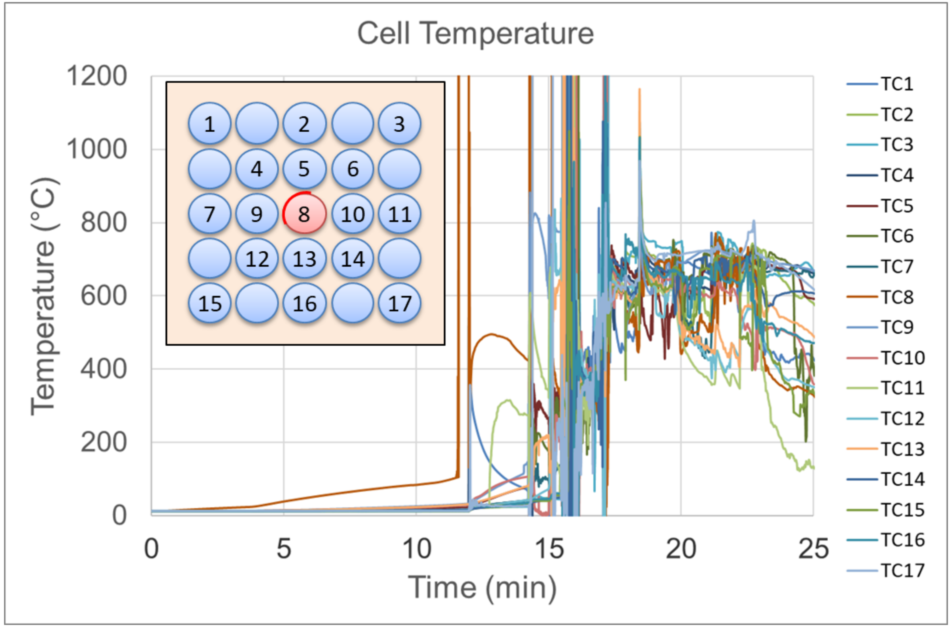
2mm cell separators between cells
Mica flame barrier on sides and top of cells
Full propagation of thermal runaway, fire

Thermal Runaway Mitigation Test - Manufacturer C
25P Cell Configuration





Side wall rupture in cell



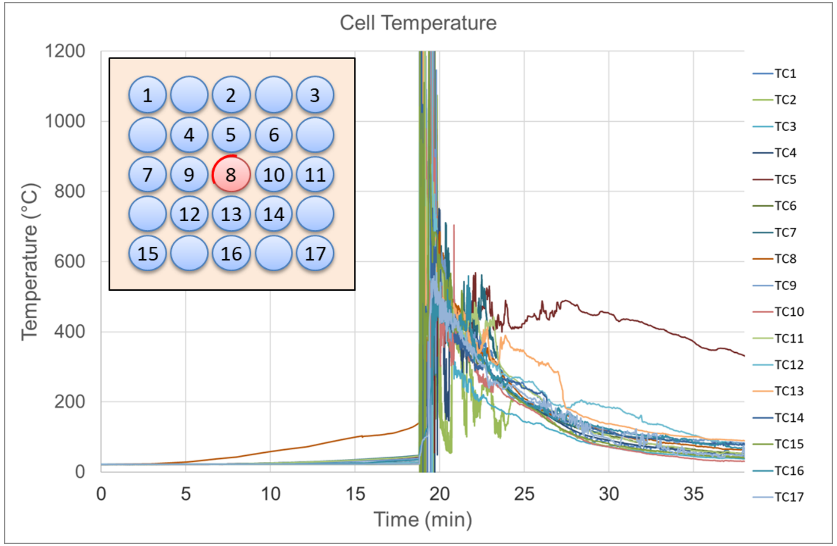
Mica tubes around each cell; 2mm separators between cells; Mica flame barrier on sides and top of cells

Full propagation of thermal runaway, fire

Thermal Runaway Mitigation Test - Manufacturer D
25P Cell Configuration







Intumescent material 2mm separators between cells; 2 mm intumescent material sheets on side and top

Full propagation of thermal runaway with fire

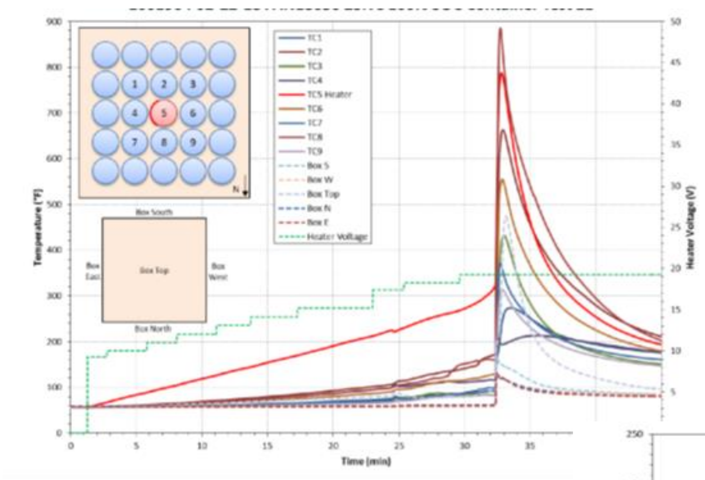
Thermal Runaway Mitigation Test - Manufacturer E - 25 Cell Configuration – not electrically connected

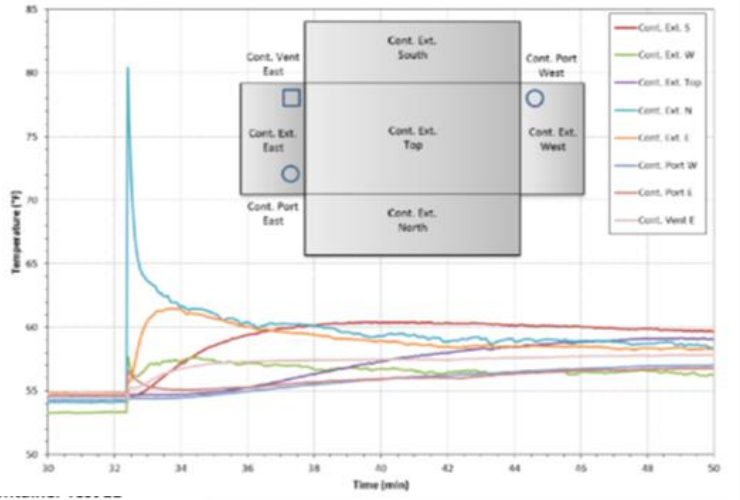
Pre-Test Configuration

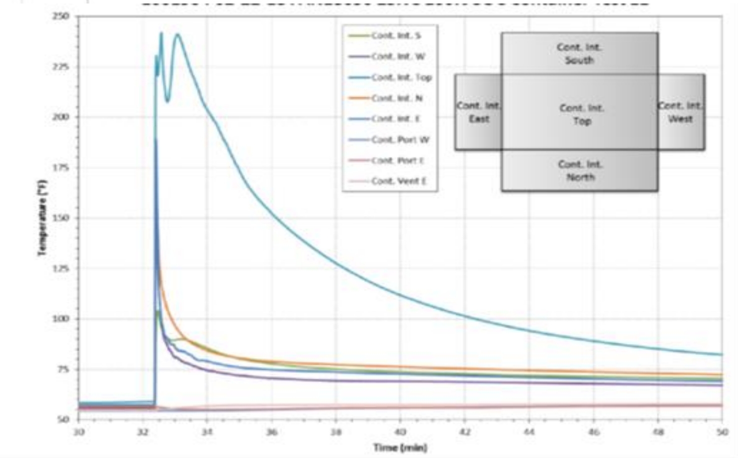
Tests carried out at
Stress Engineering Services, Inc.

Post-Test

Thermal Runaway Mitigation Test - Manufacturer E - 25 Cell Configuration – not electrically connected







		South					
		A	B	C	D	E	
East	1	4.153	4.152	4.157	4.158	4.153	West
	2	4.153	4.147	4.126	4.151	4.153	
	3	4.152	4.132	Eject.	4.146	4.153	
	4	4.153	4.151	4.142	4.152	4.153	
	5	4.152	4.153	4.153	4.152	4.158	
		North					

Tests carried out at Stress Engineering Services, Inc.

Properties of Materials Studied to-date

Materials	Thermal Conductivity (W/m.K)	Phase Transition Temperature
Manufacturer A (Kaowool)	0.06 (260 ºC) 0.12 (538 ºC)	-
Manufacturer B Block/Mold	0.65	122 ºC
Manufacturer B Pouch	0.74 (xy plane)	95-110 º C(Thermal Dissipation – 1600 -2000 J/g)
Manufacturer C Flexible Mica Tubes	0.04 (22 ºC); 0.15 (816 ºC)	-
Interlocking Cell Separators	0.13 (400 ºC)	-
Mica Plate	0.3	-
Flexible Flame Barrier	0.2 (200 ºC); 0.35 (400 ºC)	-
Manufacturer D Intumescent cell separators	0.54	Expansion Temp: 200 ºC
Intumescent flat sheets	0.54	Expansion Temp: 200 ºC

Summary and Future Work

- Materials from four different manufacturers have been studied to-date.
  - Some manufacturers provided more than one type of material and not all material combinations have been studied yet.
- Only materials from one manufacturer prevented propagation of the fire and thermal runaway.
  - Even with this, some small fires or sparks were observed the package and heavy smoke was observed in one case.
- The block/mold seems to provide better efficacy at mitigation the propagation compared to interlocking separator or sleeves.
- A comparison of the thermal conductivity of the materials shows that the materials from manufacturer B that did not display propagation seem to have the highest thermal conductivity.
- The use of materials that would smother a fire as with the materials and packaging design from Manufacturer E will also work well. The packaging design was too heavy at the time we tested these.
- The parallel connected module configuration is more prone to propagation compared to electrically disconnected single cell packages due to the transfer of heat due to the conduction between the tabs. We used regular shipping packages and not UN rated ones to simulate worst case conditions. Lastly, we tested the cells at 100% SOC which is not uncommon for battery designs when in field use but this is not a common SOC for shipments.
- Future work will involve testing the remaining combinations as well as working with other material manufacturers to find solutions.
- Future work will also involve testing cell configurations with single electrically disconnected cells to determine the effect of the conducting tabs.

Acknowledgment

Dereck Lenoir and test team at NASA-JSC for carrying out the tests

Material manufacturers for working with us to get the suitable materials and requested configurations

Underwriters Laboratories for funding this work

THANK YOU