Thermal Runaway Initiation of Large Prismatic Cells by Rapid External Heating - Challenges and Solutions

Steven Recoskie
Research Officer
Energy, Mining and Environment – Ottawa
613-853-6840

Co-authors :
NRC : Dean MacNeil, Joel Perron, Rui Zhao, Sébastien Touchette
Transport Canada : Kyle Hendershot

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Review (EVS19): Thermal challenges to rapid heating

Simplified 1D heat transfer
before physical expansion and
exothermic reactions occur

Example: CT scan showing swelling due to internal gas

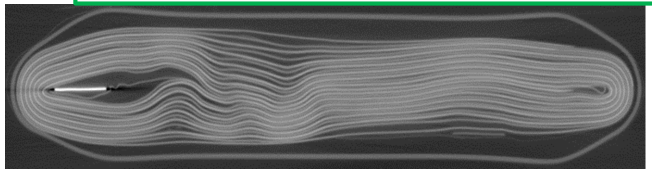


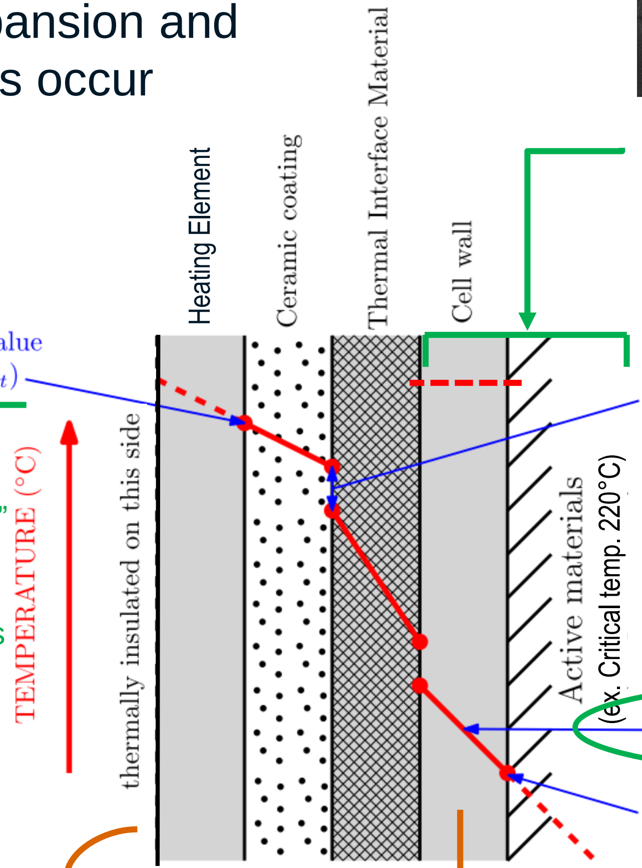
Image source: DfR Solutions

Other observed barriers to heat transfer during tests:
- Gaps between electrode windings and cell wall
- Extra separator layers
- Internal gas generation
- Element delamination due to physical expansion or improper installation

At steady state,
This temperature value
is constant ($T_{setpoint}$)

Maximum setpoint temperature is limited below cell wall failure temperature, to avoid "unnatural" side wall ruptures.

Minimum setpoint temperature is greater than thermal stability of active materials, and adjusted to account for all sources of heat transfer barriers/losses.



Contact resistance
f(Applied pressure, Surface roughness, ...)

During rapid heating, the cell's construction is the **rate limiting step to effective heat transfer** for a given element area and temperature setpoint

Thermal resistance
f(Materials conductivity and thickness)

This temperature value increases over time

Note: Thicknesses shown are not to scale

Heat losses away from target cell (ex. through insulation)

Heat losses due to thermal diffusion / capacitance (includes active thermal management)

Testing goals

1. Initiate TR in large prismatic cells consistently and reliably without element failures

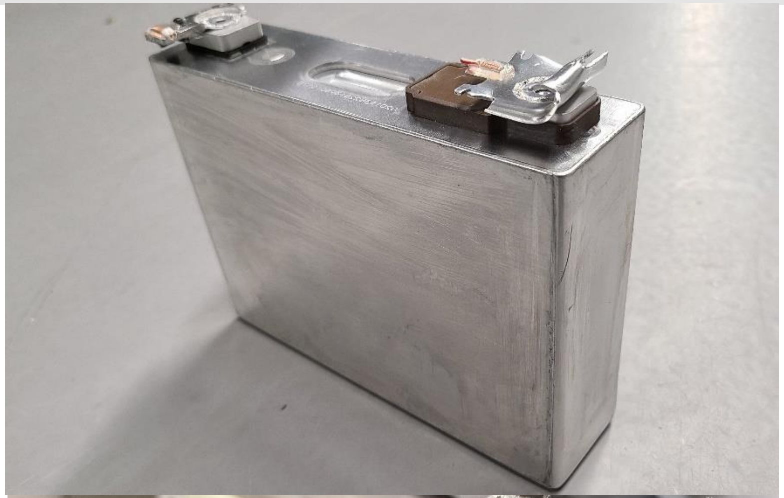
2. Initiate TR in large prismatic cells without inducing a sidewall rupture (SWR)

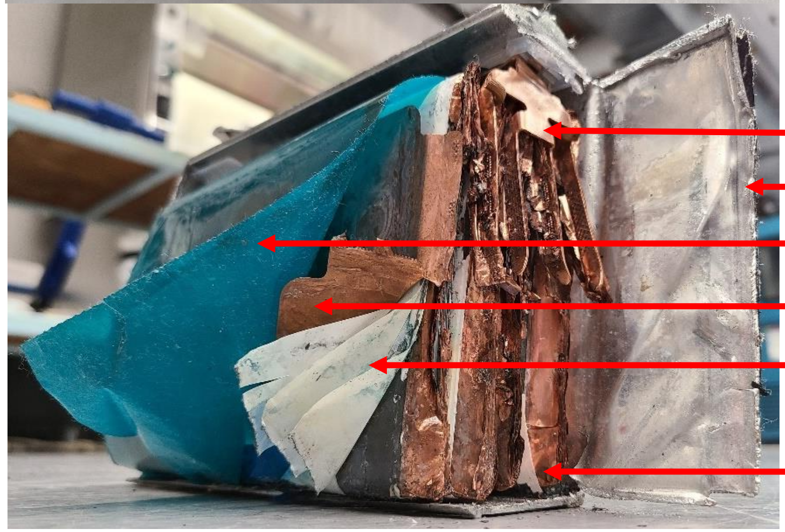
3. Qualify new heating elements

New heating elements

Version	Target Application	Image	Active heating area	Thickness of element	Thickness of connections	Retained features	Other features
V4	General use		16mm x 35mm (5.6 cm^2)	1.2mm	2.5mm	Ceramic coated Embedded temperature feedback	
V4B	Cylindrical cells		10mm x 42mm (4.2 cm^2)	0.7mm	0.7mm		Pre-curving of elements for cylindrical cells is not required
V5	Prismatic cells		39mm x 55mm (21.5 cm^2)	0.7mm	0.7mm	Low voltage DC operation	Designed to tolerate SWR, if it occurs Larger heating area supports diffusion losses

Cell description





60Ah – NMC-based lithium ion cell (2014)
Aluminum hard-cased prismatic cell

Internal structure determined by disassembly or internal scan to select suitable heating locations

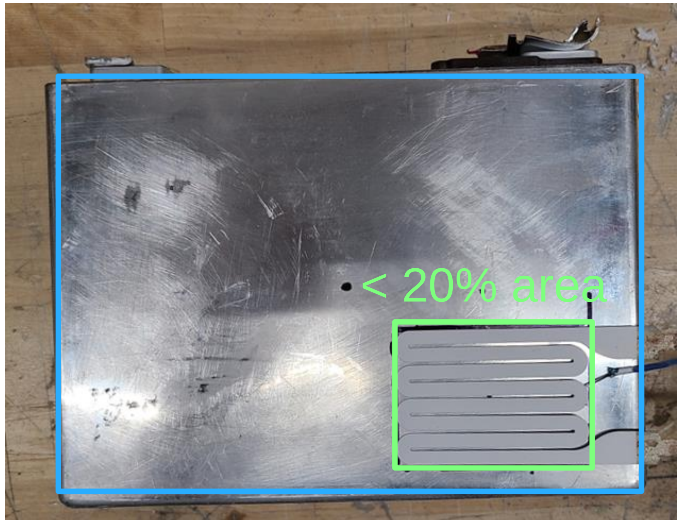
4 internal electrode rolls
Interior welded tabs (~16mm gap between rolls and side wall)
1.6mm thick outer wall
blue wrapper around electrode rolls
uncoated copper sheet
extra layers of separator

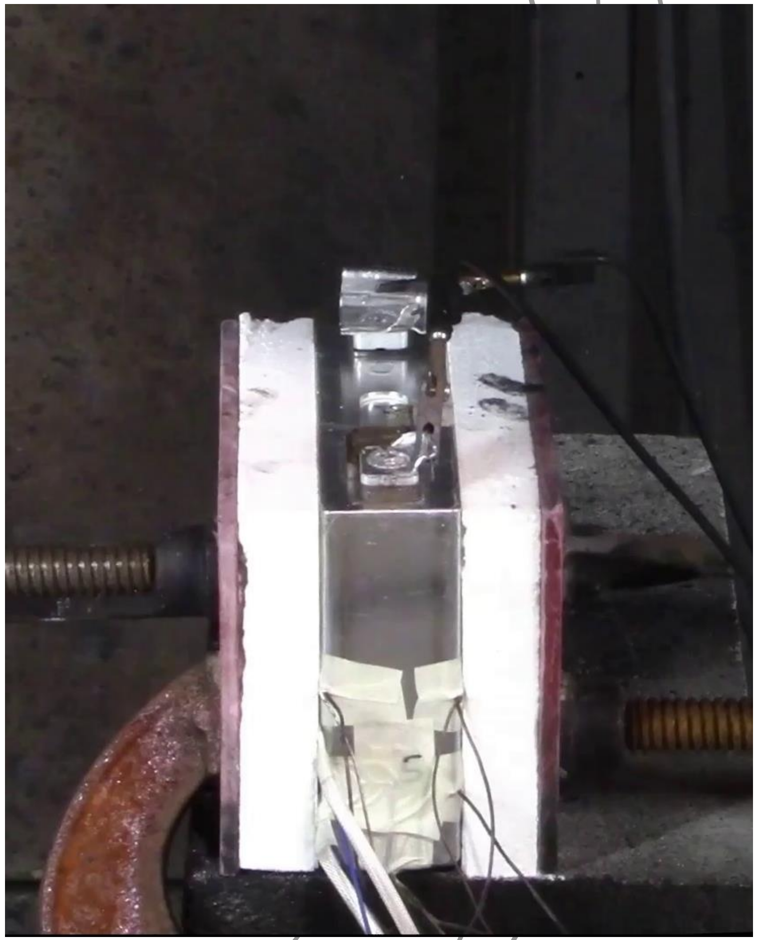
These are thermal barriers when heating largest face

Small contact area between rolls and bottom wall

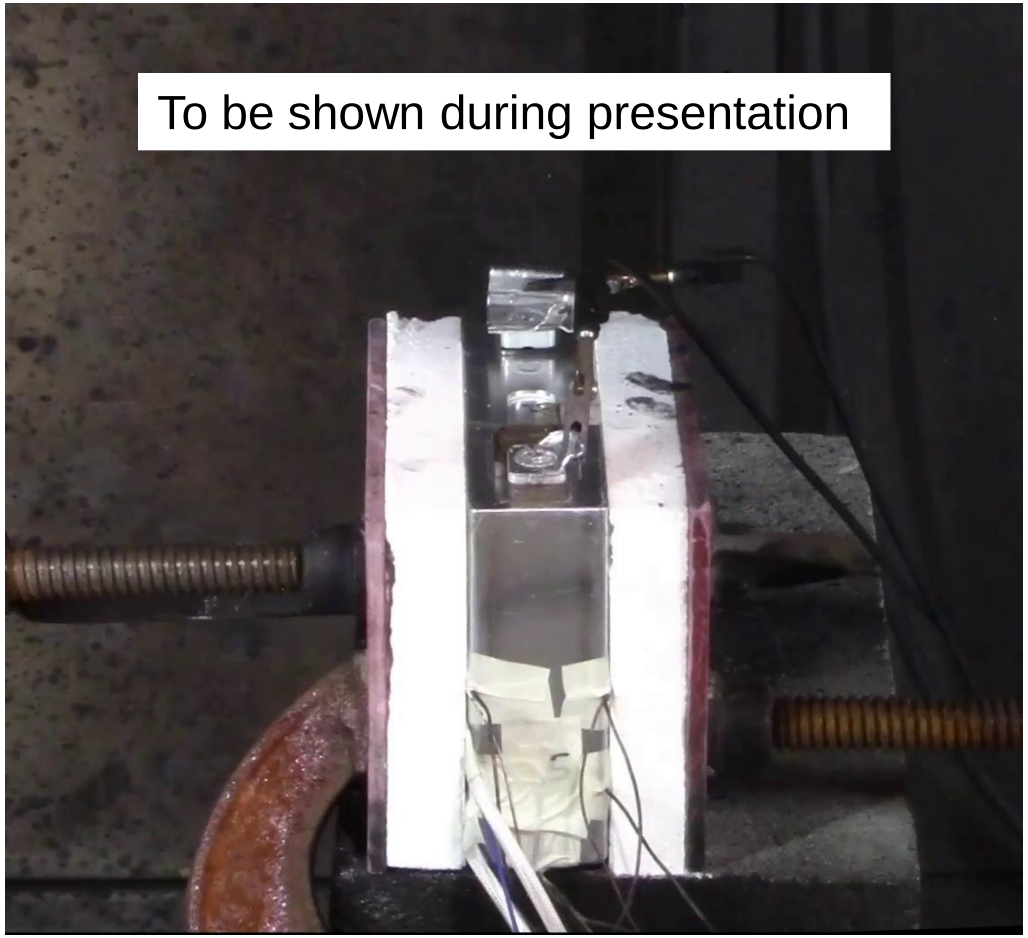
Test setup

- Cell surface cleaned of films and residue
- Cell charged to 4.2V
- Nickel-based heat transfer paste (2.6 W/mK) used as element thermal interface material
- Contact pressure estimated based on compressive strain of rigid ceramic insulation; maintained with clamps

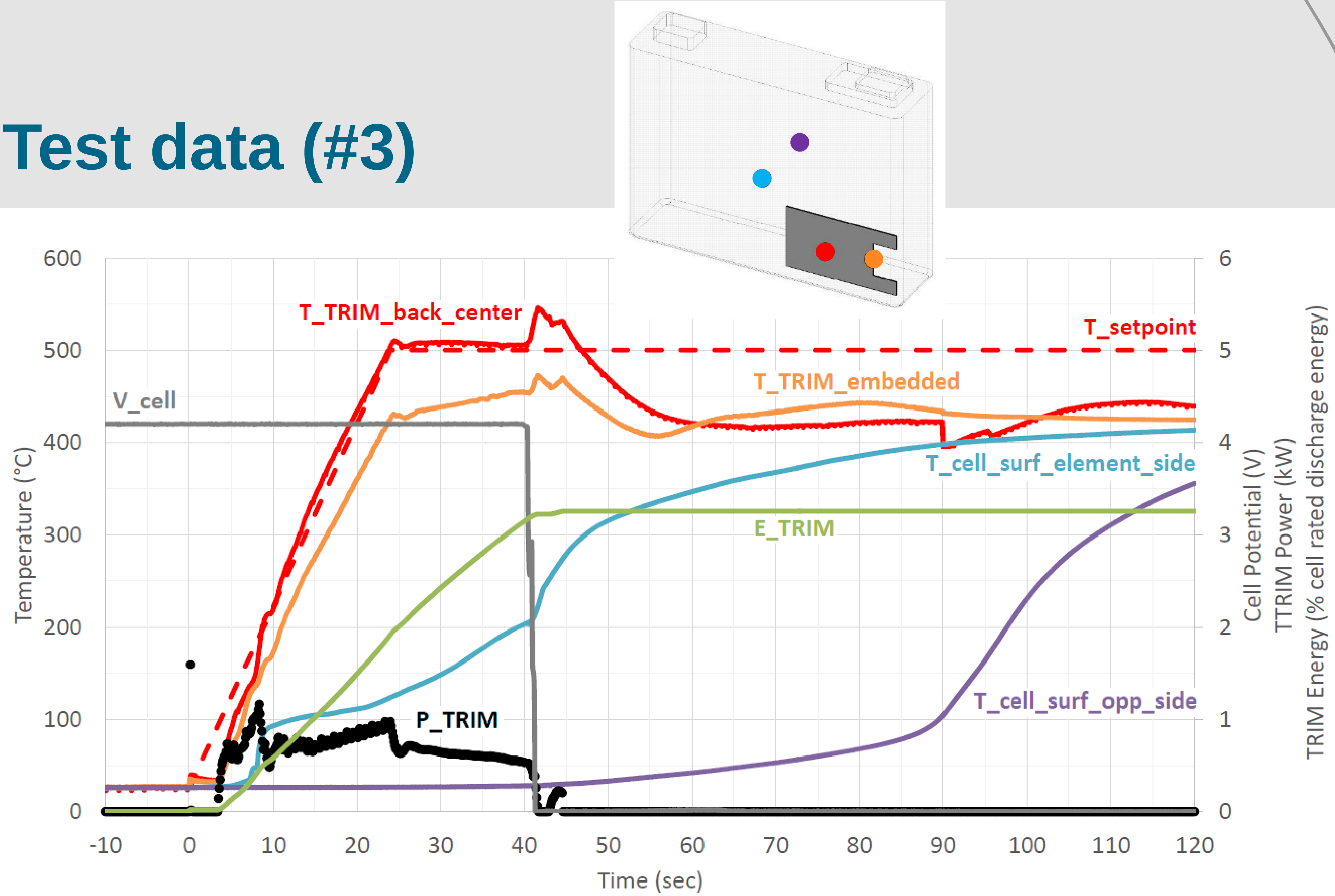




Test video (#3)



Test data (#3)



T_TRIM_back_center
T_setpoint
V_cell
T_TRIM_embedded
T_cell_surf_element_side
E_TRIM
P_TRIM
T_cell_surf_opp_side
Temperature (°C)
Cell Potential (V)
TTRIM Power (kW)
TRIM Energy (% cell rated discharge energy)
Time (sec)
600
500
400
300
200
100
0
6
5
4
3
2
1
0
-10
0
10
20
30
40
50
60
70
80
90
100
110
120

Post-test photo (#3)

Summary of test results

	Test Description			Outcomes			Key Metrics						
Test #	Target face on cell	Temperature Feedback Location	Ramp/soak at back center location	TR	SWR	Pressure relief vent opened	Time to TR (sec)	Average applied power (W)	Average applied heat flux[a] (W/cm^2)	Energy applied to TR (%)	Peak element temperature (°C)	Peak cell surface temperature (°C)	Mass Loss (%)
1	Largest face	Not used (constant power)	40°C/sec ramp, 900°C peak	YES	YES	NO	15	1464	68	4.2%	900	437	27%
2		Embedded near element edge	34°C/sec ramp, 800°C peak	YES	YES	NO	19	1057	49	3.4%	800	434	27%
3		Back center of element	20°C/sec ramp, 500°C soak	YES	NO	YES	42	654	30	3.3%	540	456	29%
4				YES	NO	YES	55	611	28	3.7%	540	467	30%
5				YES	NO	YES	75	556	26	5.3%	515	446	29%
6[b]				YES	NO	YES	650	216	10	17%	530	543	32%

Notes:

a. Calculation assumes negligible heat losses. For reference, conventional film heaters are typically rated for 1.5 W/cm^2

b. Poor element contact pressure caused by reused ceramic insulation sheets; estimated to be less than 3kPa. All other tests equal or greater than 30kPa

Key findings (1 of 2)

- **TR initiation was achieved in all tests**
- **Decomposition reactions* were similar for wide range of settings / install qualities**
  (*as assessed based on comparable peak cell surface temperatures and cell mass losses)
- **However, we know *how* energy is released may influence the system level, since it is highly directional (SWR should be avoided, as much as possible)**
- **Melting point of aluminum is 660°C but internal gas pressure and thermal weakening cause cell wall to fail closer to 580°C.**
  Important to measure (or at least account for) the hottest point on the heating element
- **Heating elements survived all tests and were still operational after tests**
  (however not advised to reuse due to cured paste)

Key findings (2 of 2)

- Achieving higher applied* heat flux is always better in terms of reduced time to TR and reduced input energy (the key principle to rapid heating)
  (* Remember: Input power is provided based on need to maintain temperature schedule; input power is not constant)

- Applied heat flux is a function of:

  1. Element thermal contact conditions

     (surface prep, element back pressure, heat transfer paste material and thickness, etc.)

  2. Cell internal structure under heating element site

     (cell wall material, distance to electrodes, additional non-active layers, thermal resistance, etc.)

- #1 can be controlled, but #2 cannot (control over heating site selection only)

Conclusions

- Initiating TR in hard-cased prismatic cells by rapid external heating is possible through thoughtful experiment design

- For these cells, on the large face, 30 W/cm2 is maximum effective heat flux to avoid risks of SWR. Below 10W/cm2 leads to longer activation times and more energy inserted

- If the goal is to avoid SWR, then cells with a high thermal resistance and dedicated pressure relief vents (ex. hard-cased prismatic cells) are more sensitive than other cell formats (ex. pouch) to the heating element installation quality and temperature schedule selection.

- If SWR is an acceptable test outcome, then TR initiation through rapid heating is achievable with a much wider range of acceptable installation sites and temperature schedules (some with even less time / energy insert), given that the heating element is properly designed or selected for this potential outcome (exposure to melting conductive metals).

Question for GTR

- We have performed significant work to develop a test method that does not induce a SWR in cells with dedicated pressure relief vents.

- IS THIS A VALID CONCERN TO THE GTR?

- In other words, is a SWR in cells with dedicated pressure relief vents an acceptable outcome for ANY TR test method?

- Please discuss and share your opinions.

Future work

- **Attempt side and bottom TR initiations**
  Element installation may be more convenient in these locations for some designs

- **Applying methodology to newer generation, higher energy density prismatic cells / modules**

- **Continue to improve and refine element design and test methodology based on constructive feedback**

- **2020 BEV vehicle level test planned for end of October 2021**

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Thank you for your kind attention!

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