Test Method for Simulating Internal Short Circuits in Lithium Ion Cells

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FIELD FAILURES

Since 2006, reports of failure but not much detail

• Highly publicized failure of laptops powered by lithium ion batteries including fire and explosion

• Reports of home fires caused by lithium-ion batteries in devices during usage or charging

• Cargo airplane fires involving bulk transport of lithium ion cells and NTSB investigation of passenger 787 plane

• Electric vehicles are based on lithium ion cell chemistries sometimes utilizing several thousands of commercial, off the shelf (COTS) cells

• In some cases, it has been noted that defects lead to internal short circuit (ISC) and thermal runaway
CPSC Recall Data (1/2008-3/2012)

Identifying lithium-ion cells as the battery type (compiled by UL staff)

467 Number of Reported Incidents

2,056,318 Quantity of Product Recalled

353 Number of Incidents with Fire/Burn Hazard

Battery can overheat posing a fire hazard
GM VOLT BATTERY INCIDENT

Incident: NHTSA post-crash fire (June 2011)
Cause: As a result of the crash, a stiffener damaged some batteries and ruptured coolant system inside battery compartment leading to short circuit.

To keep the battery operating safely, the Volt battery system “has more parts than the rest of the car combined, including 600 seals and cooling components.”
RESEARCH OBJECTIVE

Consider the need for a new test for UL 1642 to address field failures of lithium ion cells

Focus Area: Internal Short Circuit of a Cell
FAULT TREE ANALYSIS

Lithium Ion Cell

Unsafe Operation

Electrolyte Leakage

Toxic Gases

Deflagration of vented volatiles

Fire/Explosion

Unable to operate device in a safe manner

Insufficient or No Energy

Contact with Hot Surface

Internal Ignition source

Vented Volatiles from Cell

Fuel

Ambient Air (or released oxygen)

Air
DEEPER INTO THE FTA

Fuel

Vented Volatiles from Cell (from Thermal Runaway)

Exothermic Reactions
  - Self-sustaining reaction

Internal Short Circuit
  - Localized heat source

4 different types of ISC

Inadequate cooling
  - Heat Dissipation

Sufficient State of Charge
  - SOC

Breach of Separator by Particle
  - Internal Defect

Damaged Separator due to external forces
  - External Force

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INTERNAL SHORT CIRCUIT (ISC)

EXTERNAL FORCE
- Crush
- Penetration
- Indentation
- Vibration

INTERNAL DEFECT
- Manufacturing
- Aging (overcharging, etc.)

ISC

Localized Temperature Increase

Heat Dissipation

Exothermic Reactions

• Fire
• Explosive release of gases
• Leakage
• Cell to Cell propagation

Thermal Runaway

• ‘Safe Failure’
OBJECTIVE

Help support review and revision of an ISC test method that might be suitable for battery safety standard.
Review of ISC Test Methods

Slow Speed Nail Penetration Test
ITRI

Low-Melting Point Metal/Alloy Triggered ISC Test
SNL/NREL

Forced ISC Test
BAJ

Pinch Test
ORNL

Indentation Induced ISC Test
UL/NASA
INDENTATION INDUCED ISC TEST

• Features of New Test Method
  - Localized indentation of cell without penetration
  - Controlled speed and temperature conditions
  - Specified state of charge (SOC) and cycle life of cell
  - Measure cell surface temperature, open circuit voltage (OCV), displacement and force of indenter along with visual observations
  - Induce failure to assess performance of cell

Indenter moving at specified speed

Battery specimen held in place
SAMPLE RESULTS

- Observed flames and smoke
**Temperature Distribution**

**Temperature 1:**
Closest to ISC point
Peak: 139°C at 25 sec

**Temperature 2:**
Peak: 120°C at 32 sec

**Temperature 3:**
Farthest to ISC point
Peak: 109°C at 34 sec
SIMULATING FIELD FAILURES

- Localized ISC (1-2 mm radius)
- Low impedance pathway
- Depth several layers
- Maintain heat transfer pathways (do not puncture cell)
- Location is near surface of cell

0% SOC

50% SOC
STOBA IN 18650 CELLS

18650-type NMC (1950 mAh) **without** STOBA additive
25°C

18650-type NMC (2000 mAh) **with** STOBA additive
25°C
**Aging Effect on Safety**

- Capacity deterioration
- Power loss
- Material degradation
- Internal pressure increase
- Impedance increase

![Graph showing cycle performance at various charge/discharge rates.](image_url)
AGING EFFECTS ON ISC

New Cell
100% fails (N=3)

200 Cycle Aged Sample
1 cell pass and 1 cell fail

400 Cycle Aged Sample
2 cells pass

New Cell
100% fails (N=3)

100 Cycle Aged Sample
1 cell pass and 1 cell fail

400 Cycle Aged Sample
2 cells pass
PRISMATIC CELLS

Cell expanded, fire and spark

Cell casing was punctured

Lithium cobalt oxide, 1900 mAh, 4.25 V
Pouch Cells

Casing is punctured by indenter (load drops before OCV drop)

Lithium cobalt oxide, 2150-3800, mAh, 4.25 V
**Challenges**

- UL is considering safety aspects of lithium-ion cells from the single cell to large number of cells throughout the lifecycle.

- Challenges to lithium-ion battery safety testing include:
  - Access (cost) to large number of cells and/or large format batteries
  - Battery technology is still evolving and there is no single representative cell type
  - Sound safety laboratory protocols for testing program especially for many cells, modules, and packs.
SUMMARY

At the cell level, UL is working on developing a new ISC test method for battery safety standard (UL 1642)

- Simulates internal short circuit by creating a small localized defect in separator
- Induce failure of the cell for cylindrical, prismatic, and pouch
- Sensitive to design changes that affect safety performance
- Method suitable for standards testing

UL is actively improving existing standards and developing new standards building on cell safety all the way to battery system safety

- Large format focus (UL 2580, UL 2271, UL 1973)
- Revising cell requirements to address specific applications
- Verifying cell operating region
- Ensuring system maintains cell operating region
- System FMEA/Functional safety
THANK YOU.