the standard in safety

UN Transportation Tests and UL Lithium Battery Program

Underwriters Laboratories Inc. - General Experience and Status Update

November 11, 2008

Brief Status Update of UL Lithium Battery Program

1. Certification Enhancements

1. Completion of Construction Form Report
2. Development of new Standardized Appendix Pages
3. Continuation of Work on Production Requirements
4. Publishing of UL Subject 1642A, Outline of Investigation for Battery Separators (proposed inclusion in UL 1642)
5. Ongoing Research Dept. Internal Short Circuit Testing
   - Blunt Nail Crush Test,
   - Review of Forced Internal Short Circuit Test
   - Review of NASA Test Methods

UL Lithium ion Battery Research Project

The objective of the UL research project:

- develop a reliable and repeatable way to simulate an internal short-circuit.
  - the lithium ion cell shall remain SAFE even if an unexpected internal short-circuit occurs.

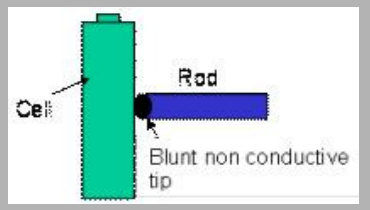
Methods analyzed to date as part of project:

Nail Penetration Test

Blunt Nail Crush test

BAJ method: Forced Internal Short-circuit test

Rod Crush Test

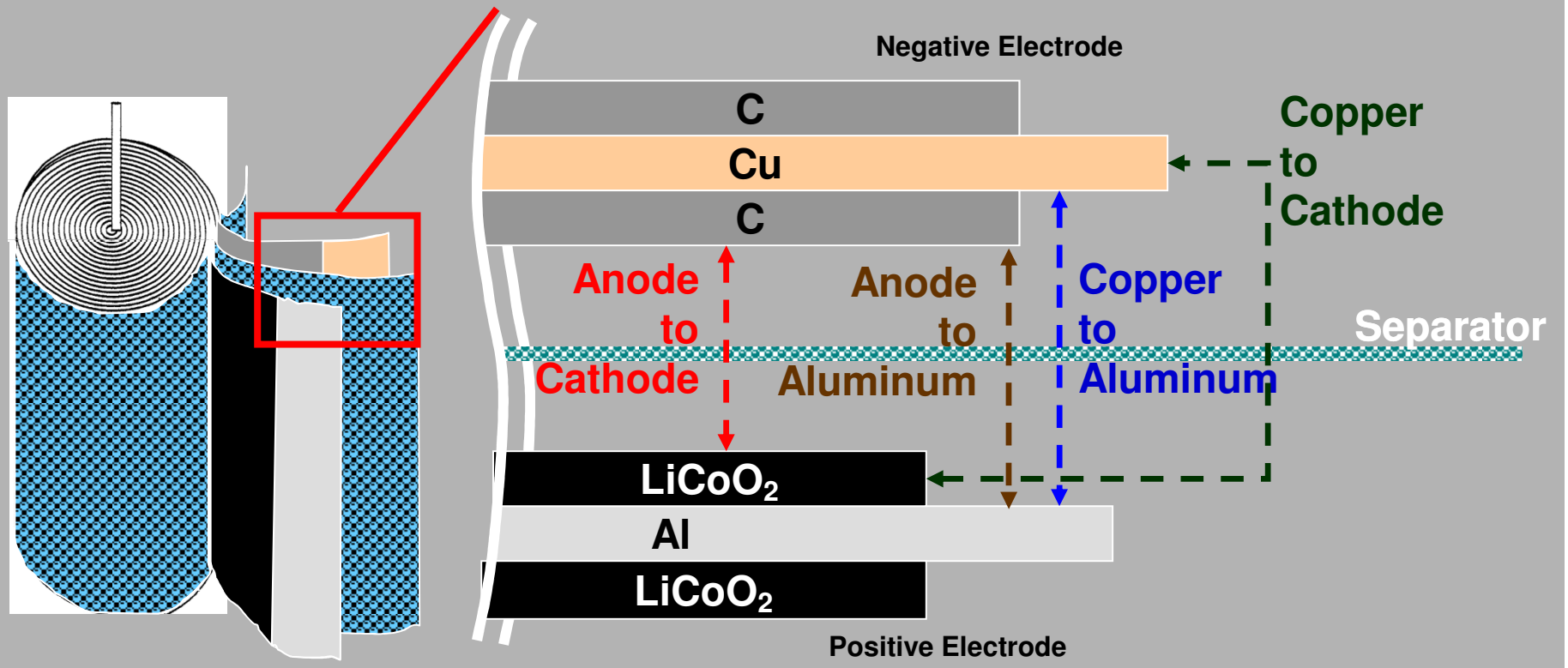


NASA method

UL Lithium ion Battery Research Project

Types of Internal Short Circuits

- There are 4 kinds of Internal Short Circuit Conditions:



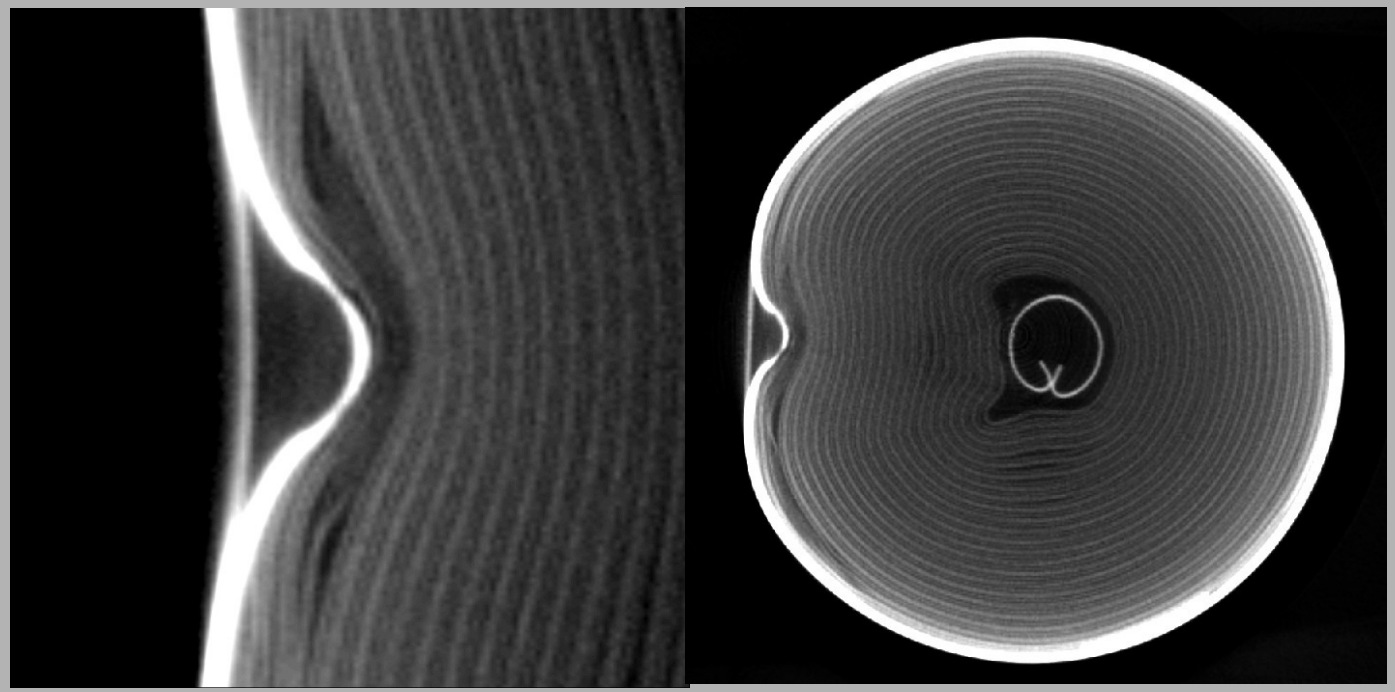
UL Lithium ion Battery Research Project

Blunt Nail Crush Test Method Overview

- Crush the cell with a Blunt Nail until detection of 100 mV open circuit voltage(OCV) drop
- Record OCV, temperature profile and qualitative test results.

UL Lithium ion Battery Research Project

Short Mechanism of BNC test



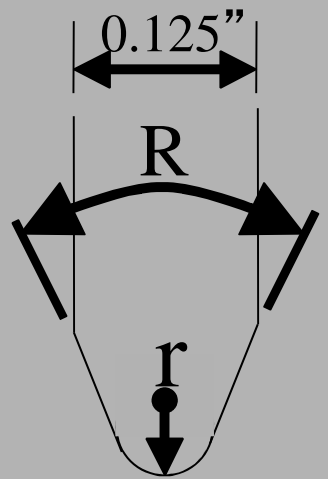
The CT-Scan of the tested cell shows the short was induced at outer layer/layers.

UL Lithium ion Battery Research Project

Critical Test Parameters for Blunt Nail Crush

- To control the scale of internal short (single layer short) accurately, some test parameters are critical.
  - Control of Press Speed - Press Equipment with servo-motor using constant press speed at 0.1mm/s
  - OCV Sampling Rate - recommended OCV scan rate is 100Hz or more.
- Testing Temperature is one of the most critical test parameters
  - Controlling the temperature of the samples is important.
- Geometry/Sharpness of Blunt Nail
  - To avoid penetration of the cell's case while testing, the tip of the nails have to be rounded.
  - The nail with tip radius 0.9 mm and tip angle 45° (recommended for testing cylindrical cells)

R: 45°
r =0.9 mm



UL Lithium ion Battery Research Project

Strengths of BNC test method

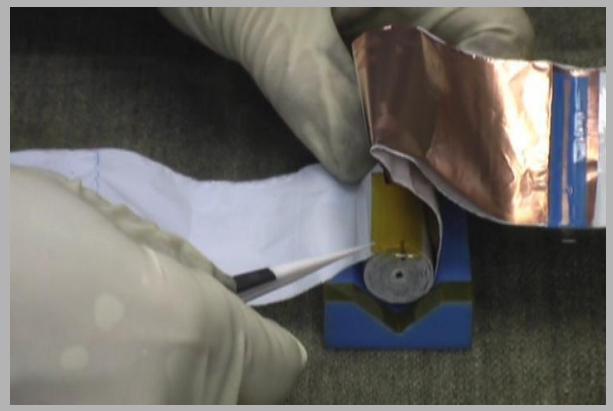
- Method does not require a lot of special sample preparation
  - Little change or deformation of sample during test
- A short circuit is obtained each time
  - 100 mVdc OCV drop requirement of test
  - Repeatable results

Weakness of BNC test method

- Cannot control exact location of short because blunt nail is pressing on the outside of the can
  - Short Mechanism depends on Internal Construction
    - Different designs may lead to different types of internal short circuits (i.e. CU – Al + Cu – Anode or CU – Al only)
- Some difficulty with controlling the number of layers shorted
  - Improved results with improved test set up

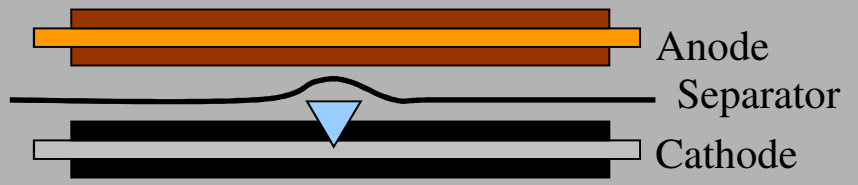
UL Lithium ion Battery Research Project - FISC Test Analysis

- Strengths of FISC test
  - **Can control location of internal short circuit**
    - **Place particle in preferred location**
    - **Anode to Cathode short represent field failures that may not be picked up with standard mfg. production testing.**
  - **Can obtain single layer short**



Weakness of FISC Test:

- **Safety concerns**
  - **Special equipment and cell preparation facilities**
- **Difficult to disassemble and re-assemble cells for the test**
- **Can induce single-layer short, but it may NOT always be an Anode-to-Cathode short.**



•If the separator is strong it is possible that the L-shape nickel particle will penetrate the cathode first and then pierce the separator to induce the short. Under this condition, the short is Cathode/Al-to-Anode but not a typical short of Anode-to-Cathode.

UL Lithium ion Battery Research Project – NASA Test Analysis

NASA Lithium ion battery test:

- Some similarities to UL BNC test
  - Use blunt nail/rod to press from the outside
- Differences to UL BNC test
  - Results influence vibration testing on samples
  - Parameters are different
  - Pass/Fail criteria of test differs
    - Pass/Failure dependent upon results of vibration testing
      - If cells fail rod test, subject to more severe vibration
      - If cells pass rod test, subject to less severe vibration

NASA method

UL Battery Standards, Update

- **UL 1642 and UL 2054**
  - Harmonization with IEC standards
  - IEEE 1625 GAP Analyses TG
  - Currently proposals under 2nd review vote
  - STP meeting in 2009
- **UL 2575**
  - Battery systems for tools and appliances
  - First Draft completed initial review period
  - STP meeting on November 16 and 17, 2008
  - Plan to Harmonize IEC 60745 and IEC 60335 to UL 2575 with addition of Appendix "P" to standards
- **UL 810A**
  - Electrochemical Capacitors
  - ANSI standard for Ultracapacitor cells and modules
  - Stationary and portable applications – non-vehicular use

UL History with UN Transportation Tests

- **UN tests at UL**
  - Service offering Under UL CITS Program
    - Primary and secondary Lithium Battery
      - Cells and Packs
    - Testing primarily conducted at UL NBK office

- **Similarities between UN Transportation Tests and UL Safety Tests**
  - Altitude Simulation
  - Thermal/ Temperature Cycling
  - Vibration
  - Shock
  - External Short Circuit/Short Circuit (55°C)
  - Impact
  - Overcharge/Abnormal Charging & Abusive Overcharge
  - Forced Discharge

UN Tests Experience by UL

T1 Altitude Simulation

- Similar to UL altitude simulation test
- No known failures to this test

T2 Thermal

- Similarities to the UL temperature cycling test
- No known failures to this test

T3 Vibration

- Similar to UL vibration test but conducted on both cells and packs
- No known failures for cells, but may be more difficult test for packs

T4 Shock

- Similar to UL vibration test but conducted on both cells and packs
- No known failures for cells, but may be more difficult test for packs

UN Tests Experience by UL

T5 External Short Circuit

- Similar to UL 55C short circuit test
- Need to designate range for resistance, as this has affect on test results (recommend using 80 +/- 20 mOhm)
- If protectors relied upon to pass test, need to indicate they are required for cell/battery
- Is the 170C limit appropriate for all lithium chemistries?
- External polymeric materials used for most packs are not rated for 170C temperatures

UN Tests Experience by UL

T6 Impact

- Similar to UL impact test except not tested under fully charged state
- Need to address polymer cells (test on thin side as noted for prismatic?)
- Need to better document details/dimensions of metal bar
- Metal bar stay in place for 6 h? (may be heat sink)
- Test not always easy to conduct with odd shaped, large and small cells
- Why not test fully charged cells?
- Crush test (flat plate type test)?

UN Tests Experience by UL

T7 Overcharge

- Similar to UL abusive overcharge test
- Need to address protectors required to pass this test
- Problems with small packs which rely upon ptc's for protection
  - Leakage current may pass through PTC upon its operation
  - If enough leakage current passes through, becomes CV test limited only by supply voltage

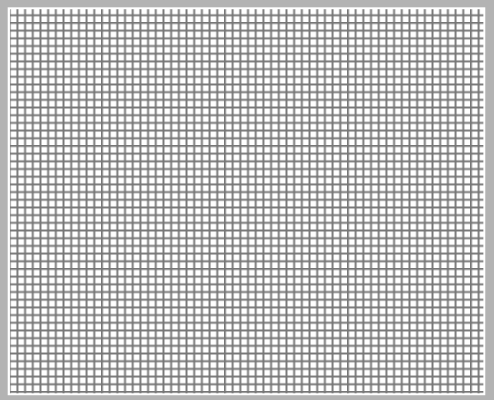
T8 Forced Discharge

- Not similar to UL forced discharge test, but same goal
- More severe as it does not allow reliance on pack protection against cell reversal

UN Tests Experience by UL

General Observations

- Disassembly vs Rupture
  - Is there a need for both disassembly and rupture terms
  - Use of cage to determine disassembly necessary?
    - May not be practical in some cases
- Samples
  - Use of less samples for conditioning and tests



Questions?

Laurie Florence
Principle Engineer
Batteries, Fuel Cells, Capacitors
Underwriters Laboratories, Inc.
847-664-3782
laurie.b.florence@us.ul.com