



Abuse Testing of High Power Batteries

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USABC Abuse Testing

- Sandia provides an independent test laboratory for DOE and USABC
- Abuse testing performed on cells and modules delivered by USABC contractors as part of their contract deliverables
- Test results generated are battery protected information and released only to the contractor and members of the USABC Tech Team



The Purpose of Abuse Testing is to Evaluate the Response Of Test Articles to Off-normal Environments

- **PASS/FAIL testing is the type of approach that Underwriters Lab (UL) or Department of Transportation (DoT) defines.**
 - Provides standard test that mature technologies must meet in off-normal environments.
 - If the article passes the test, you don't learn about failure modes.
- **CHARACTERIZATION tests which evaluate the response to abuse environments are more useful for developmental technology.**
 - Usually results in failure of the test article.
 - Documentation of conditions that cause failure.
 - Evaluate failure modes and abuse conditions using destructive physical analysis (DPA)
 - Provide quantitative measurements of cell/module response.
 - Document improvements in abuse tolerance.
- **As the technology matures, abuse testing will evolve from characterization to pass/fail tests.**





Barriers: Abuse Testing of Li Ion Batteries

- Abuse Tolerance of Energy Storage Device is identified as a barrier in USABC and DOE battery development programs.
- Immature technology for HEV/PHEV applications.
 - Much harder problem than portable electronics applications.
 - Prototype vehicles are in development and testing.
- Goal is to be *“as abuse tolerant as Ni/Metal Hydride”*
- This is a challenge since Ni/MH have lower energy content and non-flammable electrolyte.



What are Abuse Test Conditions HEV\PHEV Batteries are Likely to Encounter?

➤ Mechanical Abuse

- Controlled Crush
- Penetration
- Drop
- Immersion
- Roll-over Simulation
- Mechanical Shock

➤ Thermal Abuse

- Thermal Stability
- Simulated Fuel Fire
- Elevated Temperature Storage
- Rapid Charge/Discharge
- Thermal Shock Cycling

➤ Electrical Abuse

- Overcharge/Overvoltage
- Short Circuit
- Overdischarge/Voltage Reversal
- Partial Short Circuit

Ref.: Sandia Report SAND 2005-3123, "FreedomCAR Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications", Daniel H. Dougherty and Chris C. Crafts, May 2005



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Approach: Most Meaningful Subset of Tests For a Technology In a Developmental Stage

➤ Electrical Abuse

- **Overcharge/Overvoltage**
 - » May trigger thermal runaway
- **Short Circuit**
 - » Usually not a problem for cells, but can be an issue in battery packs.

➤ Thermal Abuse

- **Thermal Stability up to 200°C or 250°C**
 - Other types of abuse conditions often trigger a thermal abuse event.

➤ Mechanical Abuse

- **Controlled Crush**
 - Causes internal short circuit.
- **Nail Penetration**
 - Roughly simulates internal short abuse response



EUCAR Traction Battery Safety Test Description* Has Been Used to Characterize Abuse Response

| Hazard Level | Description | Classification Criteria, Effect |
|--------------|------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 0 | No effect | No effect, no loss of functionality. |
| 1 | Passive Protection activated | No defect, no leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed. |
| 2 | Defect / Damage | No leakage, no venting, no fire or flame, no rupture, no explosion, no exothermic reaction or thermal runaway. Cell irreversibly damaged, repair needed |
| 3 | Leakage Dm < 50% | No venting, no fire or flame**, no rupture, no explosion, Weight loss < 50% of electrolyte weight. (electrolyte = solvent + salt) |
| 4 | Venting Dm ± 50% | No fire or flame**, no rupture, no explosion, Weight loss ± 50% of electrolyte weight. |
| 5 | Fire or Flame | No rupture, no explosion, i.e., no flying parts. |
| 6 | Rupture | No explosion, but flying parts, ejection of parts of the active mass. |
| 7 | Explosion | Explosion, i.e., disintegration of the cell. |

* Proceedings of EVS 21, W. Josefowitz et al., “Assessment & Testing of Advanced Energy Storage Systems for propulsion – European Testing Report”, April, 2005.

** The presence of flame requires the presence of an ignition source in combination with fuel and oxidizer in concentrations that will support combustion. A fire or flame will not be observed if any of these elements are absent. For this reason, we recommend that a spark source be used during tests that are likely to result in venting of cell(s). We believe that “credible abuse environments” would likely include a spark source. Thus, if a spark source were added to the test configuration and the gas or liquid expelled from the cell was flammable, the test article would quickly progress from level 3 or level 4 to level 5. (SNL Comment.)



Standard Tests Performed for USABC Cells and Modules

Abuse Testing at Cell Level with No Mitigation Controls

| Abuse Test | Condition | Termination |
|---------------|--------------------------------|----------------------------------|
| Overcharge | 1C | To failure or stable heat output |
| “ | 3C | To failure or stable heat output |
| Short Circuit | Hard Short: 1 mohm | To failure |
| “ | Intermediate Short: 10 mohm | To failure |
| Thermal Ramp | 5 °C/min 100% SOC | To failure (> 200 °C) |
| “ | 5 °C/min 80% SOC | To failure (> 200 °C) |



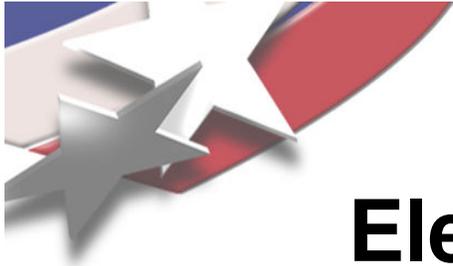
Test Description

Electrical Abuse: Overcharge

➤ Overcharge Test Description:

Test for cell heat and gas generation, thermal runaway, separator integrity, flammability of vent gases

- Starting Conditions: 100% State of Charge (SOC)
- Charge Rate: 1C and 3C
- Voltage Limit: Maximum voltage that can be delivered while in operation
- Termination Conditions: 200% SOC or failure
- Monitoring Parameters:
 - Voltage
 - Temperature
 - Current (SOC)
 - Gas Generation
 - Video



Test Description

Electrical Abuse: Short Circuit

➤ Short Circuit Test Description:

Test for internal cell shorting, thermal runaway and cell venting

- Starting Conditions: 100% State of Charge (SOC)
- Shorting Load: 1 mohm and 10 mohm
- Time Limit: 1 hour
- Termination Conditions: Stable temperature or failure
- Monitoring Parameters:
 - Voltage
 - Temperature
 - Current (SOC)
 - Gas Generation
 - Video



Test Description

Thermal Abuse

➤ Thermal Ramp Test Description:

Test for thermal stability, heat and gas generating reactions, flammability of vent gases, separator stability

- Starting Conditions: 100% State of Charge (SOC)
- Ramp Rate: 5 °C/min
- Ramp Temperature Limit: 250 °C
- Ignition Source: Test for flammability
- Termination Conditions: Stable temperature or failure
- Monitoring Parameters:
 - Voltage
 - Temperature (Cell, Block, Air)
 - Cell Heating Rate
 - Gas Generation
 - Video



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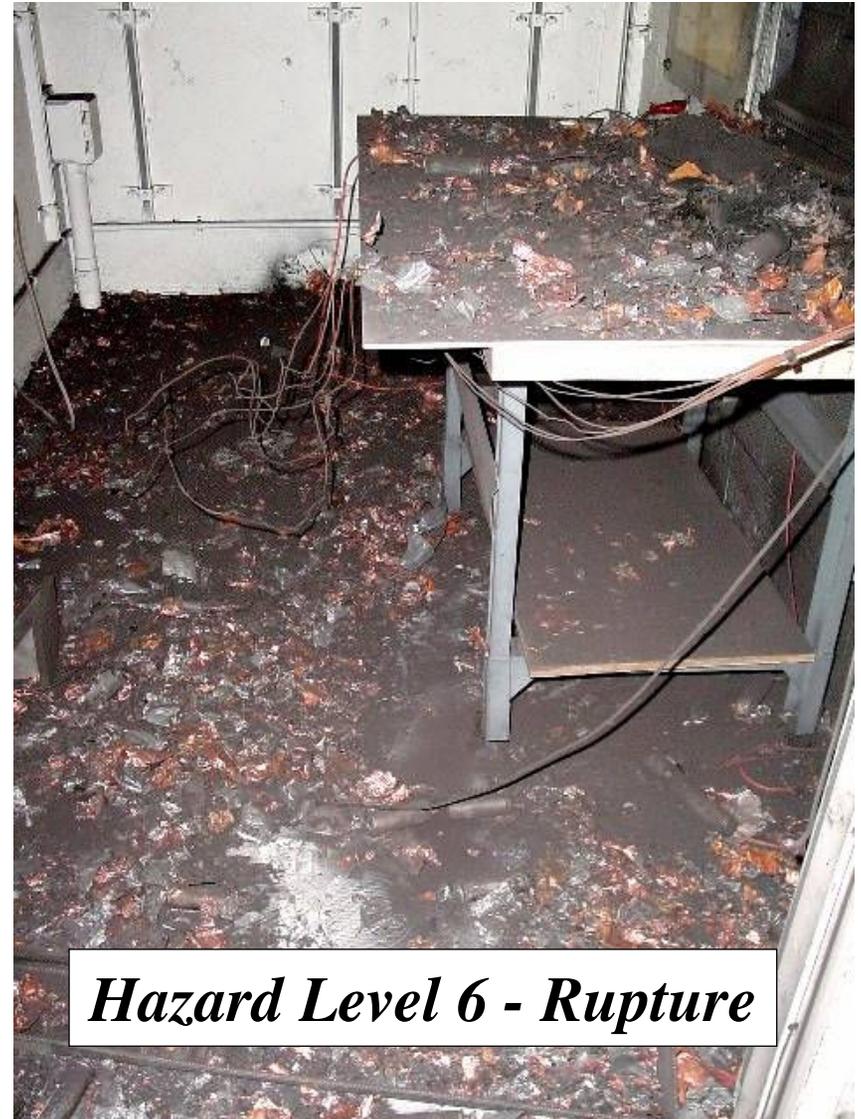
Module Level Tests Can Create Additional Failure Modes

- Cell response to abuse events should be thoroughly understood.
 - These are important tests, but do not represent all types of failures in many applications.
- Modules have additional failure modes due to interaction of energy stored in cells.
 - Charging of weak cells by stronger cells.
 - When one cell in a string becomes more resistive (e.g., the shutdown separator melts), it can receive the applied load of the series-connected cells, or be driven into reversal by the other cells in the series.



Abuse of Li Ion Modules Can be Exceptionally Violent

These pictures were taken
after overcharge of a
prototype HEV module at
SNL Abuse Test Labs.



Hazard Level 6 - Rupture



Abuse Testing USABC HEV Contracts

- Johnson Controls-Saft
 - Cell Level Tests Completed
- Compact Power Inc.-LG Chem.
 - Cell Level Tests Completed
- EnderDel
- A123
- NessCAP (supercapacitors)



USABC Abuse Testing Future Work

- **HEV – Final cells and modules to be delivered from USABC contractors before end of second quarter this year**
- **PHEV – New high-energy density cells to be delivered starting first quarter of FY09**
- **New testing requirements will include nail penetration**
 - **Limited confirming tests will be performed at SNL**



Publications and Presentations

All data developed as part of this USABC testing is battery protected information and is not presented in the open literature



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