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Examination of Techniques for Internal Short Circuit Testing on Lithium-Ion Batteries

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Short Circuit Cell Failure

- Internal
  - Normal operations
    - Manufacturing Defects
  - Abuse operations
    - Electrical abuse
    - Physical/mechanical abuse
    - Thermal abuse
- External
  - Accidental bridging of contacts
  - Electrical circuit failure

The Growing Problem

- **The dangers of battery failure are growing with scale**

A failure rate of ~1 in 5 million

In a 1000 cell pack becomes a failure rate of ~ 1 in 500 if the failure of a single cell propagates through an entire pack

A few short years ago a failure rate of ~1 in 200000 triggered a recall of 6 million Li-ion packs in laptops

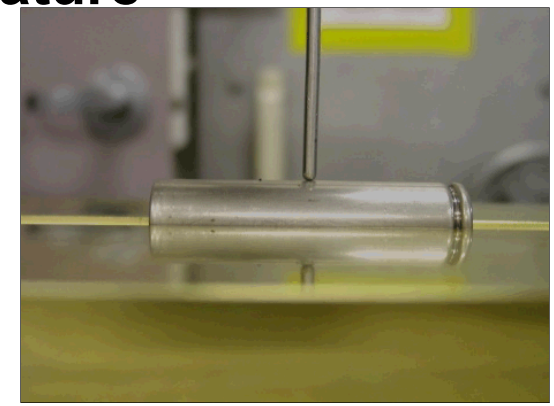
Internal Short Circuit Testing Methods

- **Mechanical techniques**
  - ***Blunt rod (conducting/insulating)***
  - ***Nail penetration***
  - ***Crush***
  - ***NASA***
  - ***Battery Association of Japan (BAJ)***
  - ***Motorola/ORNL***
  - ***SAE J2464 (ISC test omitted)***
- **Internal triggers**
  - **TIAX**
  - **NREL**
  - **SNL**
  - **Saft (Internal heater)**

Mechanical Short Circuit Testing at SNL

- **Blunt rod and sharp nail**
- **Hydraulic and mechanical crush**
- **Transverse and axial loading cells**
  - **Elevated temperature testing**
- **Post-mortem CT examination**

Test conditions			
Speed	2 mm/min		
Construction	316 SS		
Nail Tip	5 mm		
Temperature	RT	60C	
End Conditions	100 mV drop	20 mm penetration	



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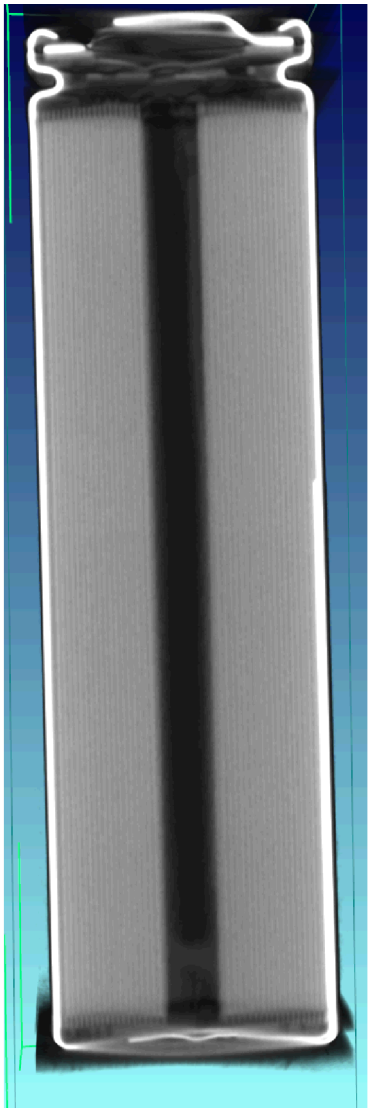
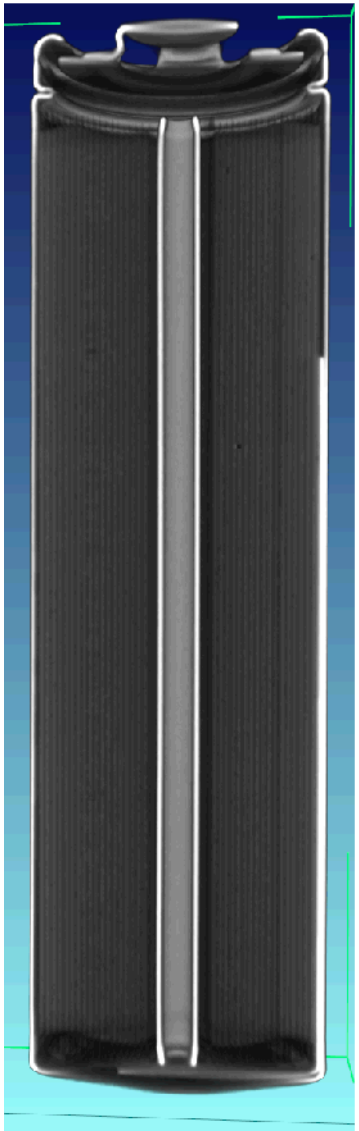
Commercially Available 18650 Cells



Differences in basic cell construction may lead to differing responses to abuse conditions

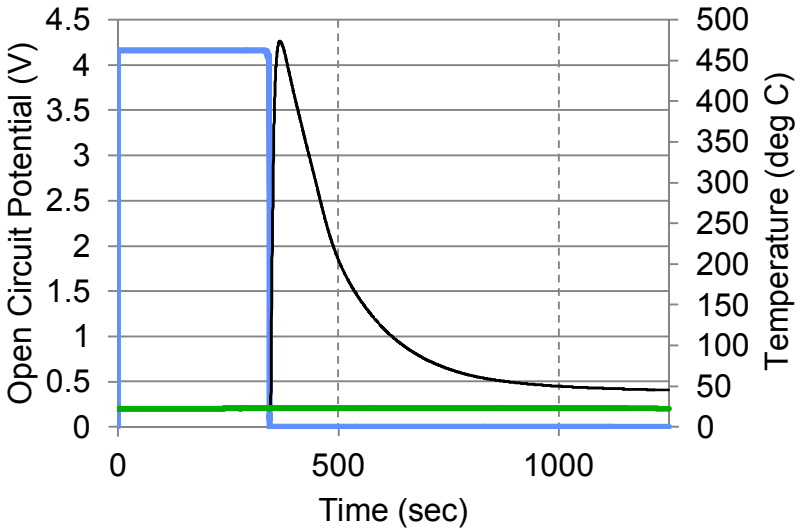
- Presense/absence of center rod
- Dead space in can
- Differing size/position of negative tab

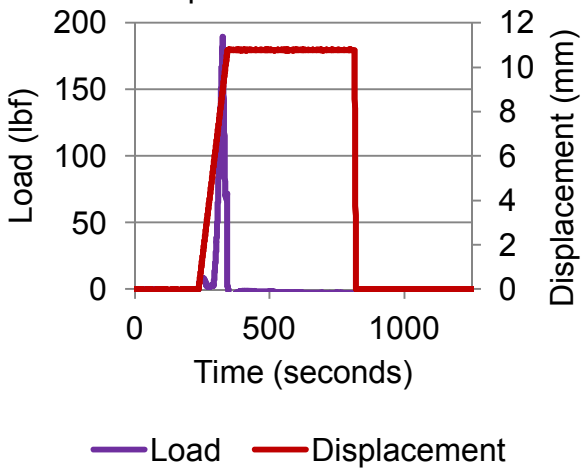
Cell type A



Cell type B

Results: Axial Loading





- Blunt rod off center, off negative tab.
- Resulted in hard short with high temperature and sharp drop in voltage
- Not shown: crush directly on center difficult to fully short as rod passed through empty center

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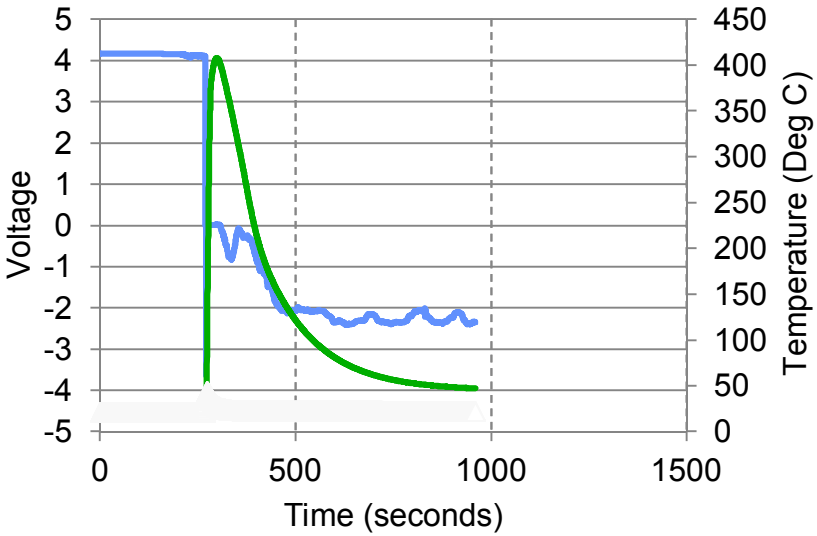
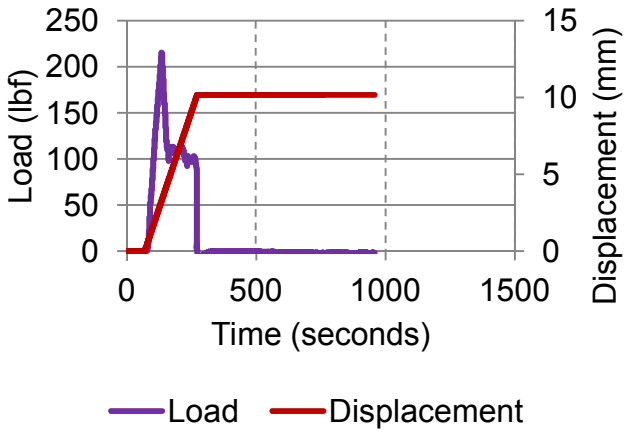
Results: Axial Loading





- Off center, on negative tab
- Noisier voltage curve after short
- Hard short occurs shortly after penetration

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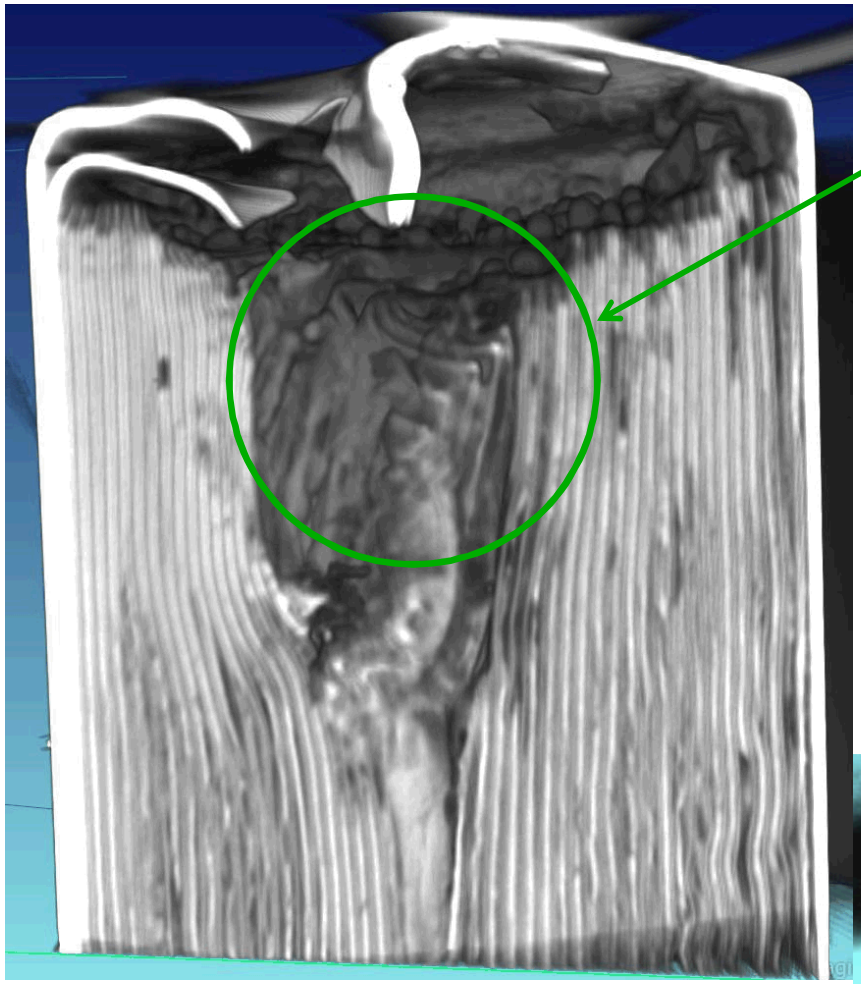
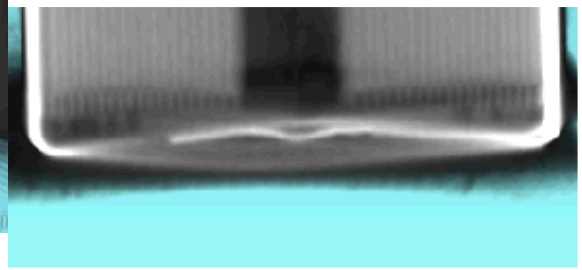
Internal damage – Axial load



Short location

Propagation of short through cell towards vent. Damage becomes more extensive near vent from flow of escaping gas

Large gap between can and electrodes prevent contact without cell puncture



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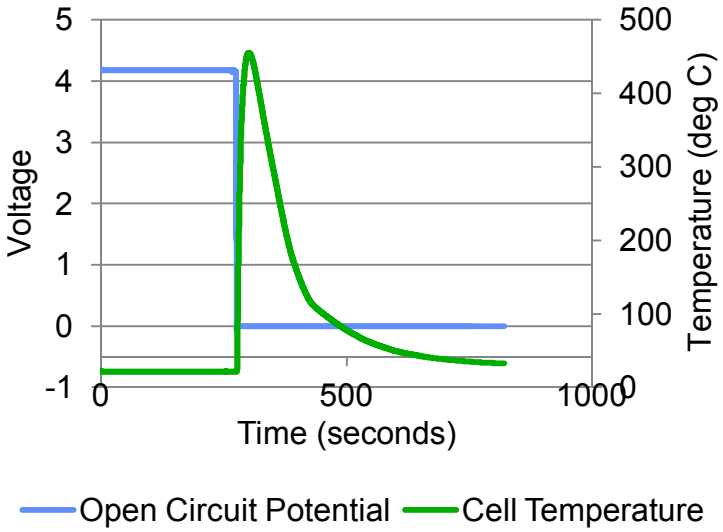
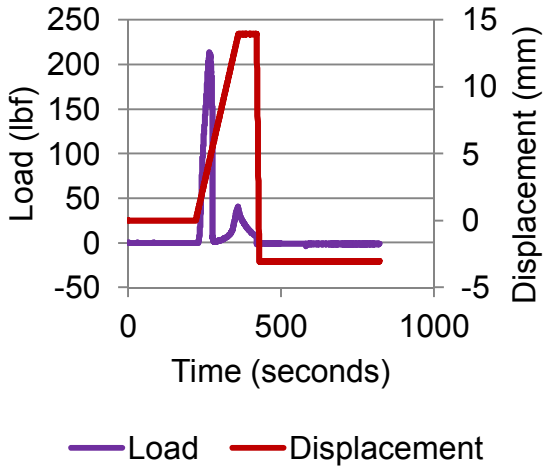
Results: Transverse load





Cell type A: no internal core

Catastrophic cell failure; all escaping gas comes through puncture or vent

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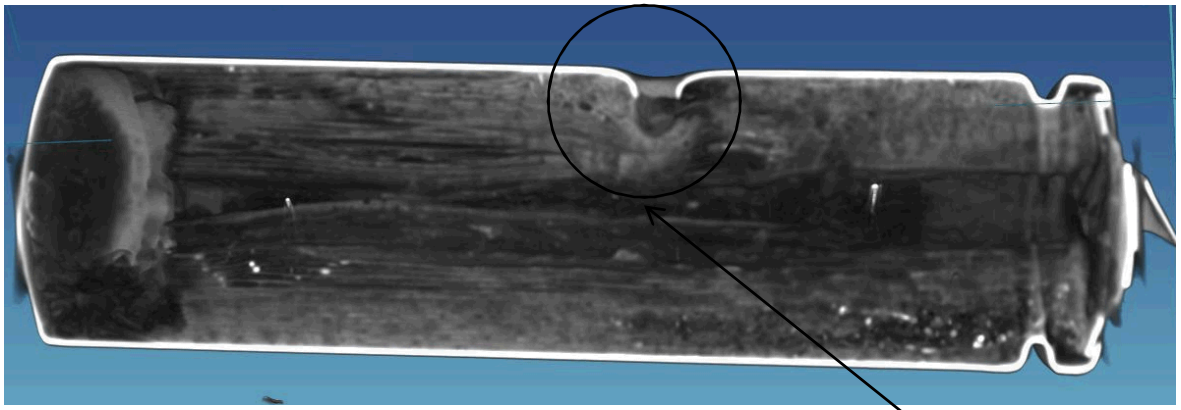
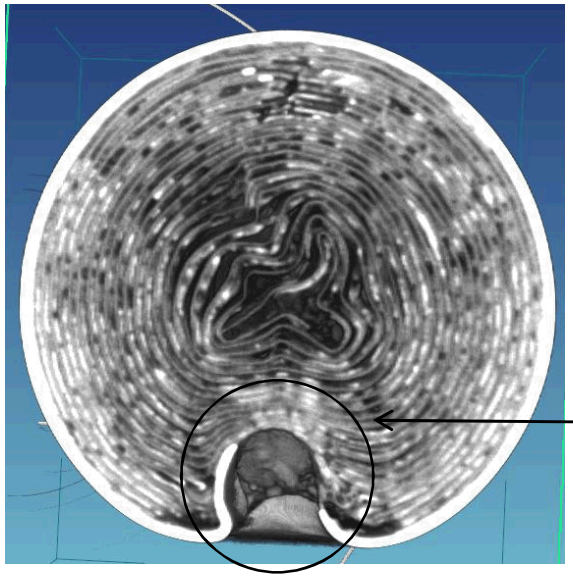
Catastrophic short failure



Propagation of failure through cell



Short location – electrode collapses into core and escaping gas through vent forces jelly roll up towards vent

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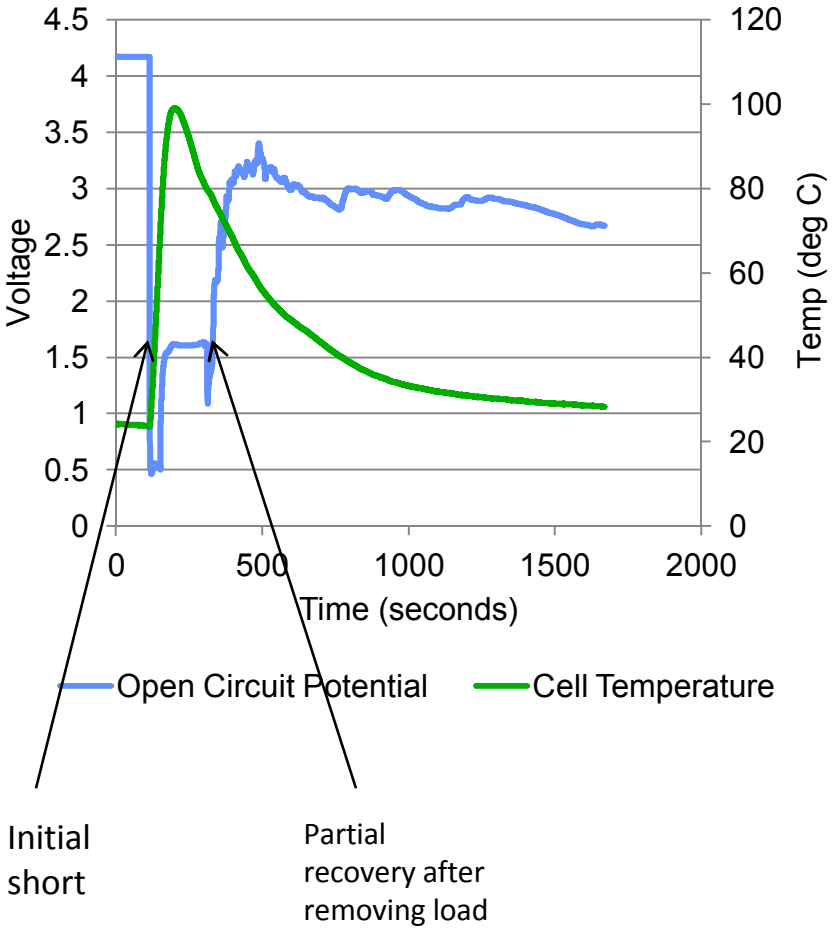
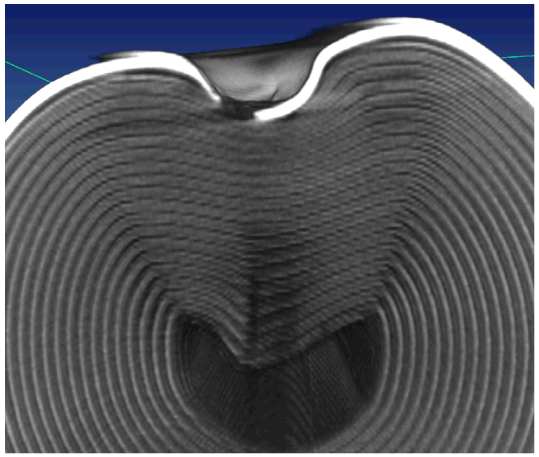
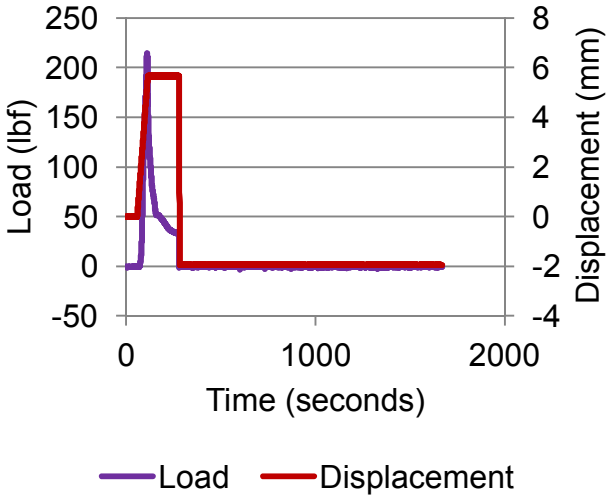
Failure: Soft short with partial recovery





Cell shorting between layers. Electrode is able to deform and collapse into open space in core of cell.



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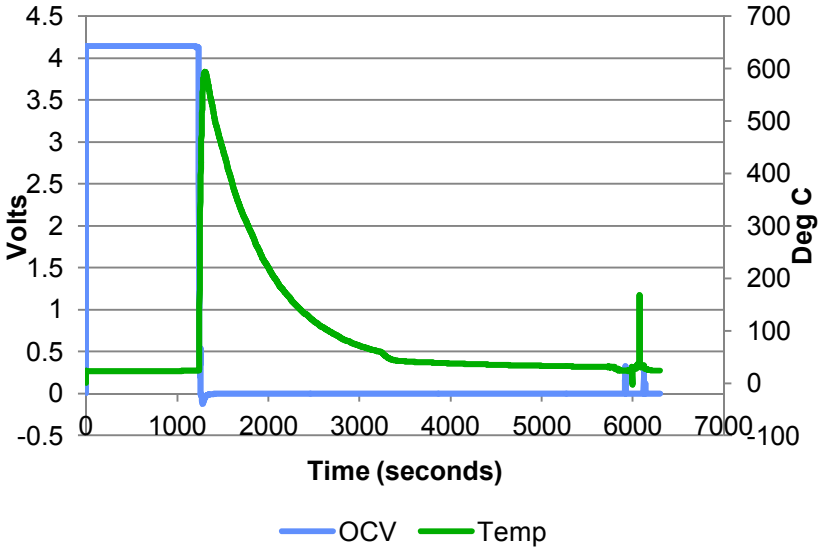
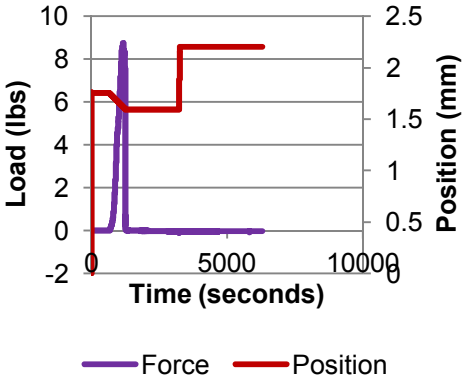
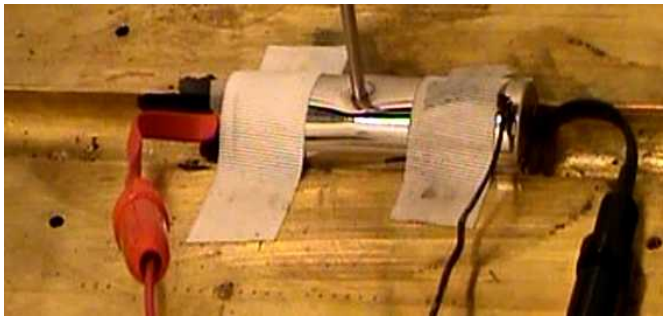
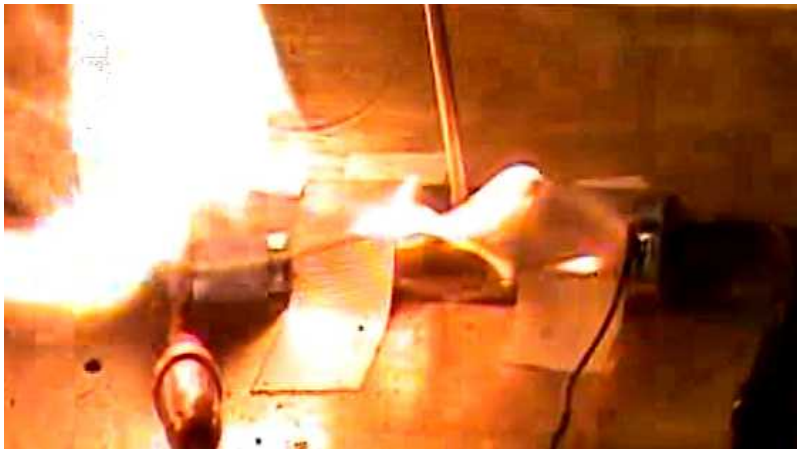
Effect of Cell construction: Cell type B









- Catastrophic failure readily seen
- Very high temperatures with spark source allowing for fire

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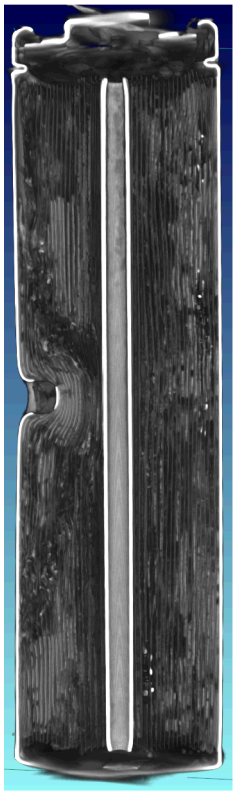
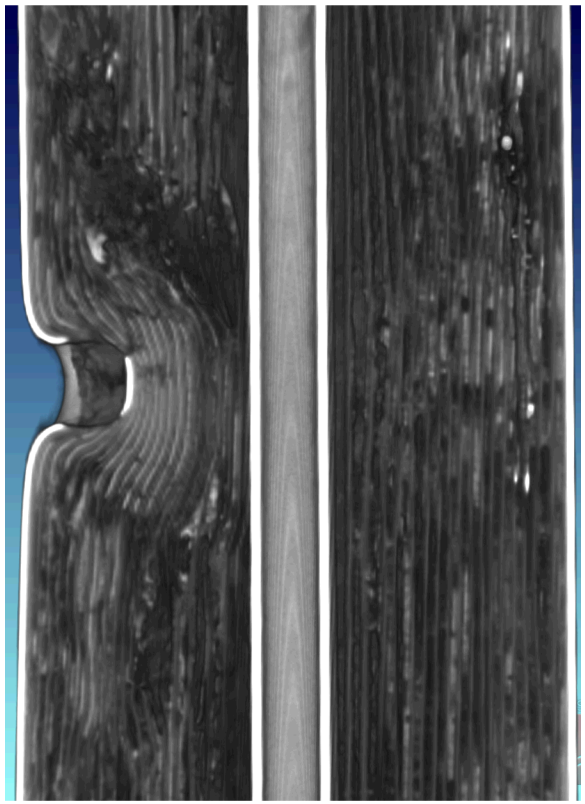
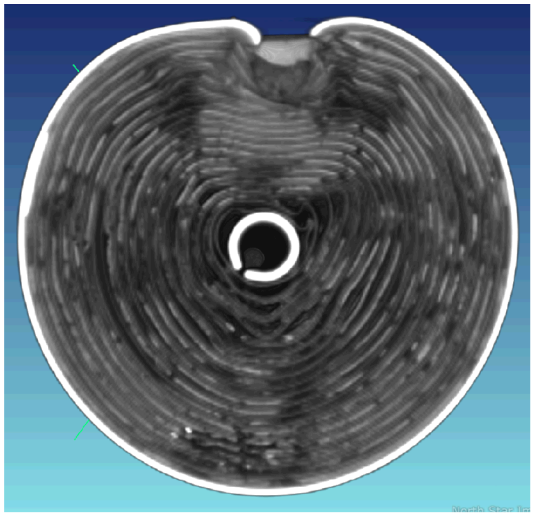
Cell type B continued





- Center core restricts contents during catastrophic failure
- Creates an effective “backing plate” allowing the electrode to be sandwiched between blunt rod and core



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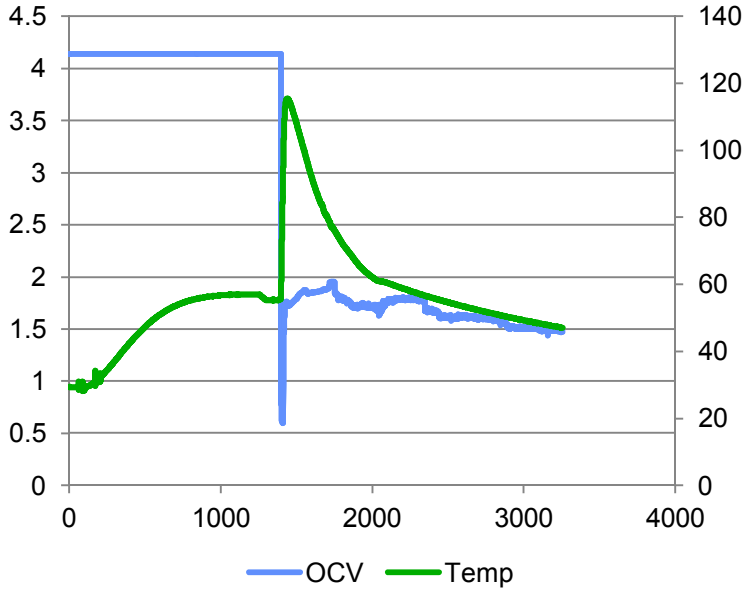
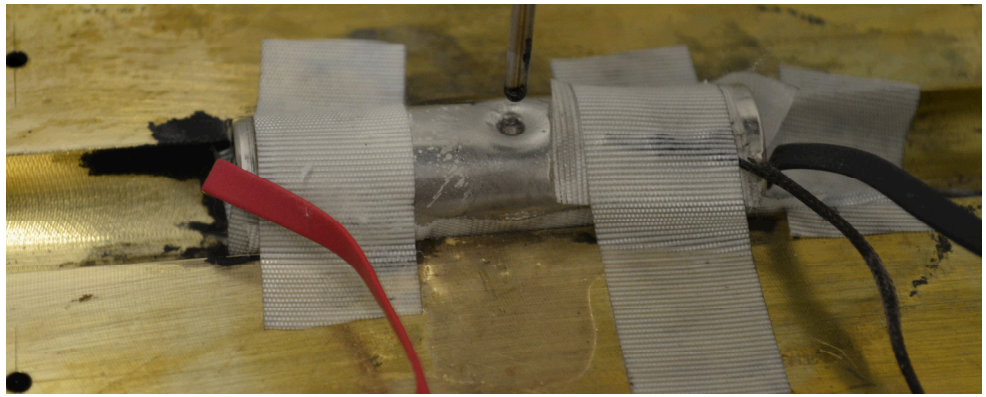
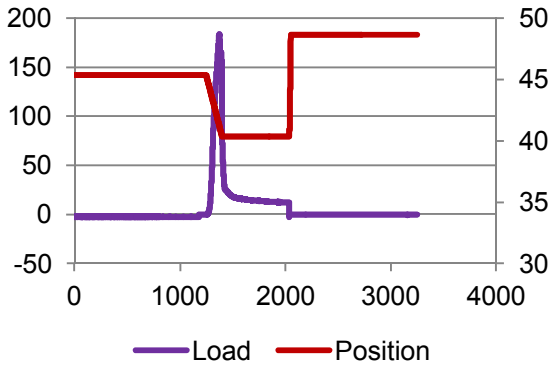
Elevated temeprature - Cell type A







Full short observed, but no catastrophic failure

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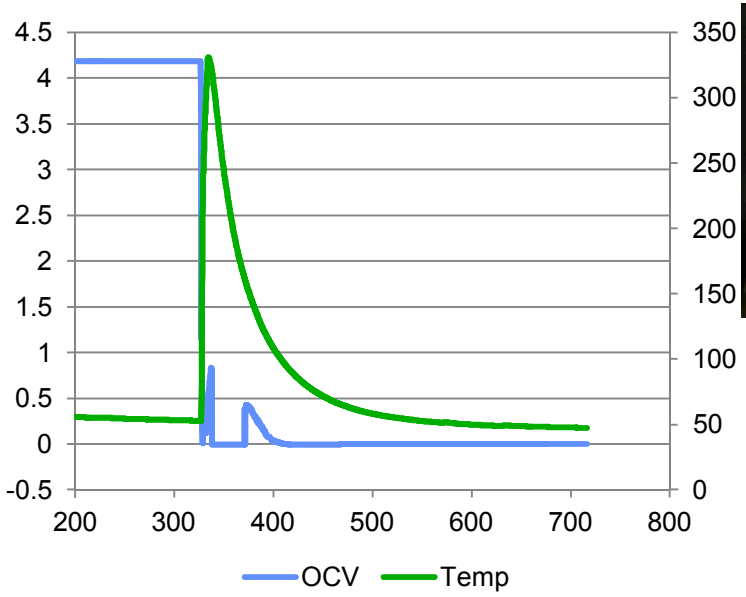
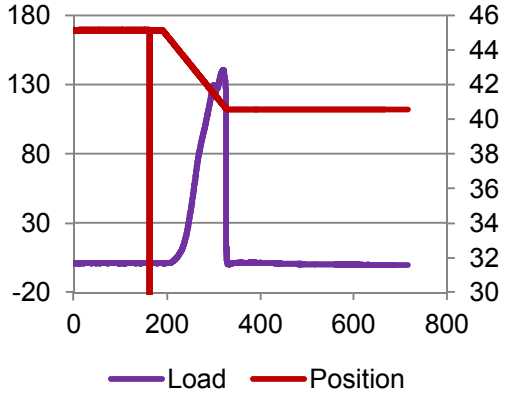
Elevated temperature – Cell type B





- Very catastrophic failure
- Rupture of can
- Ejection of cell contents

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Summary and Conclusions

- Repeatability of mechanical testing dependant heavily on cell construction
  - Differences in manufacture designs can have an effect on results
  - Level of uniformity of manufactured cells may contribute to results
  - Central core restricts expansion of cell contents during catastrophic failure
- Reproducible results with axial penetration
  - Candidate technique for propagation through multi cell packs

Future Directions

- Evaluation of prismatic cells
- Evaluation of other mechanical testing methods
- Propagation of single cell short through multi cell packs

Acknowledgements

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