

Are Soft Short Tests Good Indicators of Internal Li-ion Cell Defects?

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Battery Safety 2013

November, 2013

Outline

- Cell Characteristics
- Outline of Tests conducted
- Results
- Destructive Analysis Discussion
- Summary and Conclusions

Li-ion Cells and Test Protocols

- Cylindrical 18650 Cell: ~2.0 Ah (Manufacturer/Cell A)
- Polymer Prismatic Pouch: ~ 4.0 Ah (Manufacturer/ Cell B)
- Cylindrical 18650 Cell: ~3.0 Ah (Manufacturer/ Cell C)
- Prismatic Metal Can Cell : > 50 Ah (Manufacturer/ Cell D)

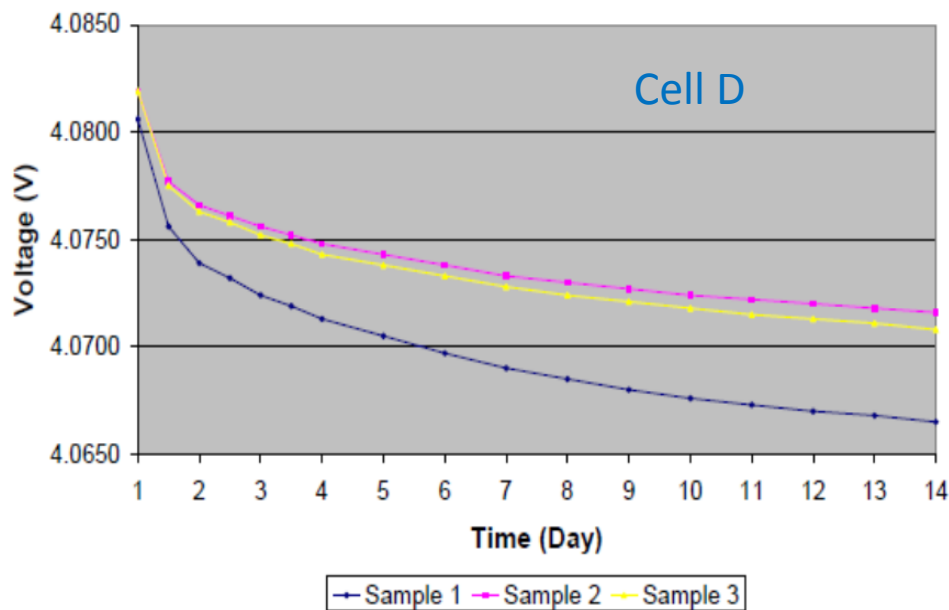
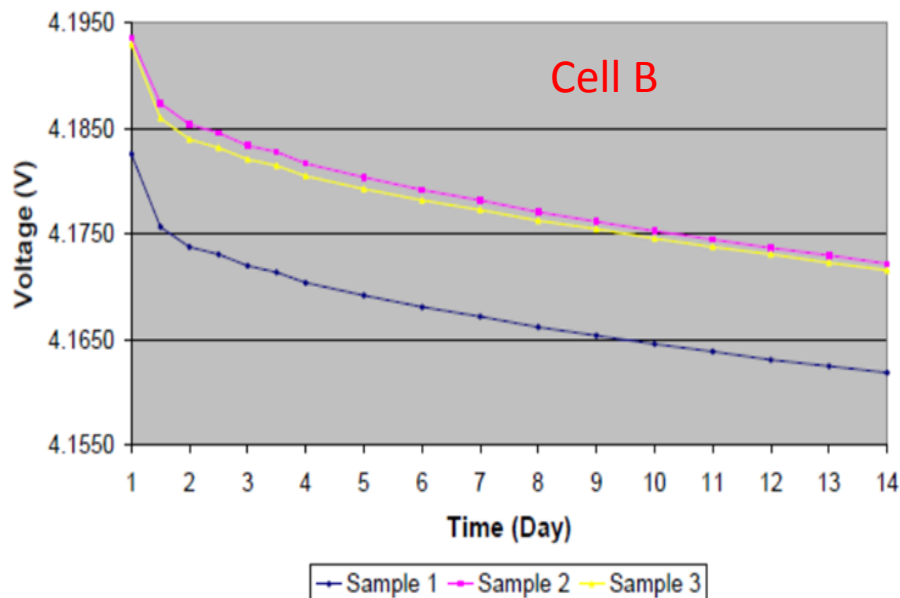
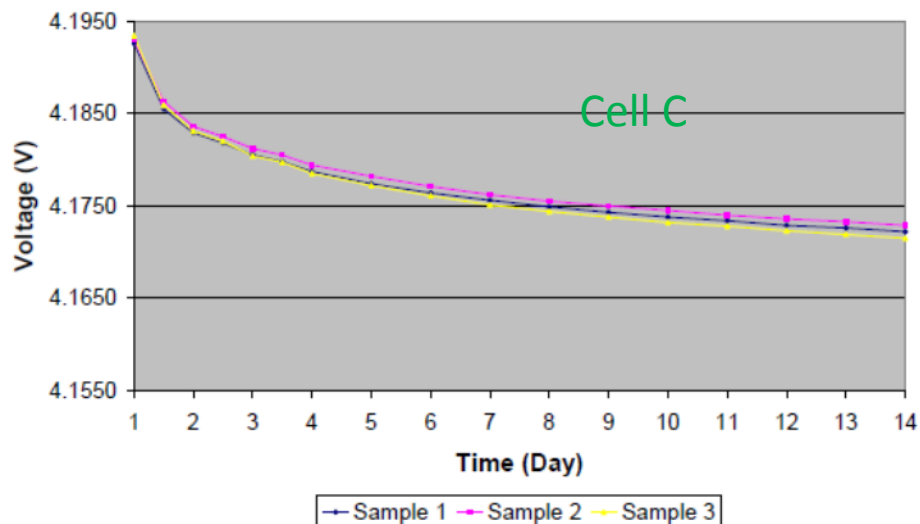
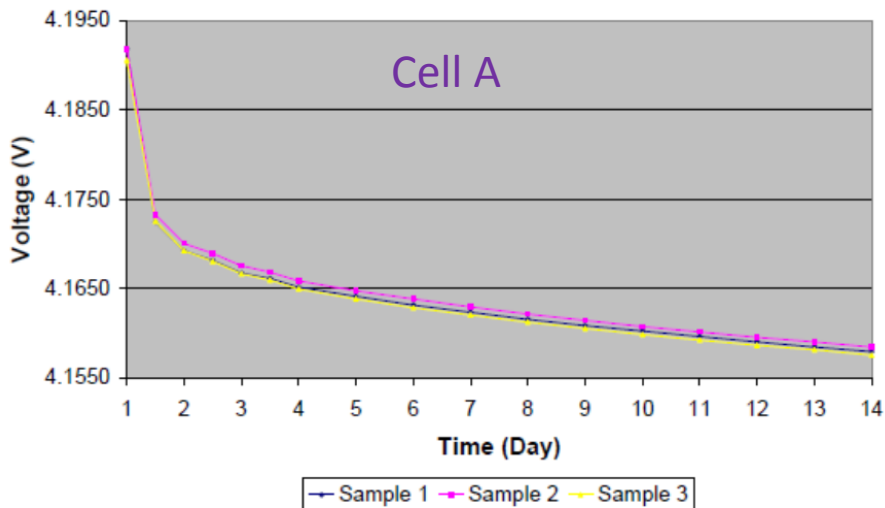
Tests:

1. Self Discharge Test: Fully charged cells shall be placed in Open circuit stand for 72 hours (OCV measurement twice a day); continue for total of 14 days with 1 reading per day
2. Soft Short Test 1: Fully charge; cells discharged to manufacturer's end of disch. Voltage (EODV) cutoff at C/5 rate; stand for 30 minutes; discharge with C/500 to the same EODV. stand for another 30 minutes; discharge the cells again using C/1000 current to the same EODV. OCV measurements twice a day for 72 hours and then for total of 14 days (data collection same as in 1.)
3. Soft Short Test 2: Fully charge; cells discharged to the manuf. EODV with a C/13 constant current; provide a 10 hour rest, discharge again to the same EODV with a current of C/250, provide a 10 hour rest, discharge again using a C/250 rate, provide a 24 hour rest, charge using C/250 to 3.15 V (for ~12 hours). OCV measurements twice a day for at 72 hours. (data collection same as in 1.)
4. Soft Short Test 3: Fully charge; cells shall be discharged using C/10 current to manuf. EODV. Allow the cell to remain at Open circuit for 10 seconds. Discharge the cell at C/20 rate to the same EODV, hold open circuit for 24 hours. Discharge the cells at C/200 rate to the same end of voltage cutoff and hold open circuit for 24 hours. Discharge the cells one more time at C/200 rate to the same EODV and hold open circuit for 36 hours. Charge at C/200 rate to 3.15 V and hold for 3 days. Record OCV during the open circuit stand periods every 12 hours and at the beginning and end of the 3 day hold (include the 12 hour OCV recording during this time also).

Capacity Cycling: Cells with declining voltages – one cell from each manufacturer chosen for cycling

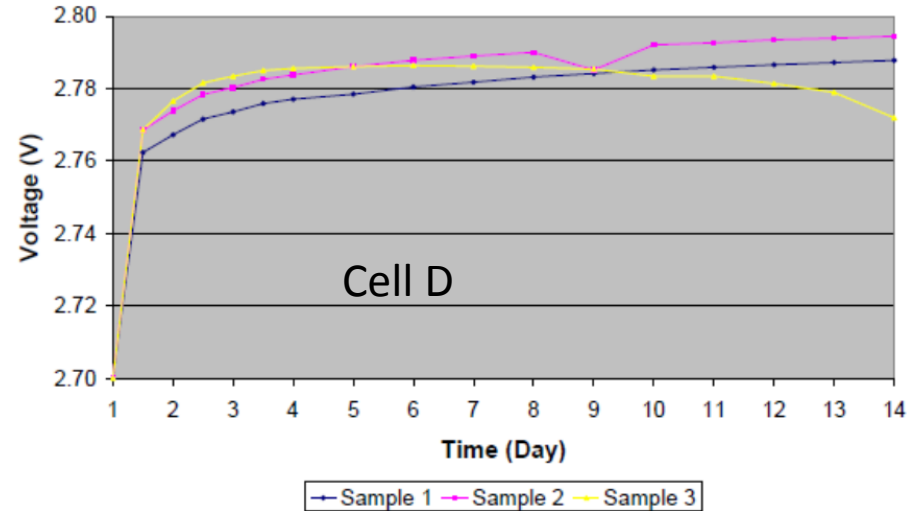
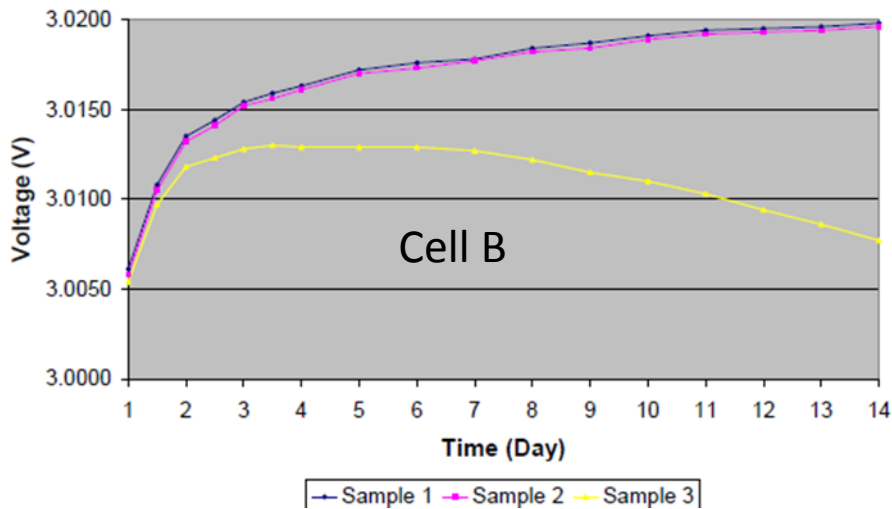
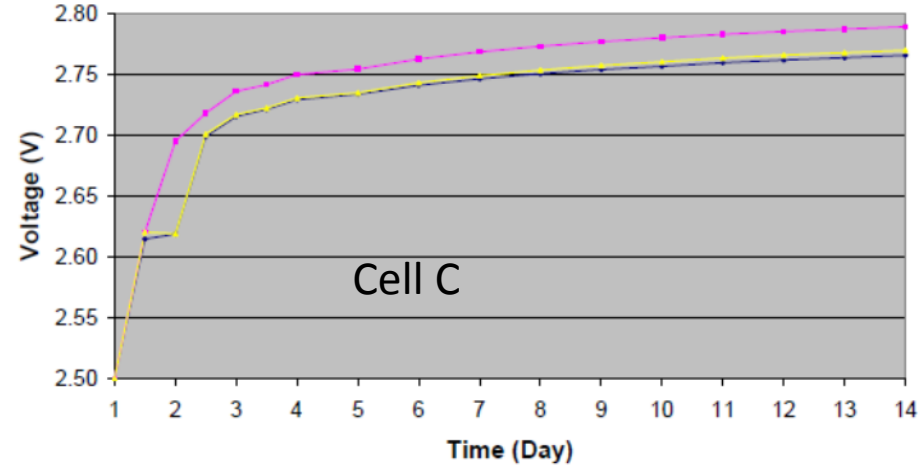
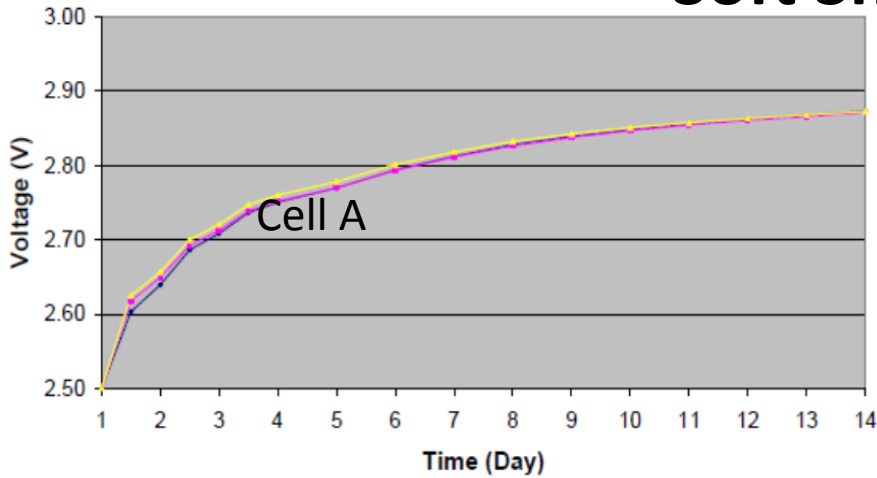
Destructive Physical Analysis (DPA): Cells with and without decline chosen from each lot for DPA.

Self Discharge Tests



Max self discharge observed in cells from Manufacturer A (Cell A)

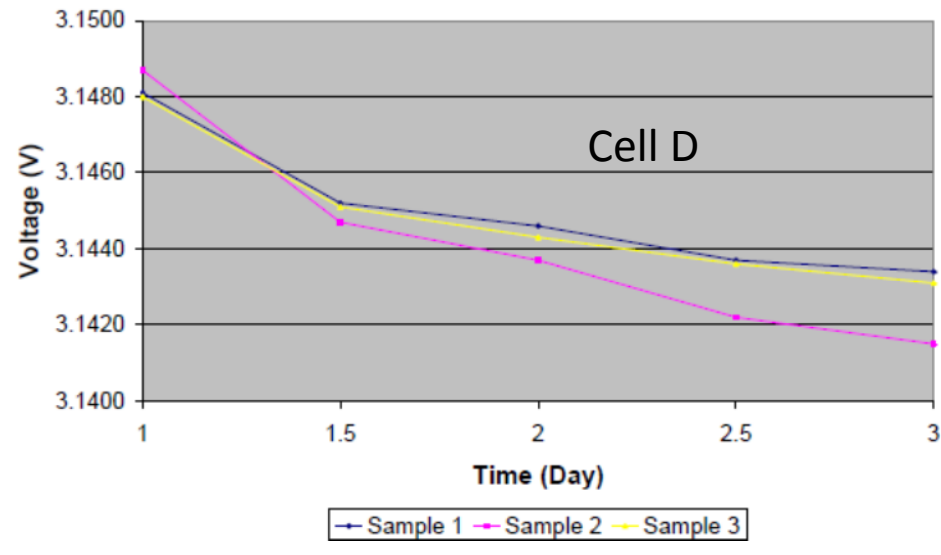
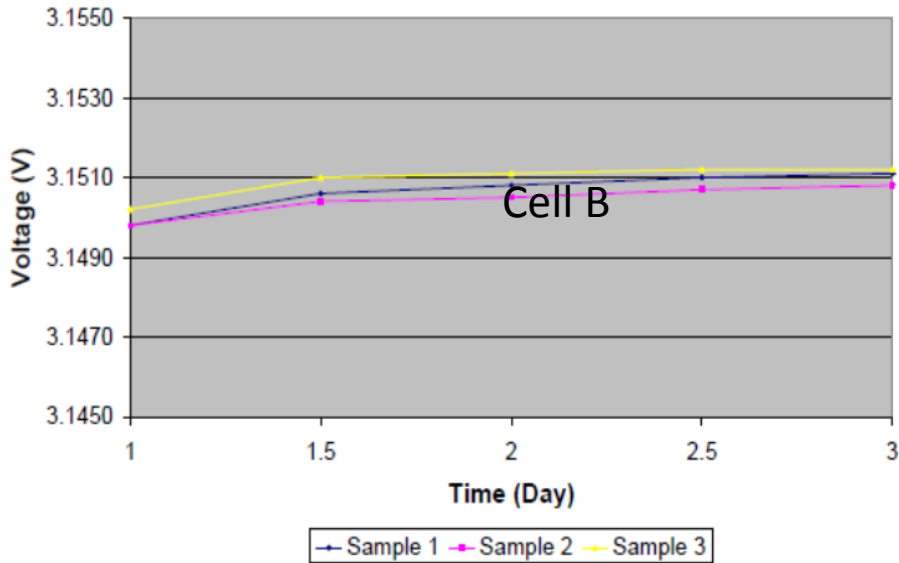
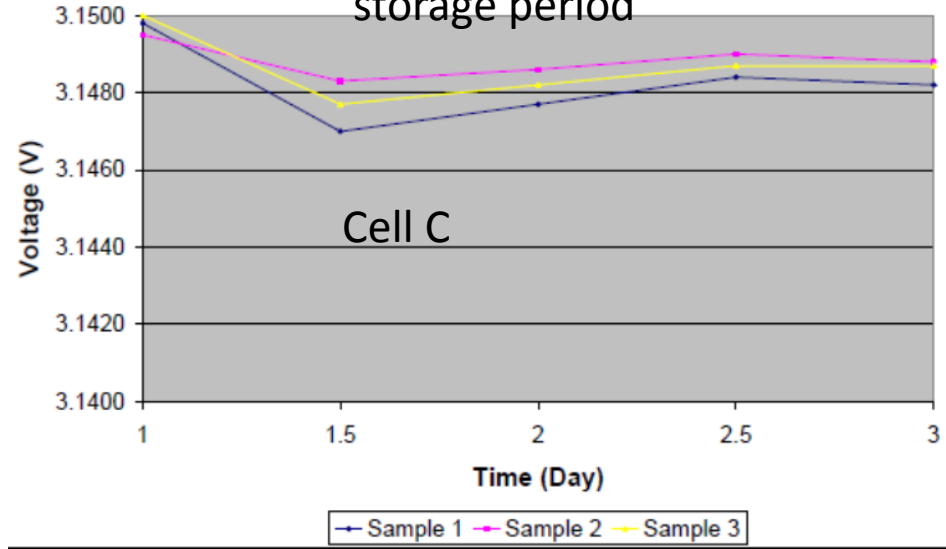
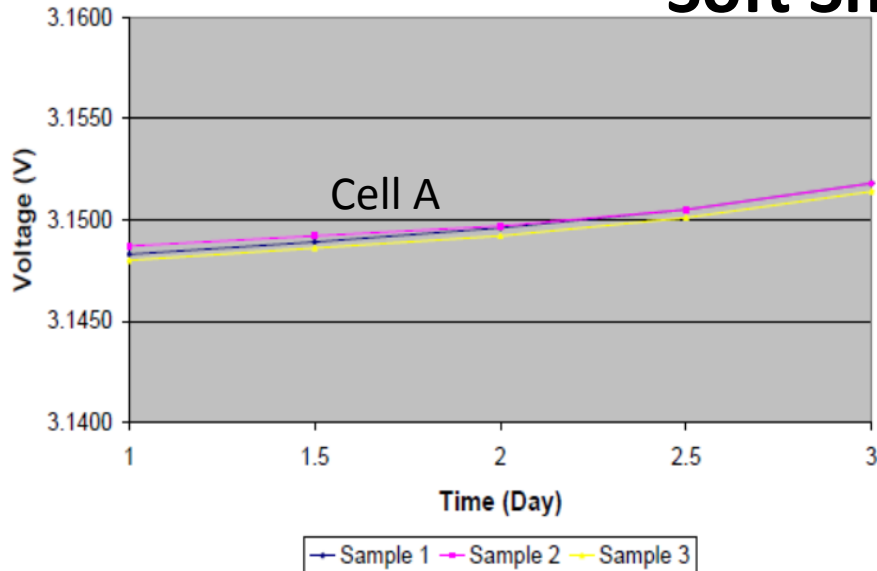
Soft Short Test 1



No OCV fall was observed in cells from Manufacturer A (Cell A)
Manufacturer D had cells that increased in voltage and then dropped
Manufacturer B had one cell that had a larger fall in voltage.

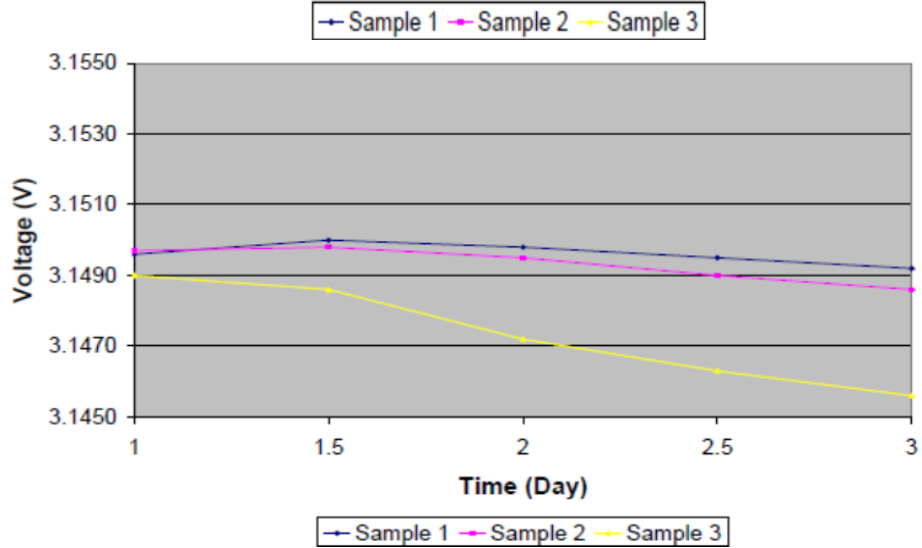
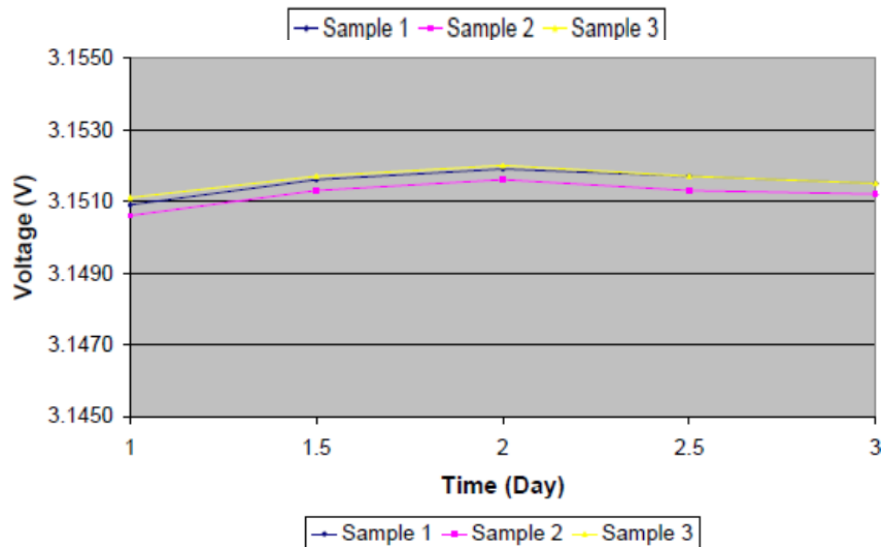
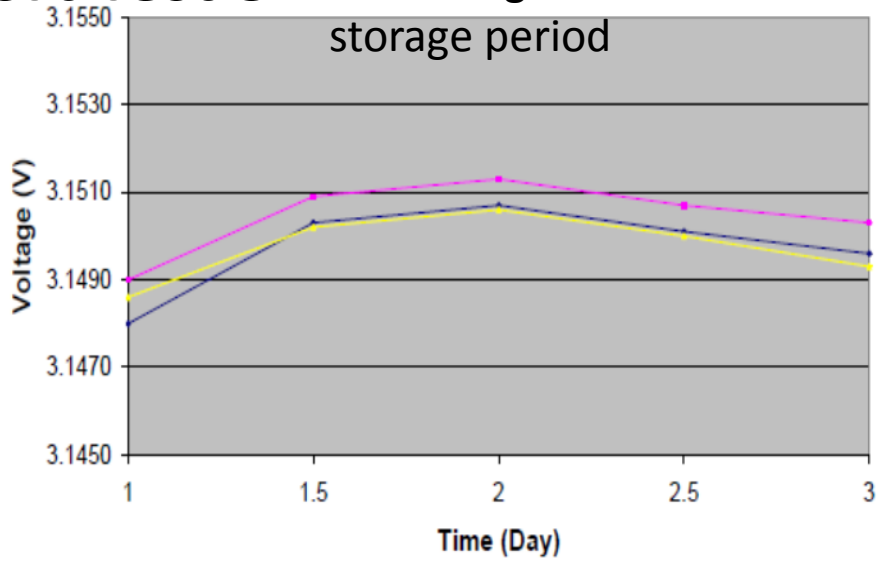
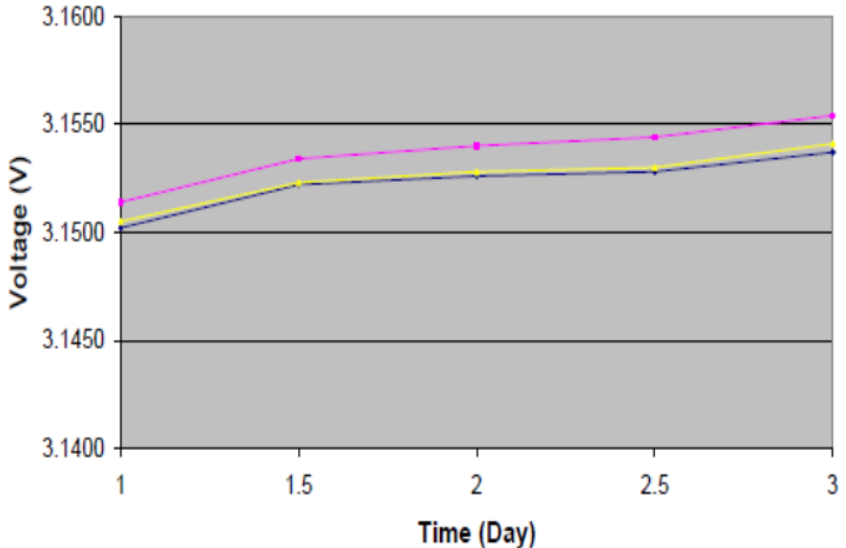
Soft Short Test 2

Cells charged to 3.15 V before storage period



No OCV fall was observed in cells from Manufacturer A (Cell A) and B (Cell B)
Manufacturer C showed drops and increases in voltage
Manufacturer D had larger fall in voltage

Soft Short Test 3 Cells charged to 3.15 V before storage period



No OCV fall was observed in cells from Manufacturer A (Cell A)
 Manufacturer B and C showed drops and increases in voltage
 Manufacturer D had larger fall in voltage

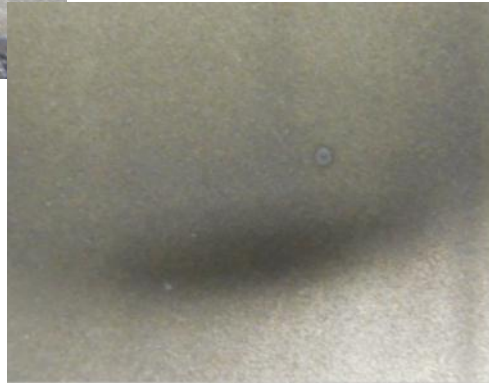
Destructive Physical and Chemical Analysis

Manufacturer A

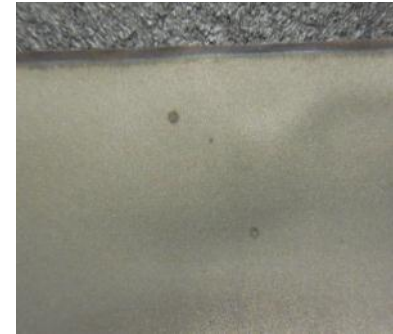
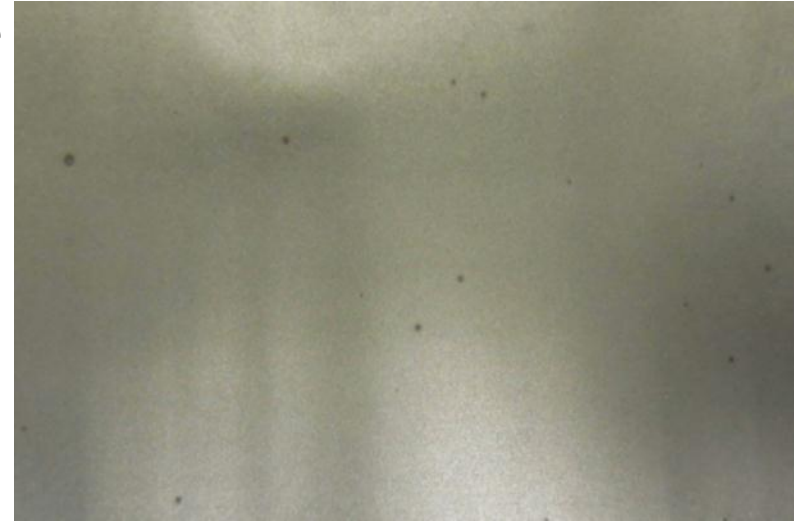
Sample Cell from
Self Discharge Test



Manufacturer A had the
highest self discharge
voltage loss



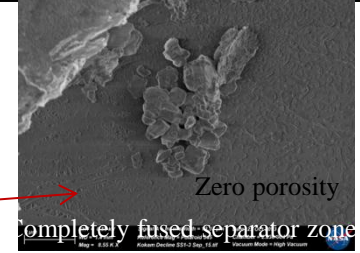
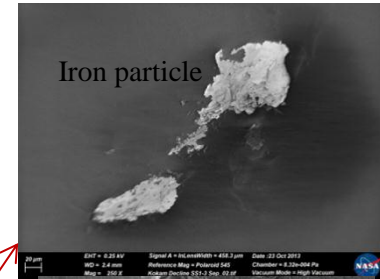
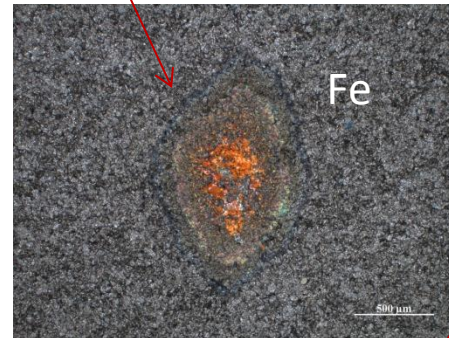
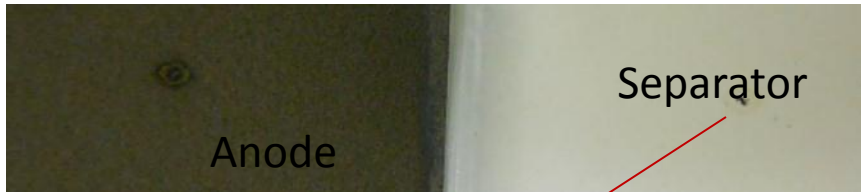
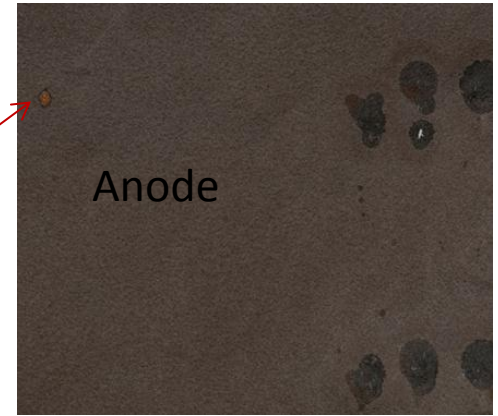
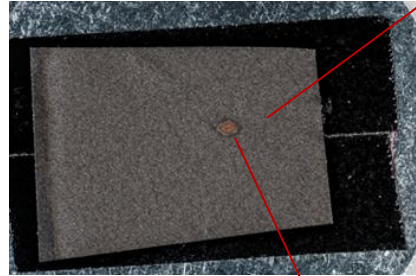
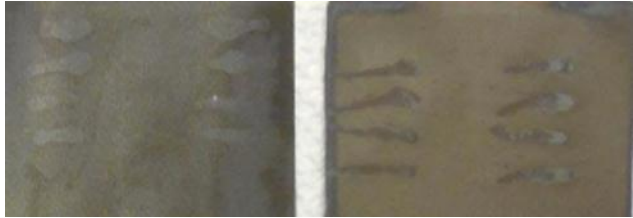
Sample Cell from
Soft Short Test 1



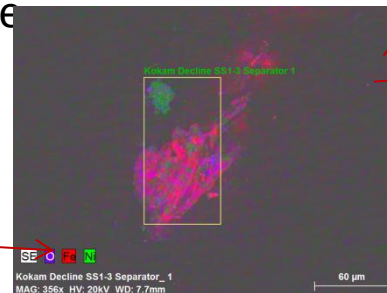
No voltage declines observed under
any of the soft short tests

Manufacturer B

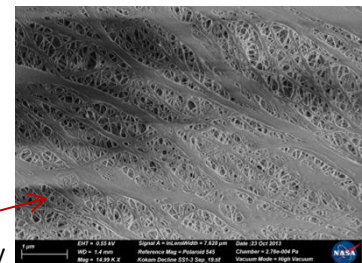
Voltage rise (8 mV) and decline (6 mV) in Soft Short Test 1



Separator
Side facing anode



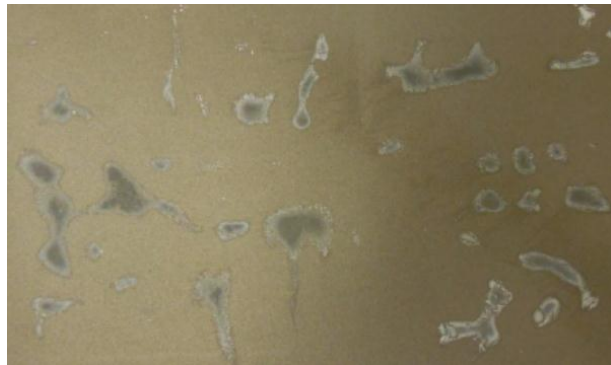
Separator away
From defect
Showing porosity



Manufacturer C

All electrodes and separator of Sample with no voltage decline had no marks or blemishes

Cell with No Voltage Decline
(soft short test 1; sample 2)



Dry Anode



Tear on Separator



Obvious Residue
on Separator

Manufacturer D

Cell with Large Voltage Decline
(soft short test 2: sample 2)

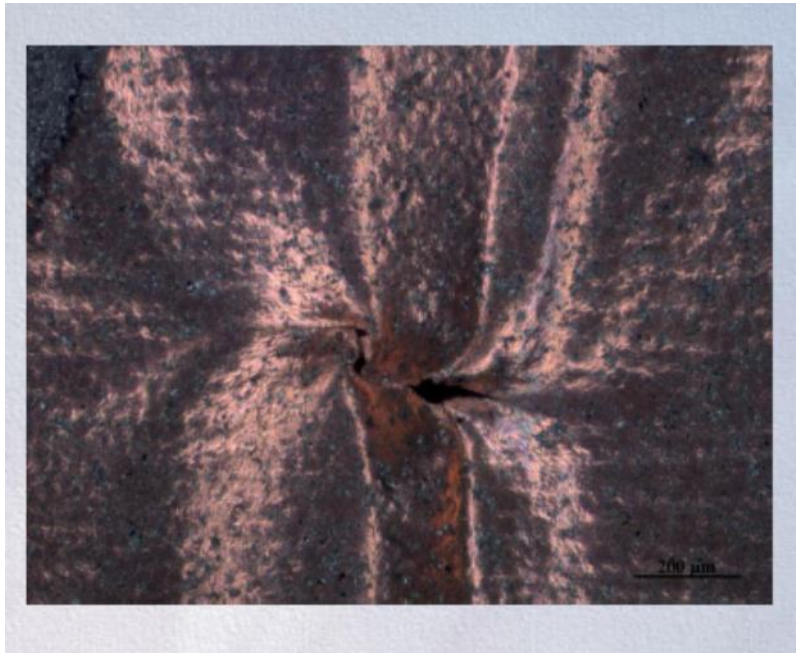


Wet
Anode



Tear in Top Layer of Cell
No other marks or blemishes

Other Screening / Detection Techniques



Ac Impedance : 38.7 mohms compared to All others in the range of 26 to 27 mohms.

Impact Sensor Batteries Flight Battery Test Data

Initial Discharge Capacity (Ah)	Post-Vibe Discharge Capacity (Ah)	ΔAh	Change %
0.882	0.875	0.007	0.79
0.878	0.870	0.008	0.91
0.819	0.763	0.056	6.84
0.874	0.865	0.009	1.03
0.857	0.848	0.009	1.05
0.889	0.880	0.009	1.01
0.866	0.856	0.010	1.15
0.884	0.874	0.010	1.13
0.870	0.860	0.010	1.15
0.829	0.825	0.004	0.48
0.844	0.785	0.059	6.99
0.802	0.800	0.002	0.25
0.760	0.758	0.002	0.26
0.766	0.765	0.001	0.13
0.774	0.769	0.005	0.65
0.775	0.771	0.004	0.52
0.762	0.761	0.001	0.13
0.771	0.766	0.005	0.65
0.772	0.775	0.003	0.39
0.759	0.750	0.009	1.19
0.779	0.828	0.049	6.29
0.779	0.763	0.016	2.05
0.764	0.760	0.004	0.52
0.788	0.781	0.007	0.89
0.777	0.773	0.004	0.51
0.778	0.774	0.004	0.51
0.771	0.766	0.005	0.65
0.763	0.758	0.005	0.66

Summary and Conclusions

- The self discharge test at full state of charge, may not be a good one to detect subtle defects since the li-ion chemistry has the highest self discharge at full state of charge. One should characterize self discharge versus storage time for each cell manufacturer/design to differentiate between normal self discharge and that due to a subtle manufacturing defect.
- The various soft short test methods indicate that if this test is carried out at full discharge (0% SOC) with all capacity removed (by lowering the current load in a stepwise manner to the same end of discharge voltage), then the cells need to be placed in storage for more than 72 hours to get a good analysis on the presence of subtle defects since it takes more than 72 hours to achieve voltage stabilization.
- If the cells are to be charged up even to a small percentage (ex. 1%), 72 hours are sufficient to determine issues. However, the pass/fail criteria should be based on a valid OCV decline. Less than 10 mV voltage decline is not a good method to detect subtle defects. As mentioned in the first bullet, self discharge is a competing reaction when a charge is introduced and hence a characterization of the self discharge versus storage time is required to fully correlate voltage decline to a failure due to a subtle defect.
- Soft short test method cannot be relied on for defect detection because cells with and without voltage decline seemed to have similar defects and characteristics.
- Screening methods such as internal resistance and capacity as well as a 3-sigma range for OCV, mass and dimensions should be used to screen out outliers.
- A very critical aspect in the understanding of subtle defects is to carry out destructive analysis of cells from every lot to confirm the quality of production and screen all cells and batteries in a stringent manner to have a high quality set of flight cells.

Acknowledgments

- PCTest Engineering for patiently carrying out all the tests
- James Martinez in the Materials Lab at NASA-JSC for carrying out all the chemical analysis.