Tolerance of Li-ion Pouch Cells to Varied Space Environment Pressures

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Background

- Commerical off-the-shelf (COTS) li-ion cells are frequently subjected to a standard set of tests to determine their performance and safety in order to add them to a database that allows users at NASA, specifically at Johnson Space Center, to choose cell designs for different applications.
- In recent years, Li-ion polymer cells in pouch format are used increasingly in portable equipment applications and are commonly being referred to as lithium polymer cells, although these cells are not of the true polymer types.
- Several Li-ion polymer or pouch cells have been tested at NASA-JSC in the past 15 years Cells of this type have developed from being low rate (Ultralife, 1998) to medium rates (Valence, Samsung, Kokam, etc. ~2005) and then on to high energy and high rates (~2010-).
- Testing of these li-ion polymer cells have shown that long term storage as well as vacuum exposures cause swelling of the pouch; there is also a variance in their safety characteristics under off-nominal conditions.
- Recent test programs at NASA-JSC have focused on testing the li-ion polymer cells for their safety as well as their performance under different rates and temperatures, and in addition to this, under vacuum and reduced pressure conditions.
- The most recent tests included cells of the following types:

SKC 15 Ah (high-rate capability)

Tenergy 6 Ah (medium rate medium energy density)

Altairnano 13 Ah (nanotitanate anode with high rate capabiltiy)

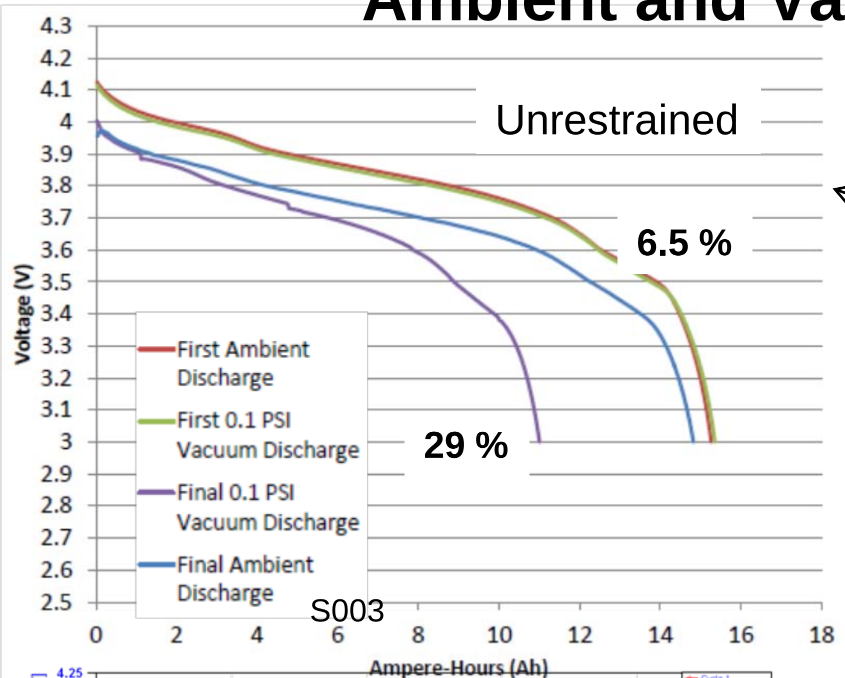
Wanma 5 Ah (medium rate medium energy density)

iPad Battery ~4.0 Ah

GMB 3.9 Ah

Kokam 5.0 Ah

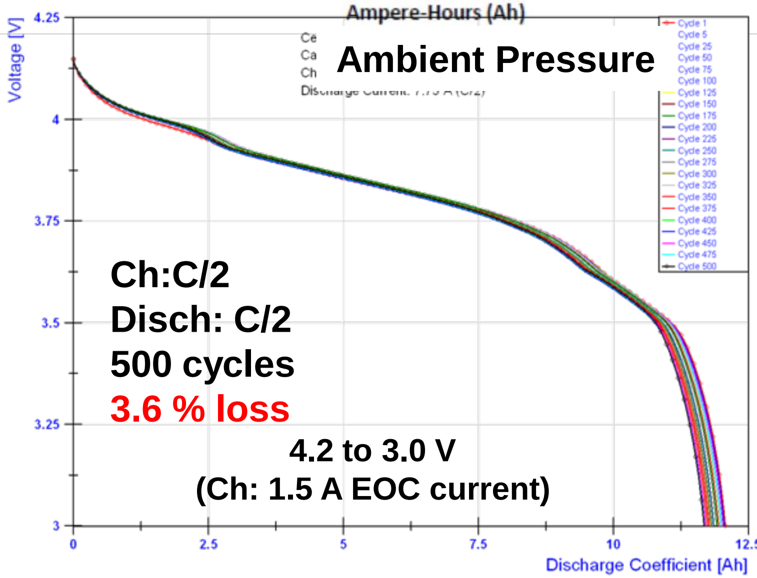
SKC 15 Ah Li-ion Cell with Continuous Cycling Under Ambient and Vacuum Environments

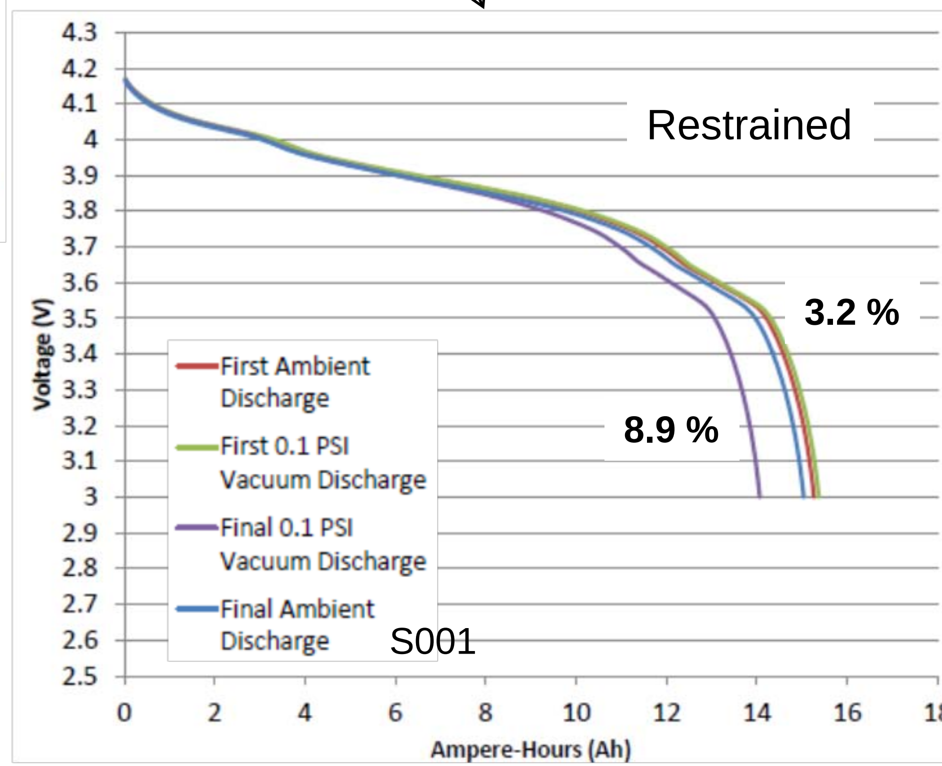


Cells show loss in capacity when cycled under vacuum conditions

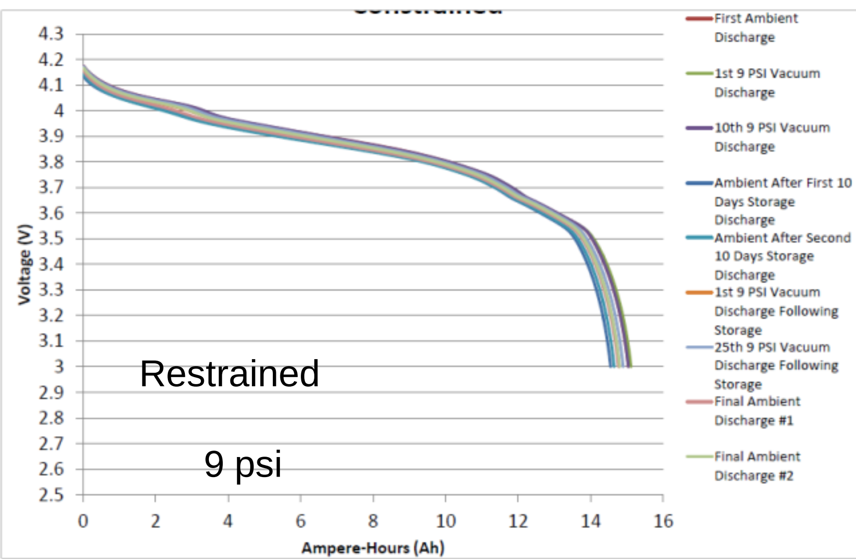
Vacuum : 30 cycles

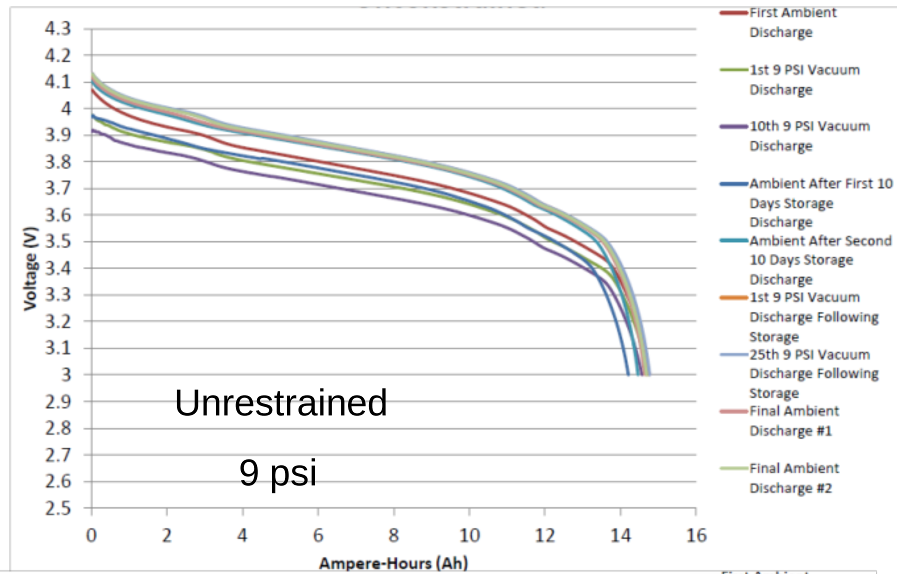
C/2 Charge and Discharge

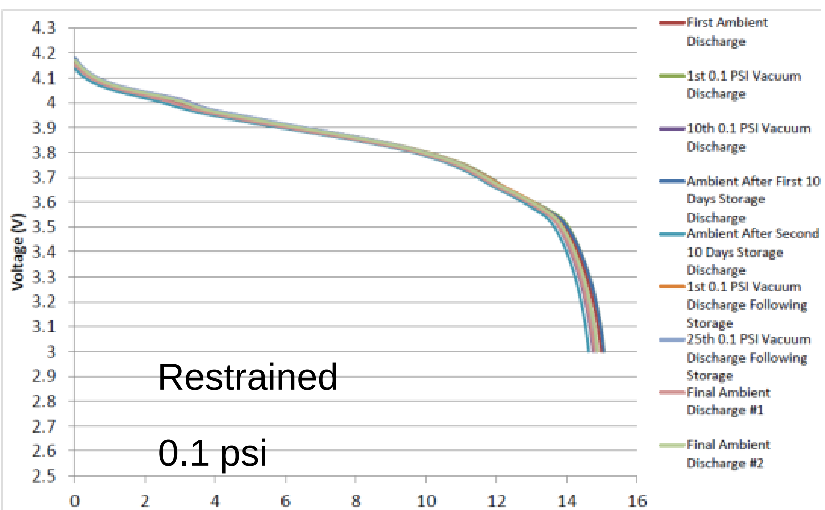


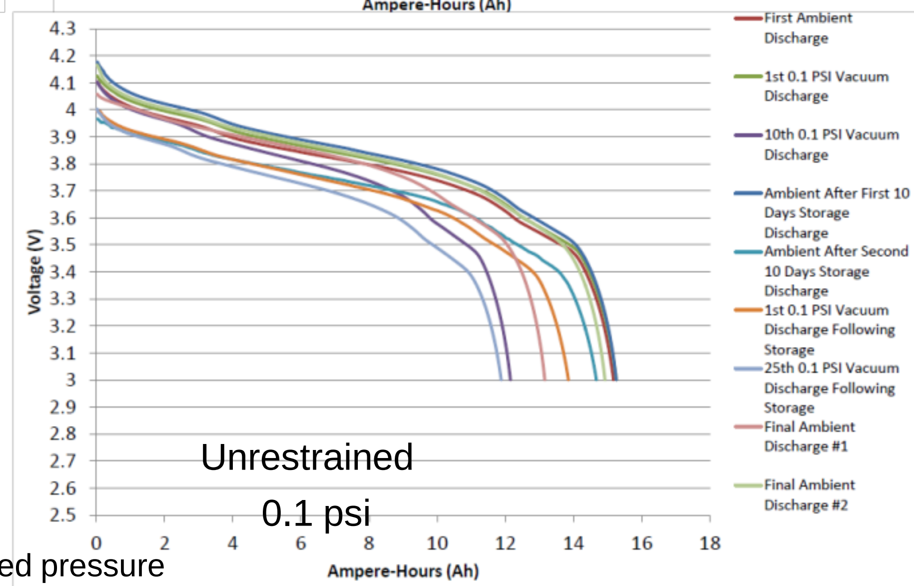


SKC 15 Ah Li-ion Cell with Cycling Under Low Pressure and Vacuum Environments



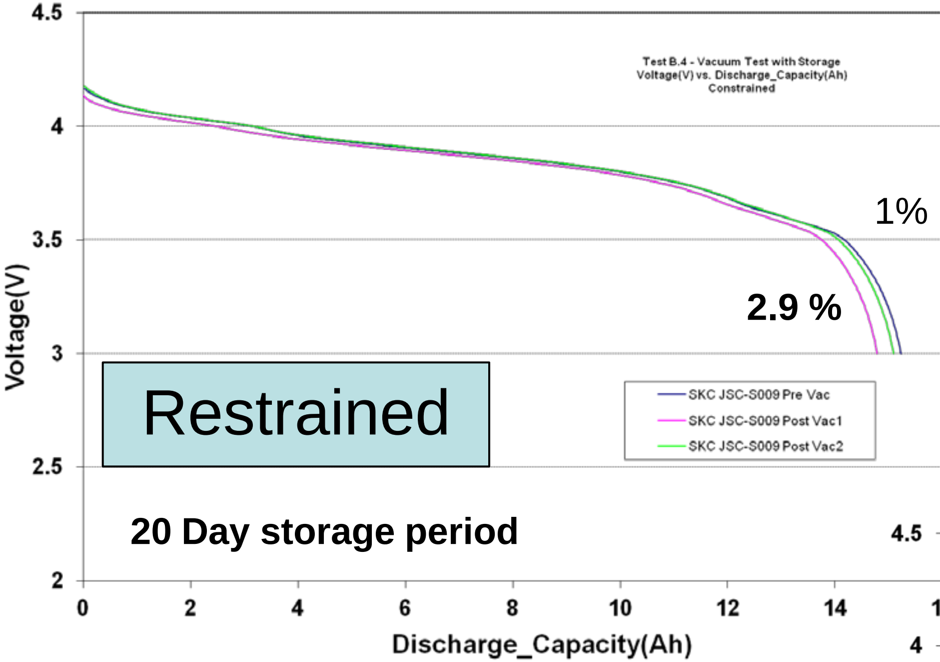




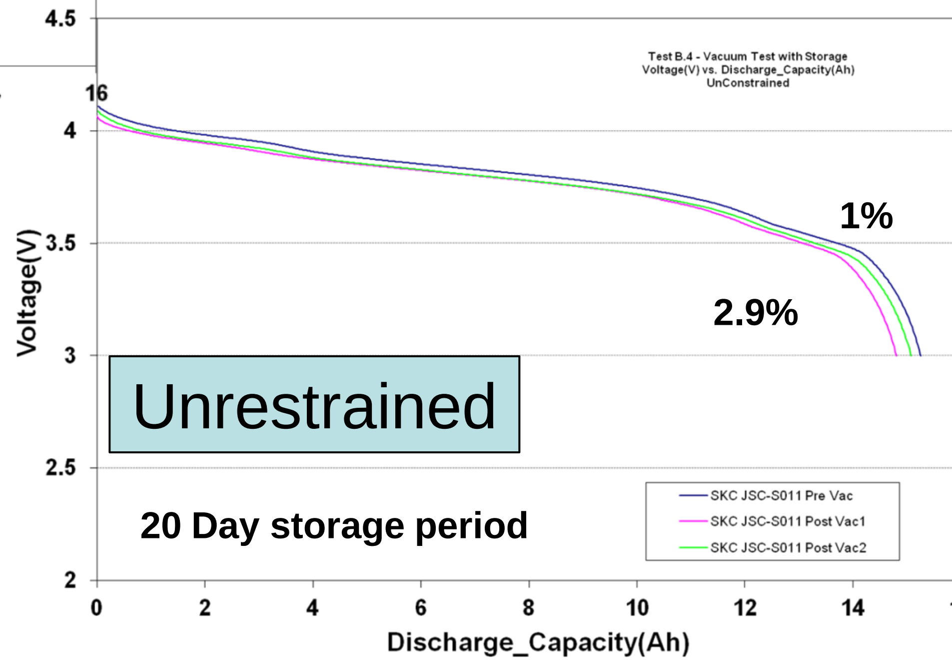


Under restraints, the performance of the cells at reduced pressure And vacuum remains similar. The performance for both without cell restraints is very poor

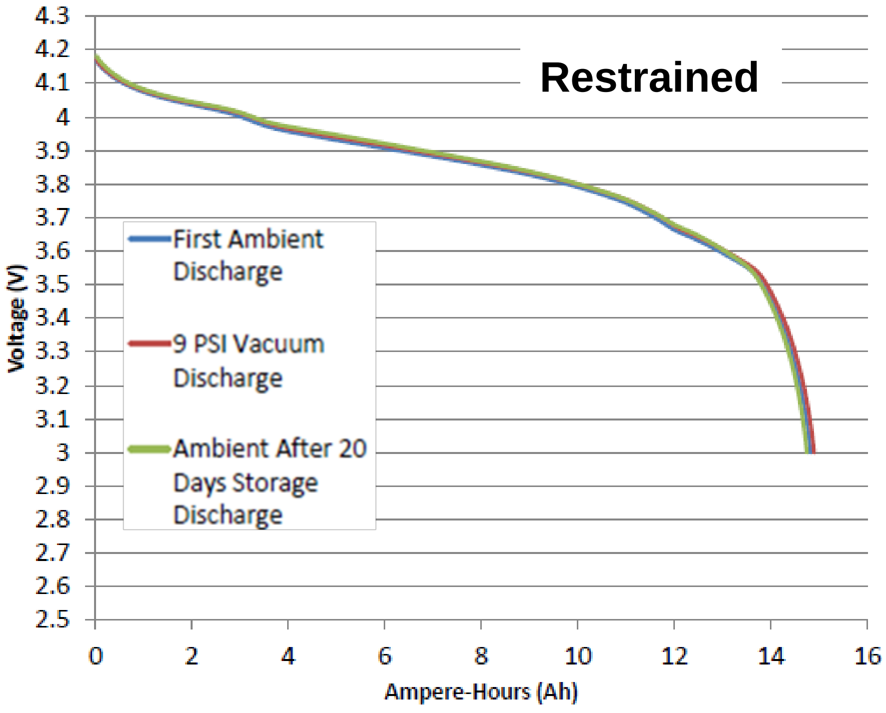
SKC Li-ion Cell Performance After Charge Under Vacuum and Storage at Ambient Pressure



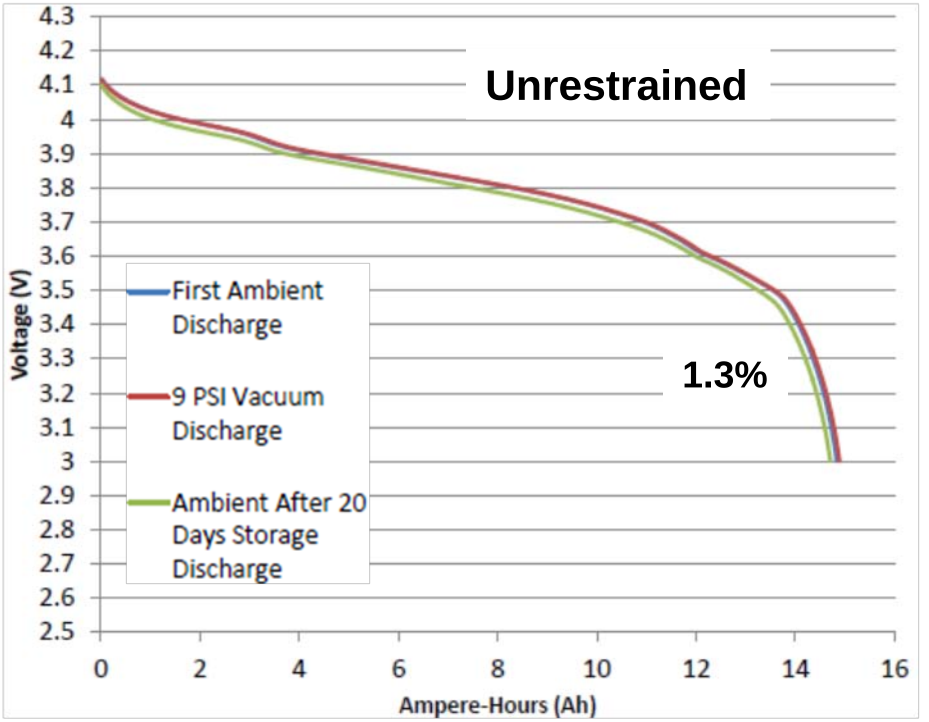
One charge under vacuum; storage at full charge at ambient pressure for 20 days



SKC Li-ion Cell Performance After Cycling Under Reduced Pressure and Storage at Ambient

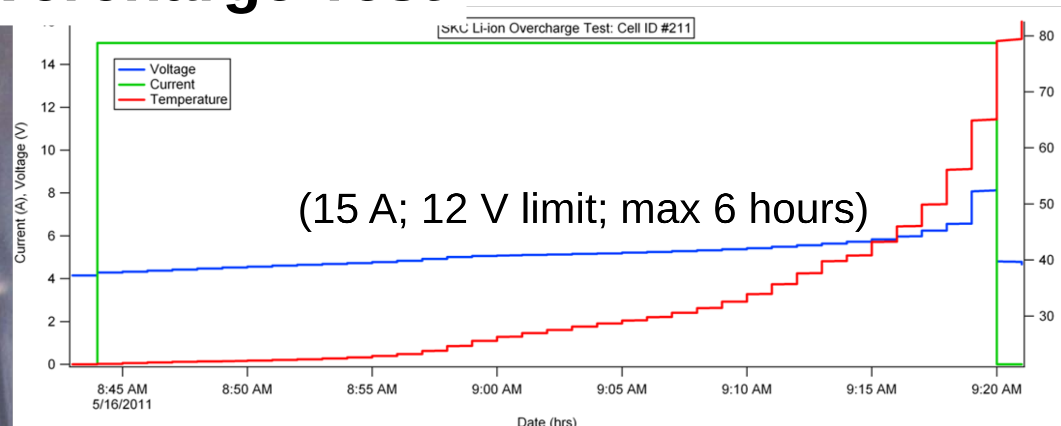


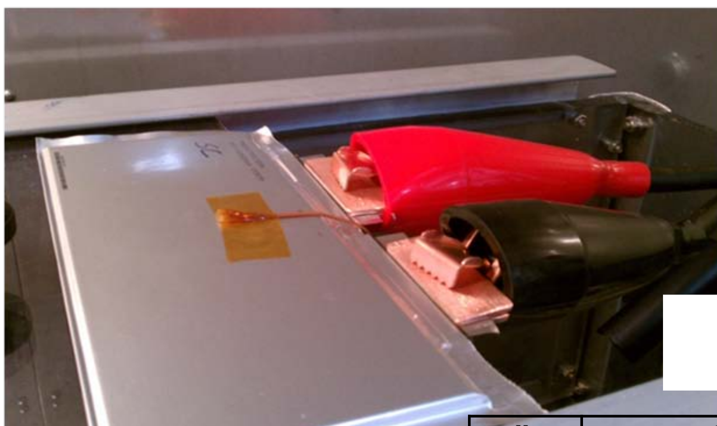
One cycle under reduced pressure; storage at full charge at ambient pressure for 20 days

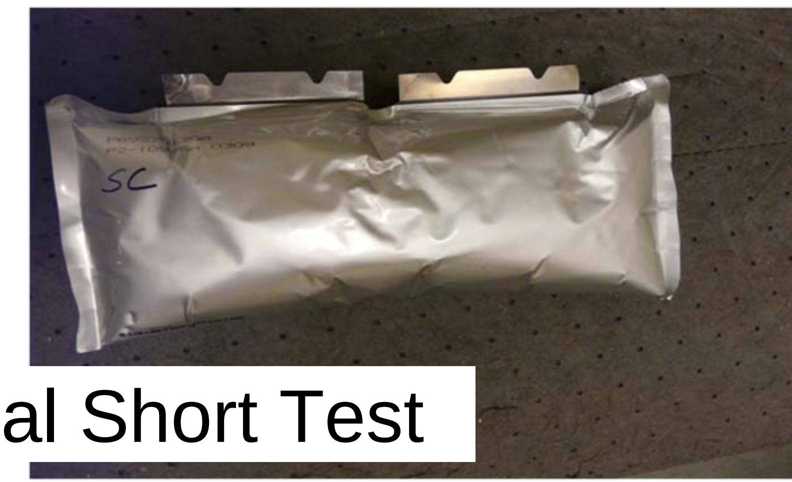


SKC 15 Ah Cell Safety Tests

Overcharge Test





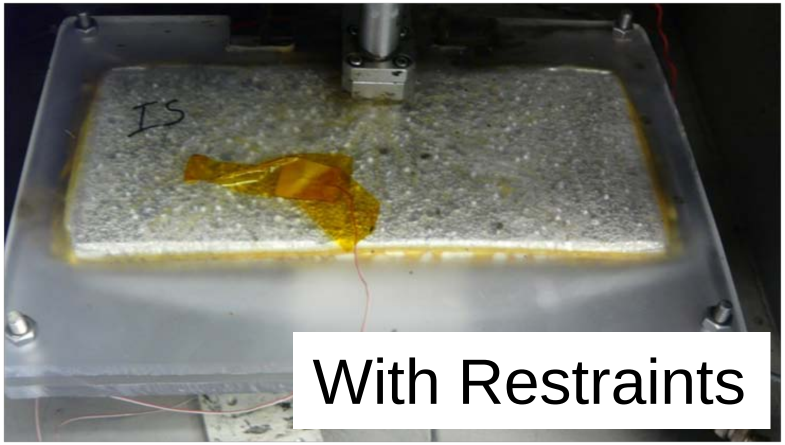


Cell swelling

External Short Test

Cell ID	Pre OCV (V)	OCV at Peak Current (V)	Post OCV (V)	Load Value (mΩ)	Peak Current (A)
204	4.165	≈2.03	1.353	3.60	482.00
301	4.148	≈2.49	4.083	1.76	1,410.10
302	4.151	≈2.37	1.733	1.76	1,393.30
309	4.137	≈2.77	0.658	1.60	1,395.80
313	4.161	≈2.96	2.853	1.60	1,404.10

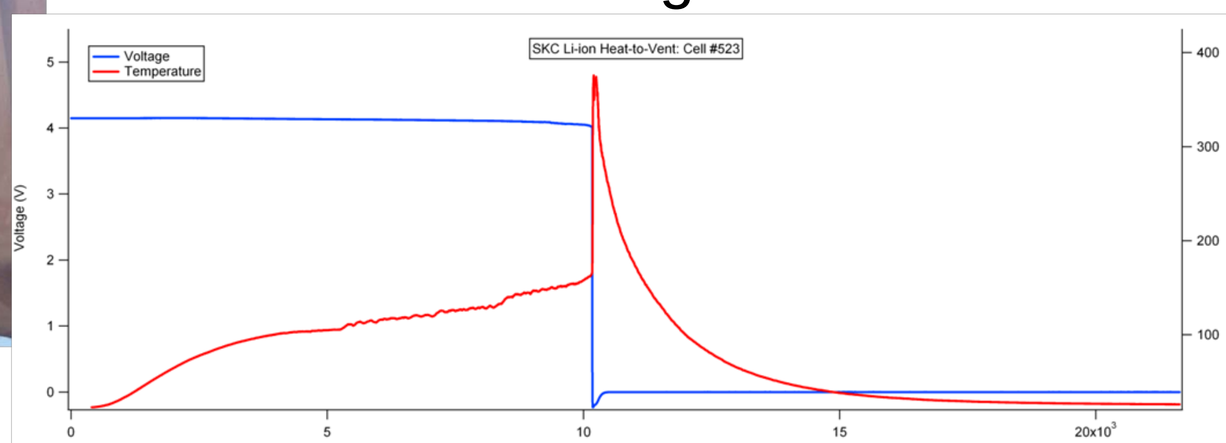
SKC 15 Ah Li-ion -Simulated Internal Short Test



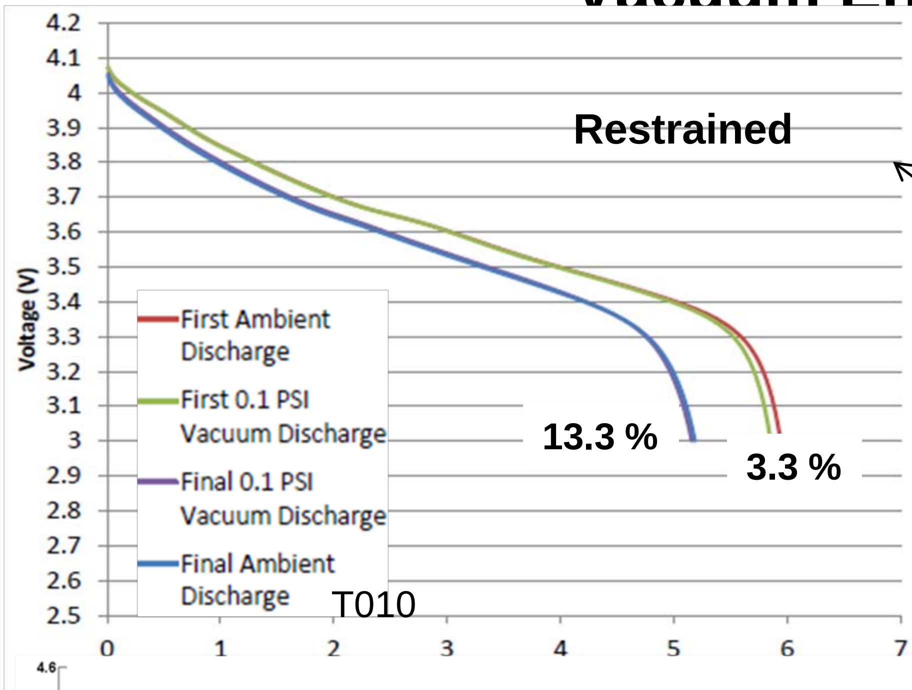
Thermal runaway

SKC 15 Ah Li-ion - Heat to Vent Test

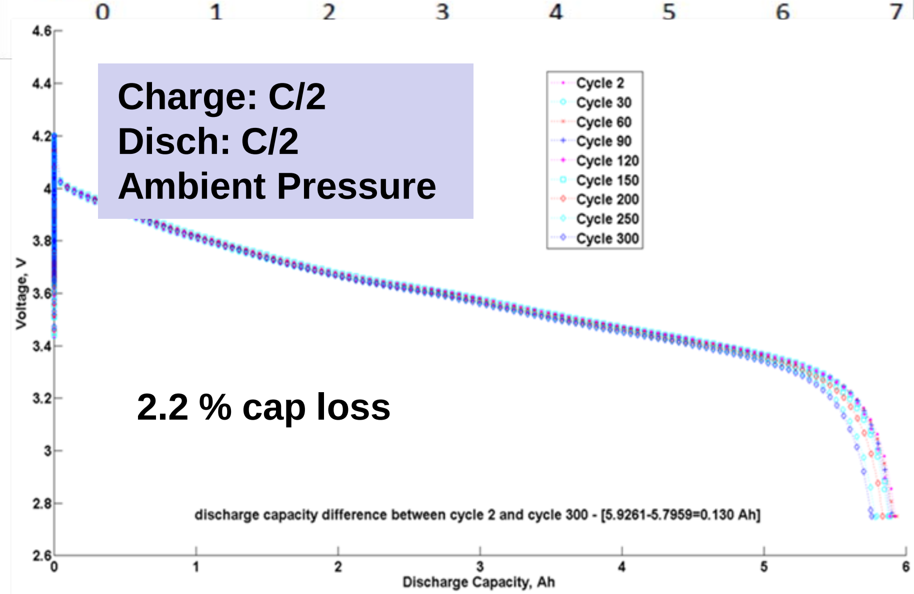
Venting and thermal runaway above175 deg C

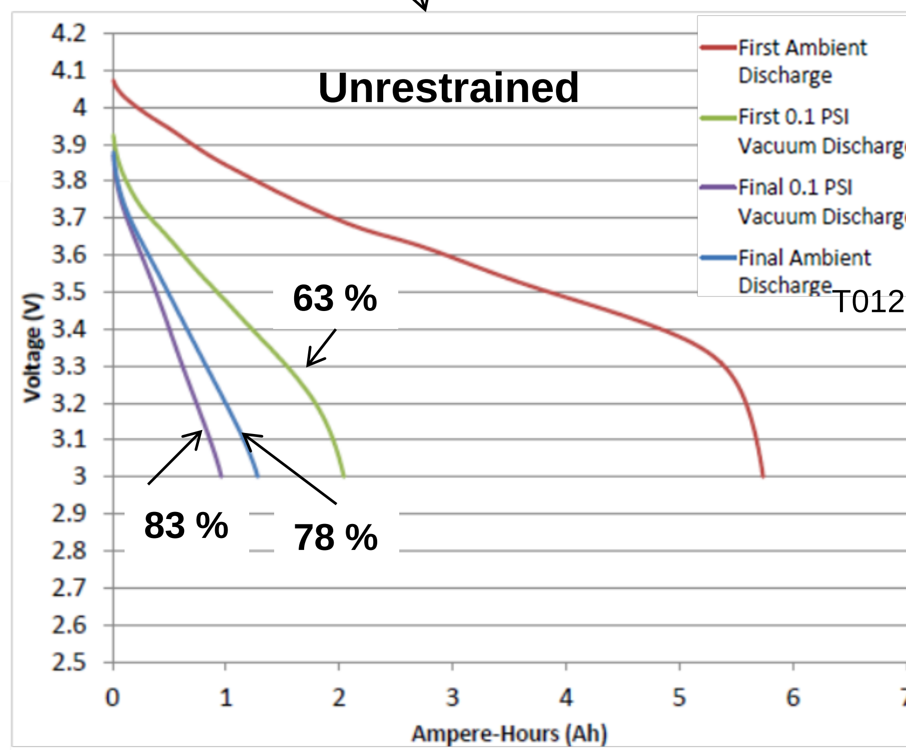


Tenergy 6 Ah Li-ion Cell with Continuous Cycling Under Vacuum Environments

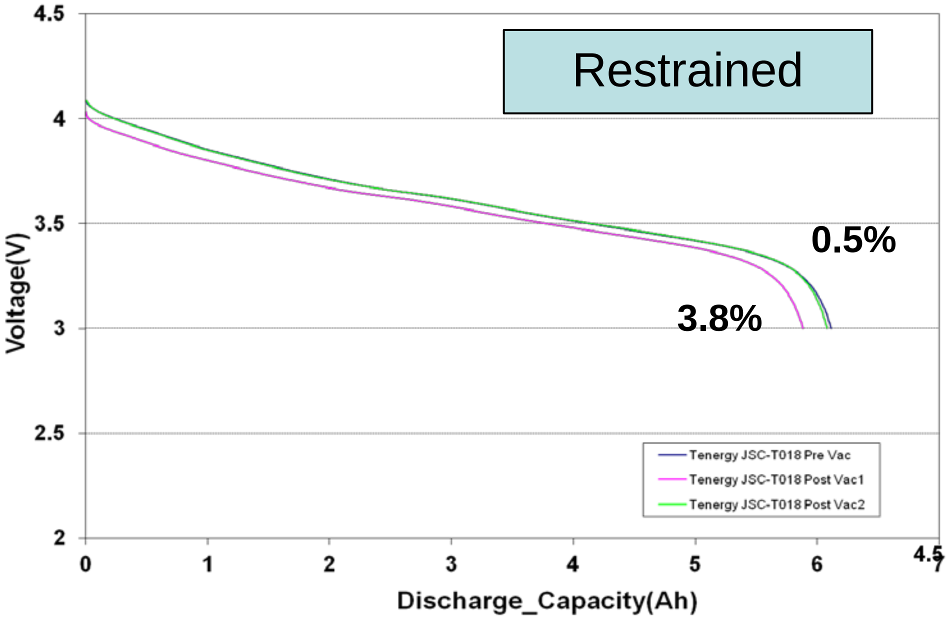


C/2 charge and discharge
Vacuum; 30 cycles

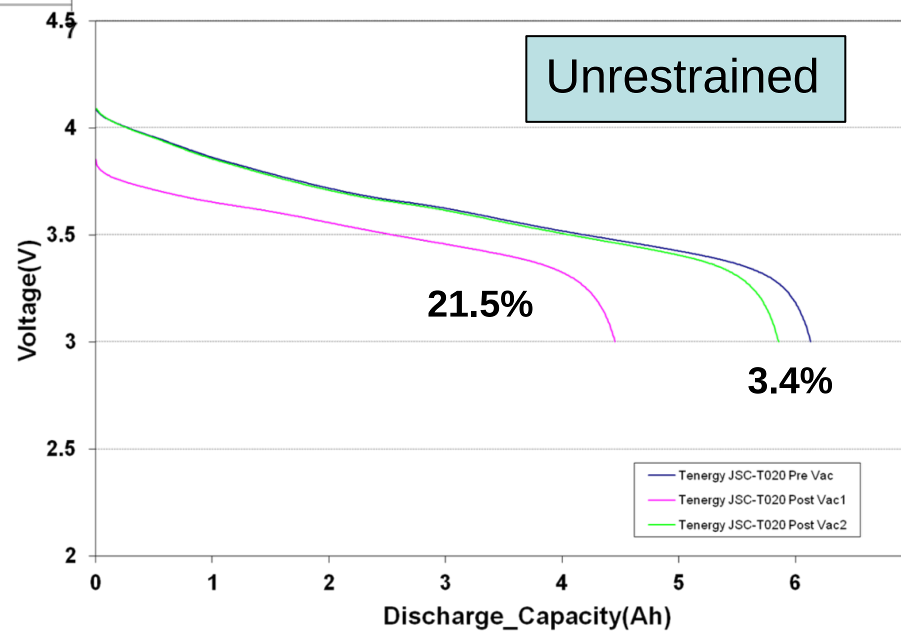




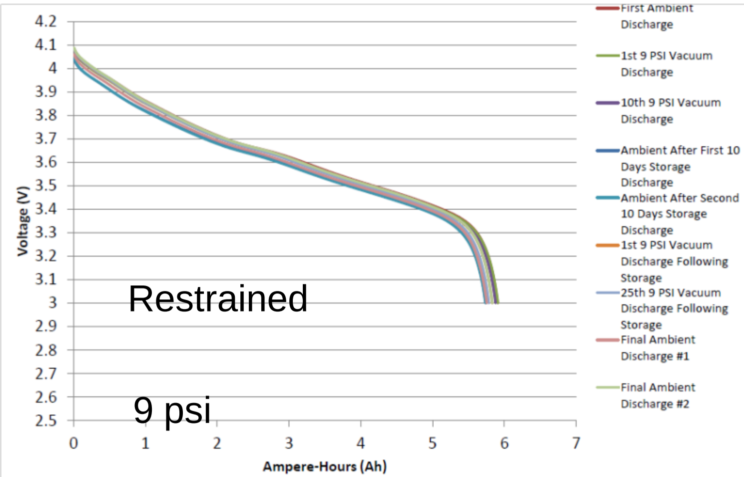
Tenergy Li-ion Cell Performance After Charge Under Vacuum and Storage at Ambient Pressure

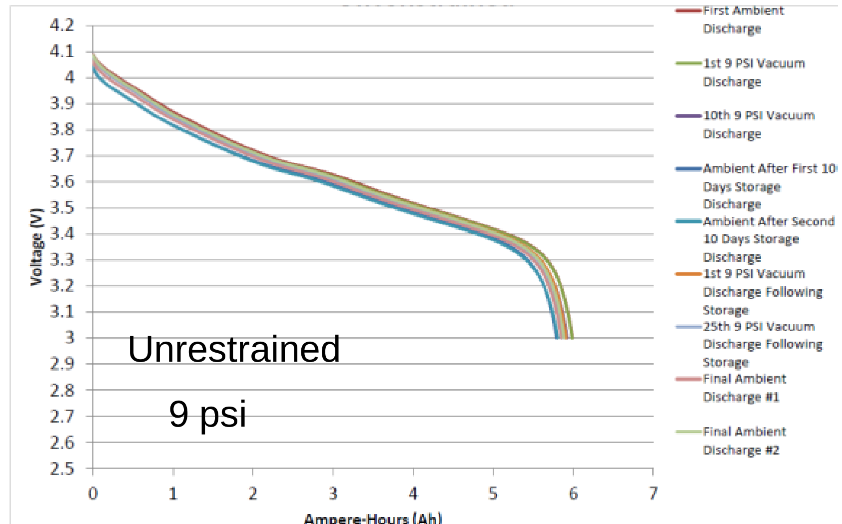


One charge under vacuum; storage at full charge at ambient pressure for 20 days

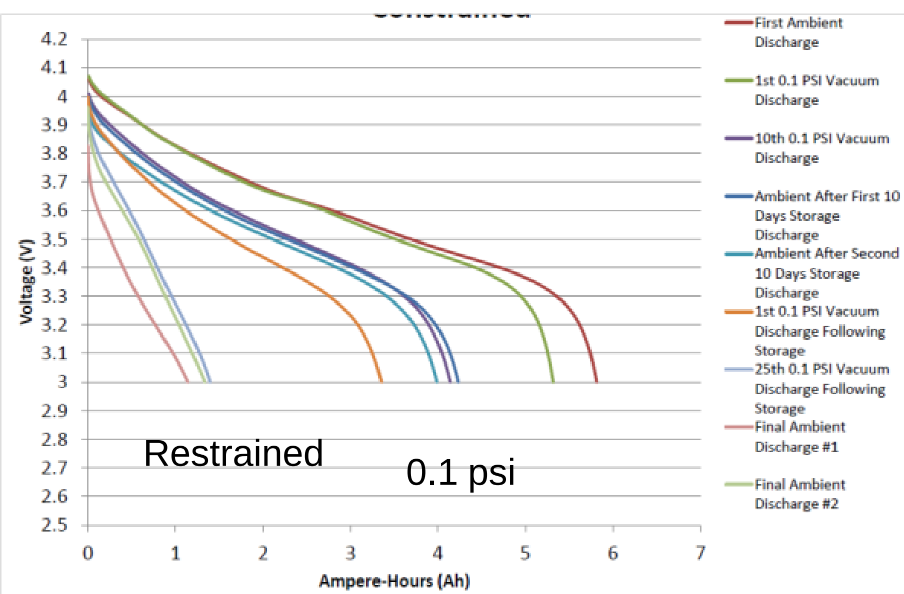


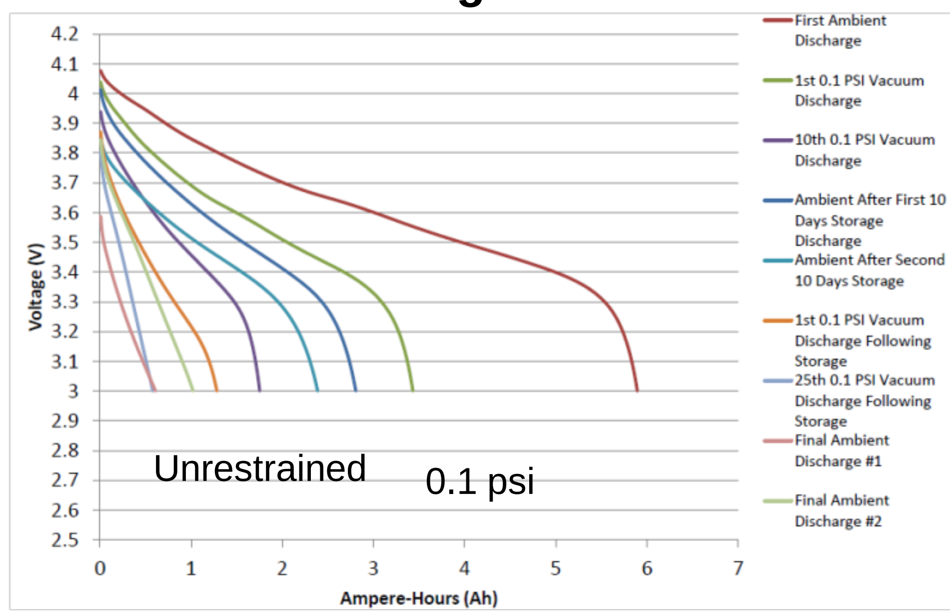
Tenergy Li-ion Cell Performance Under a Combination of Reduced Pressure Cycling and Ambient Pressure Storage





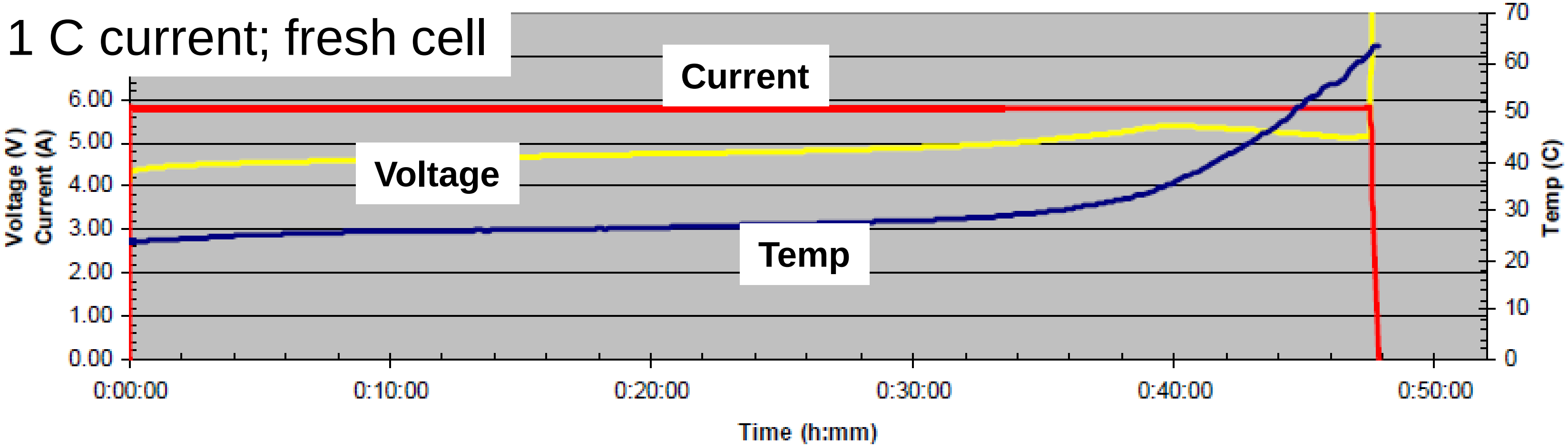
Tenergy Li-ion Cell Performance Under a Combination of Vacuum Environment Cycling and Ambient Pressure Storage





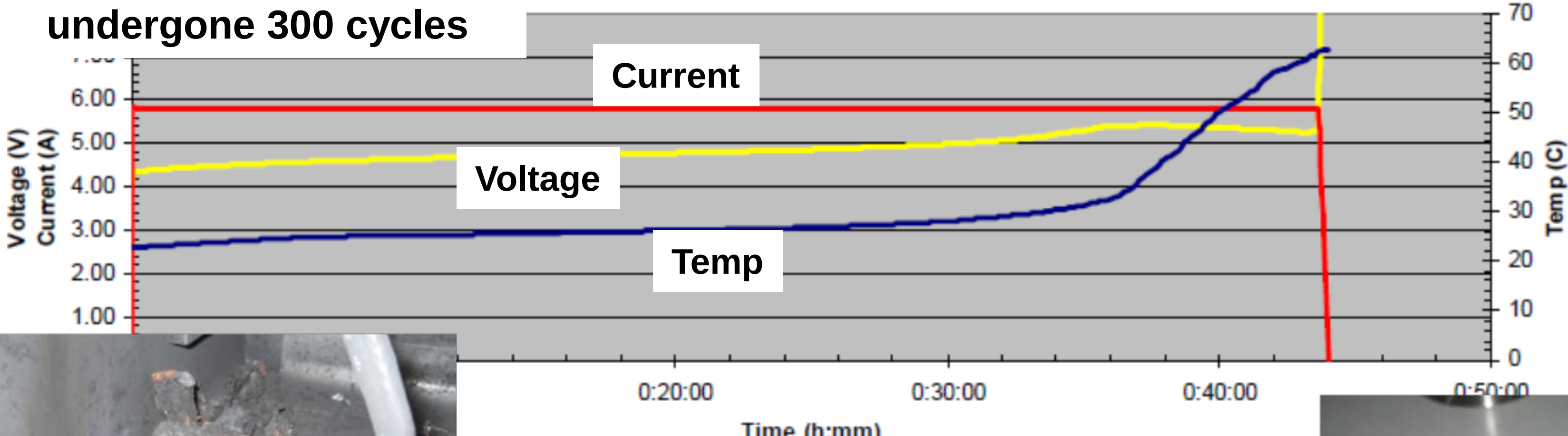
Tenergy 6.0 Ah Li-ion Prismatic Pouch Cell Overcharge Test

1 C current; fresh cell



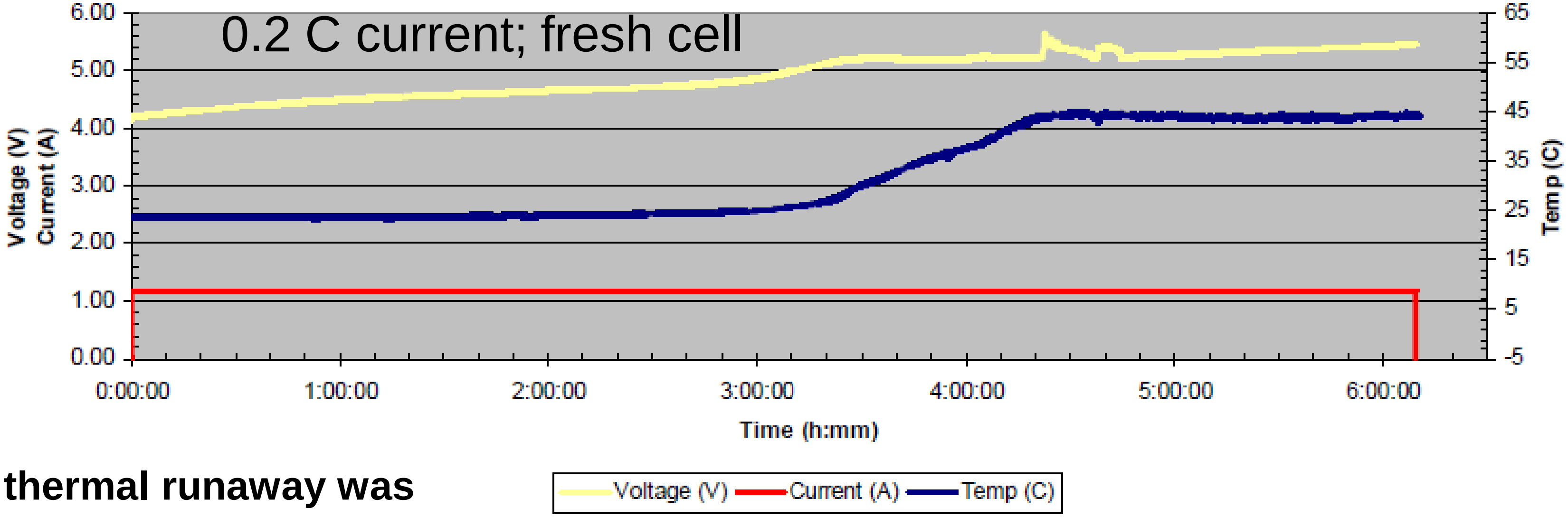
1 C current; Cell had undergone 300 cycles

Both cells vented violently

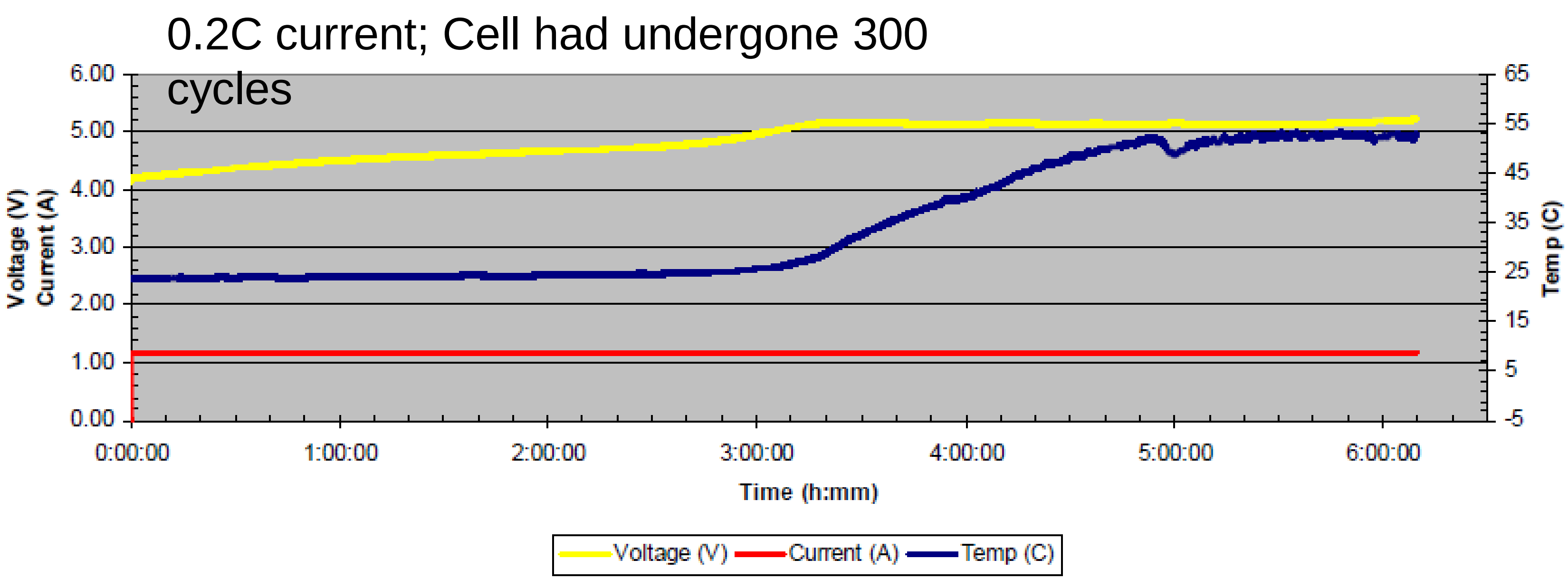


0.5Ccurrent overcharge produced same results

Overcharge Test of Tenergy 6.0 Ah Li-ion Cell

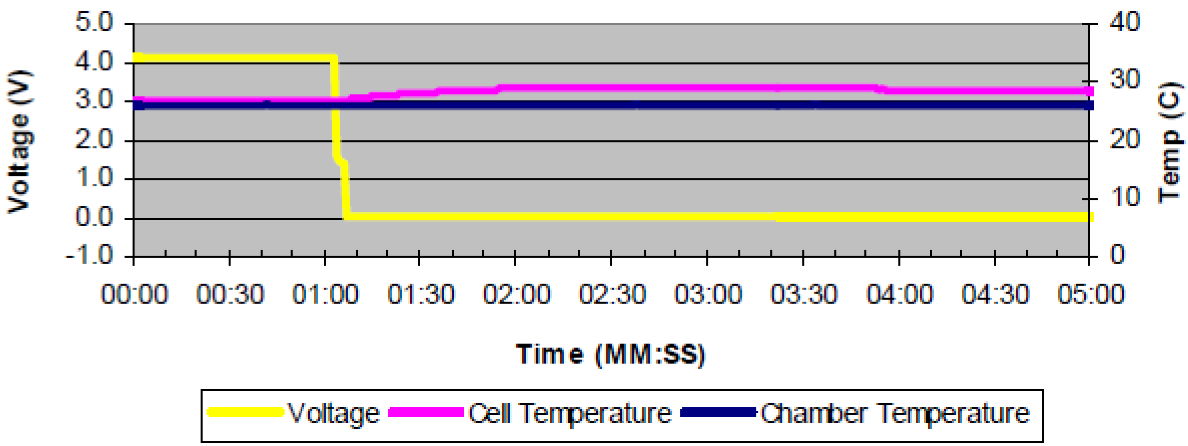


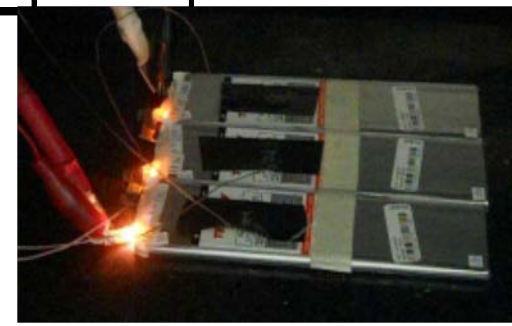
No thermal runaway was observed in both cases

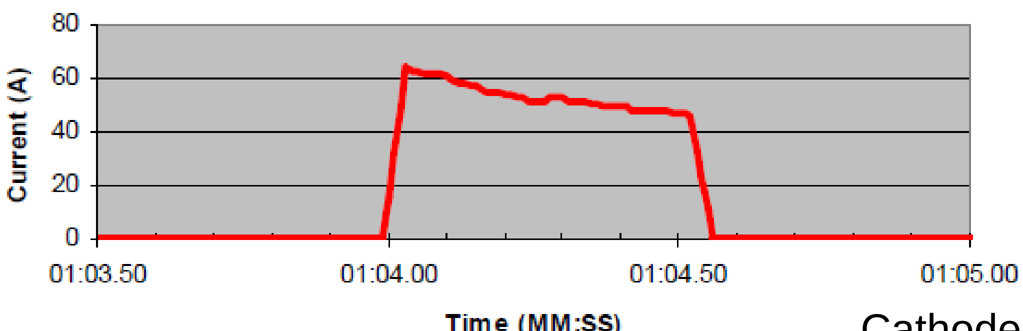


External Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp (°C)	Sample Condition	Sample #	Sample ID	Resistance (mOhm)	Initial OCV (V)	Initial ACR (mOhm)	Maximum Temp (°C)	Maximum Current (A)	Notes
20	Fresh Chg	1	11	30	4.1284	20.4	28.9	62.0	Cathode tab burned off
20	Fresh Chg	2	8	30	4.1327	20.4	27.2	63.0	Cathode tab burned off
20	Fresh Chg	3	9	30	4.1325	20.3	29.7	65.0	Cathode tab burned off
20	Fresh Chg	3-Cell	25,28,27	27	12.431	63.2	27.2	113.0	Cathode tab burned off



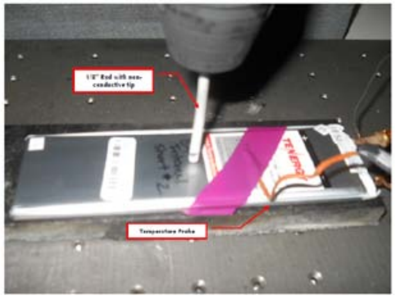




Cathode Tabs from all three cells burned off and became disconnected

Simulated Internal Short Test on Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Maximum Temp ('C)	Notes
20	Fresh Chg	1	172.6	Fire
20	Fresh Chg	2	309.8	Fire



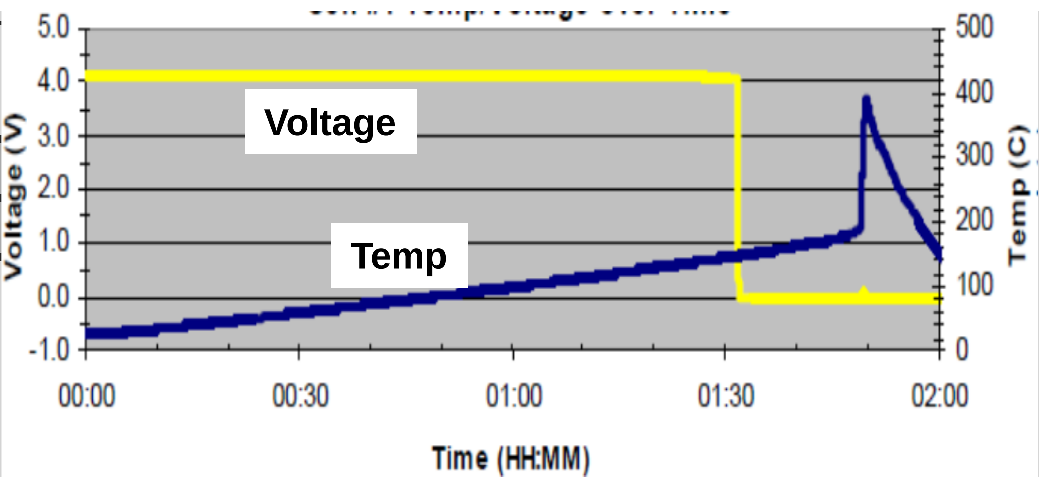
Burst Pressure Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Sample ID	Max Pressure (kPa)
20	Fresh Chg	1	40	662
20	Fresh Chg	2	5	617

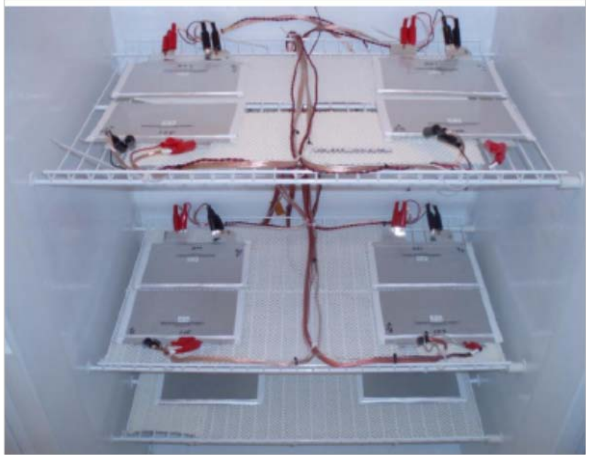
89/96 psi

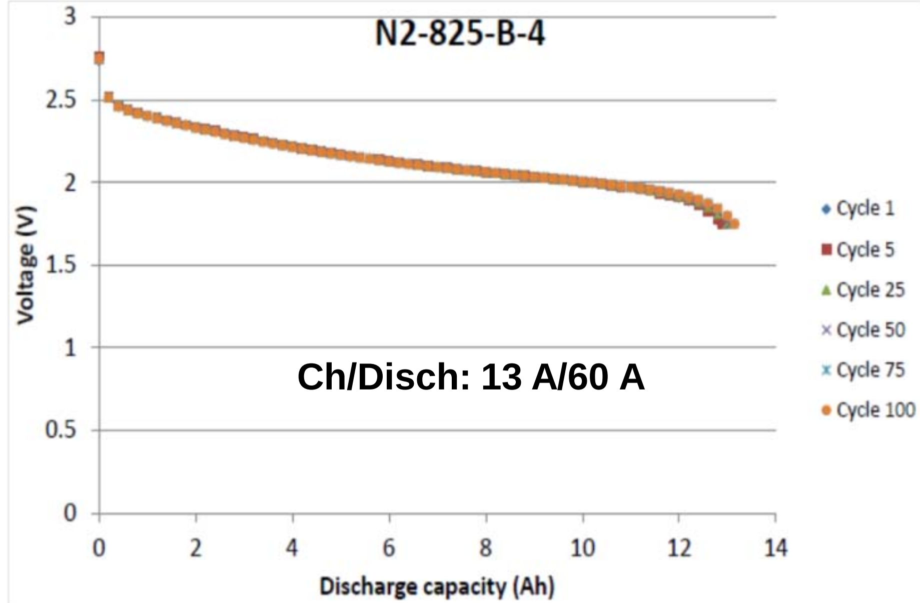
Heat-to-Vent Test for Tenergy Li-ion 6.0 Ah Prismatic Pouch Cell

Test Temp ('C)	Sample Condition	Sample #	Maximum Temp ('C)	Notes
20	Fresh	1	189.8	Fire
20	Fresh	2	192.0	Fire

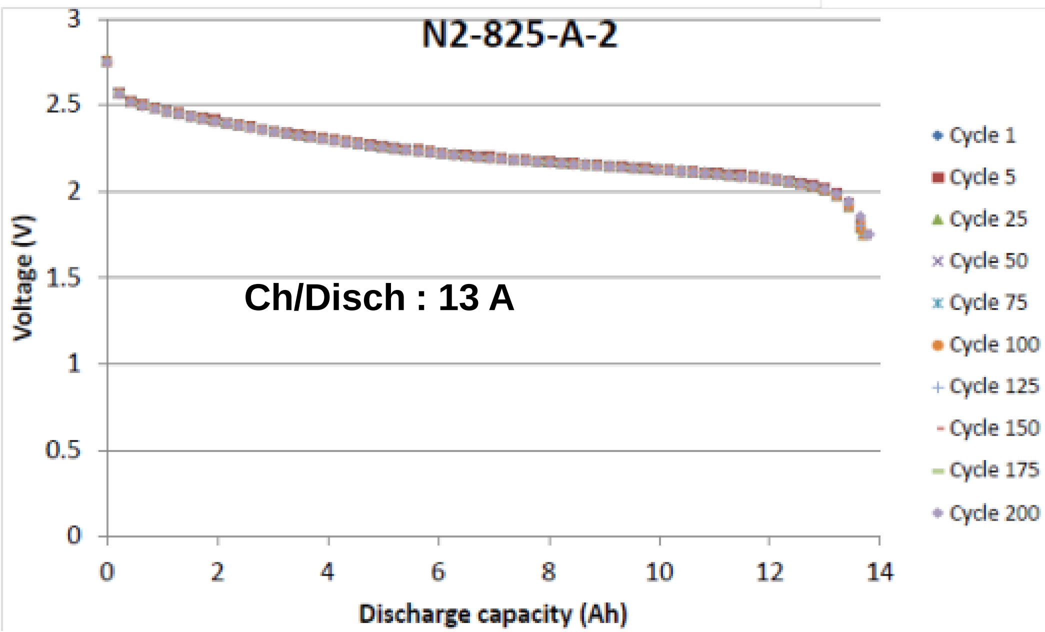


Altairnano 13 Ah Li-ion Cell Tests

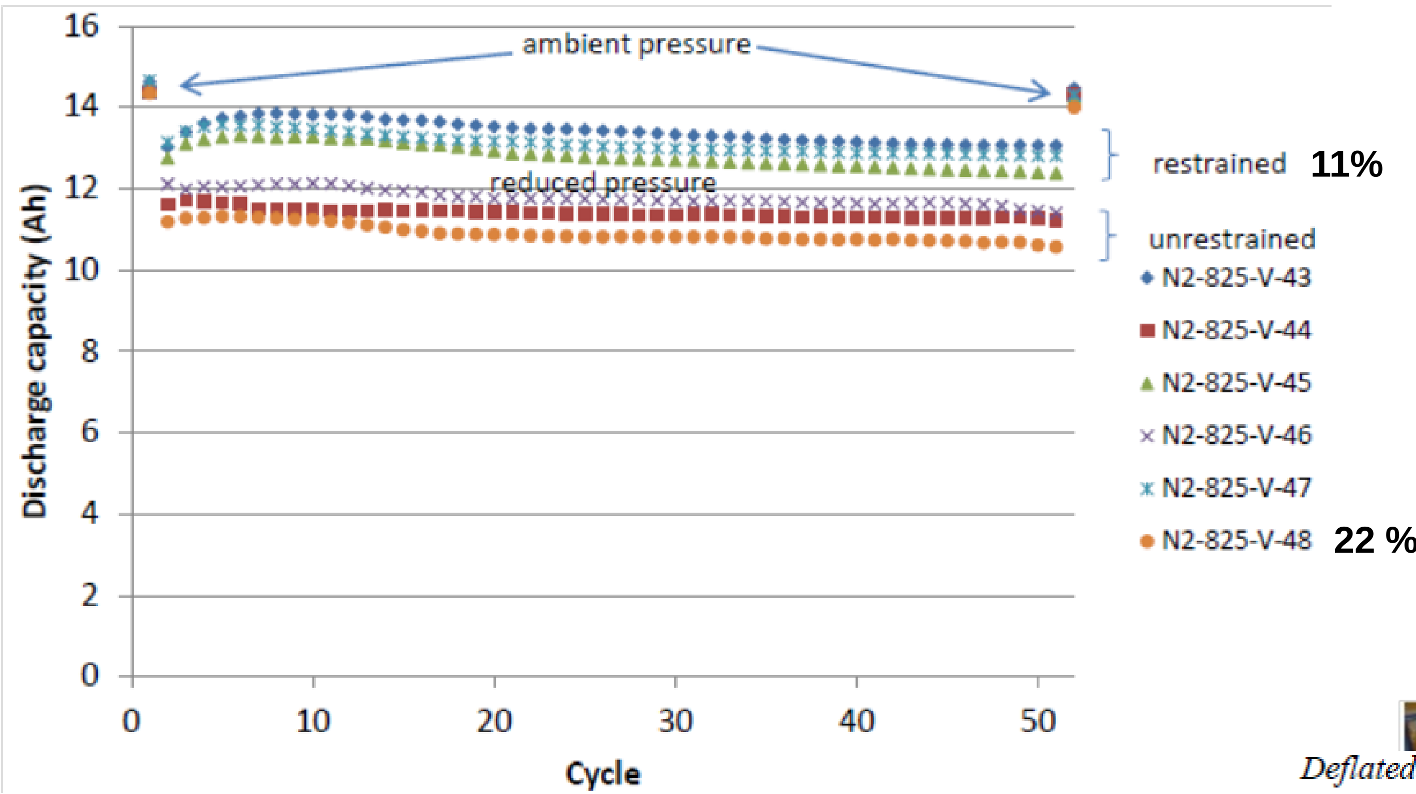




Nameplate Capacity: 13 Ah
Average Capacity at C/2: 14.3 Ah



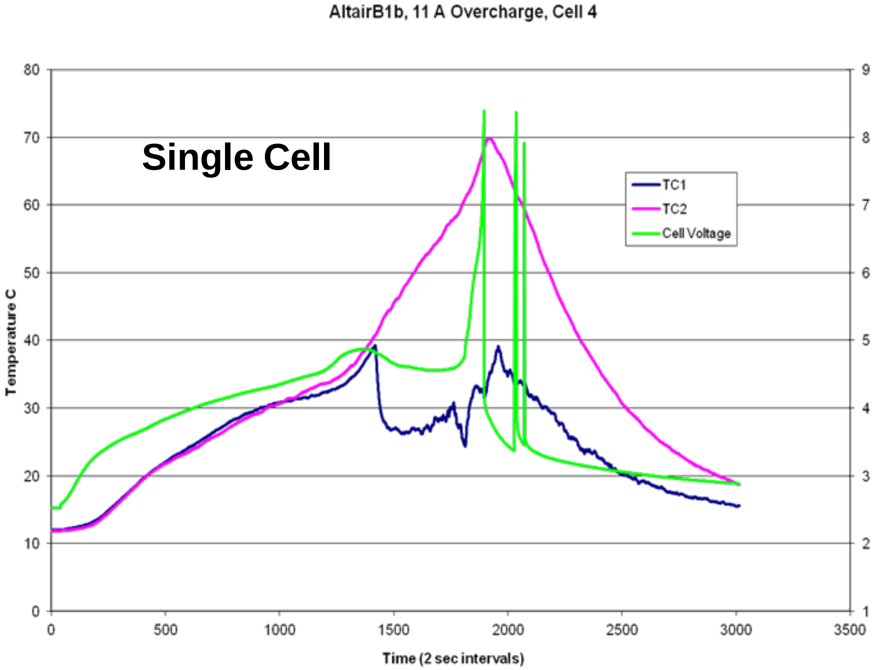
Altairnano 13 Ah Continuous Cycling in Vacuum Conditions

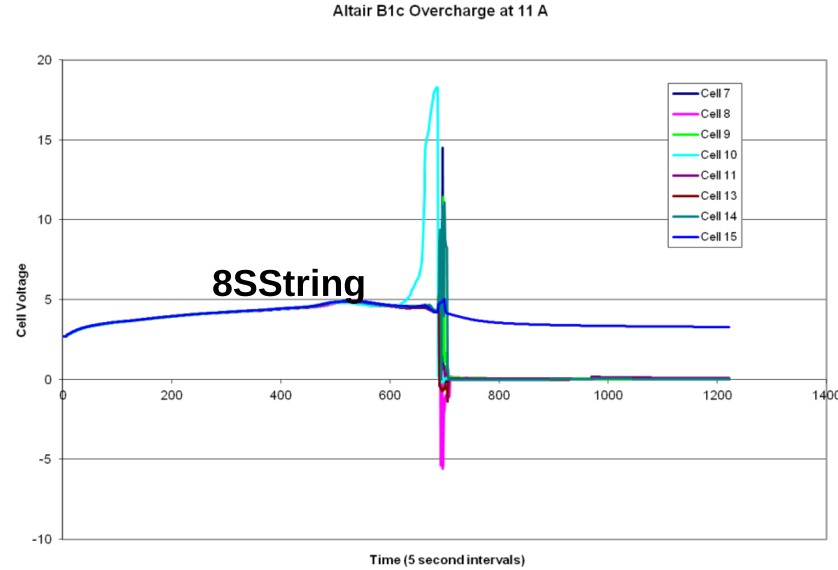


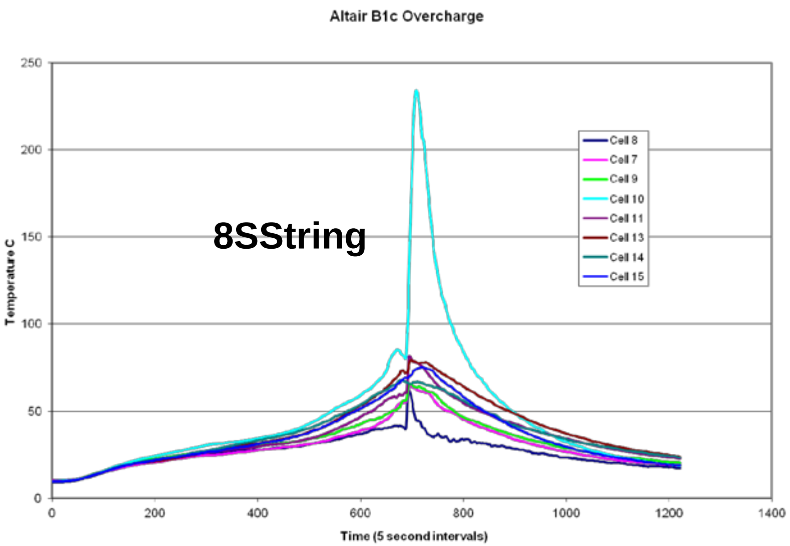
Burst Pressure:
23 to 31 psi

Higher capacities observed with restrained than with unrestrained cells

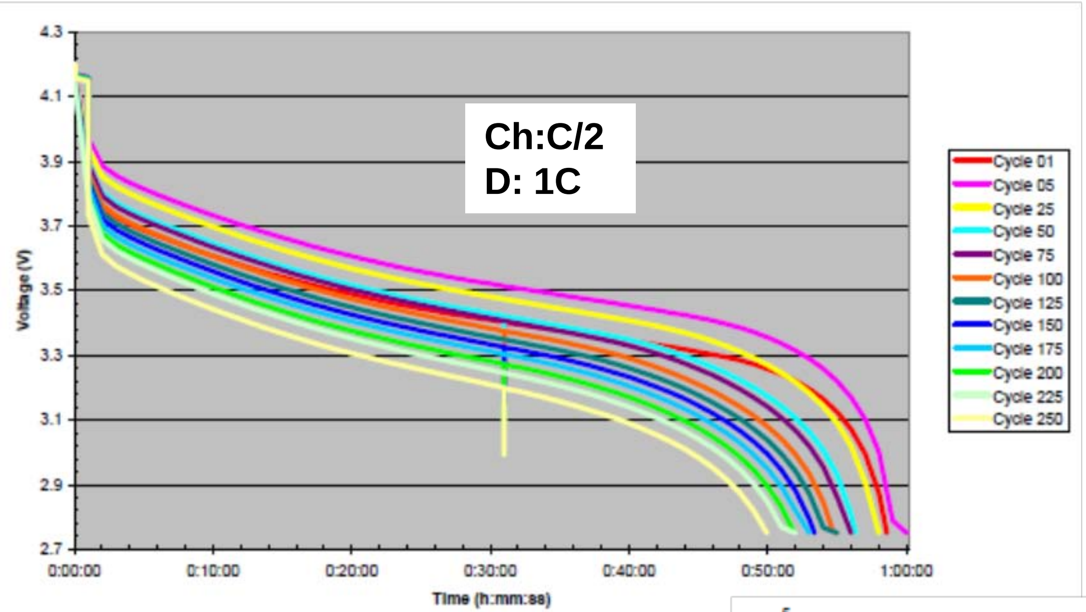
Altairnano Safety Tests





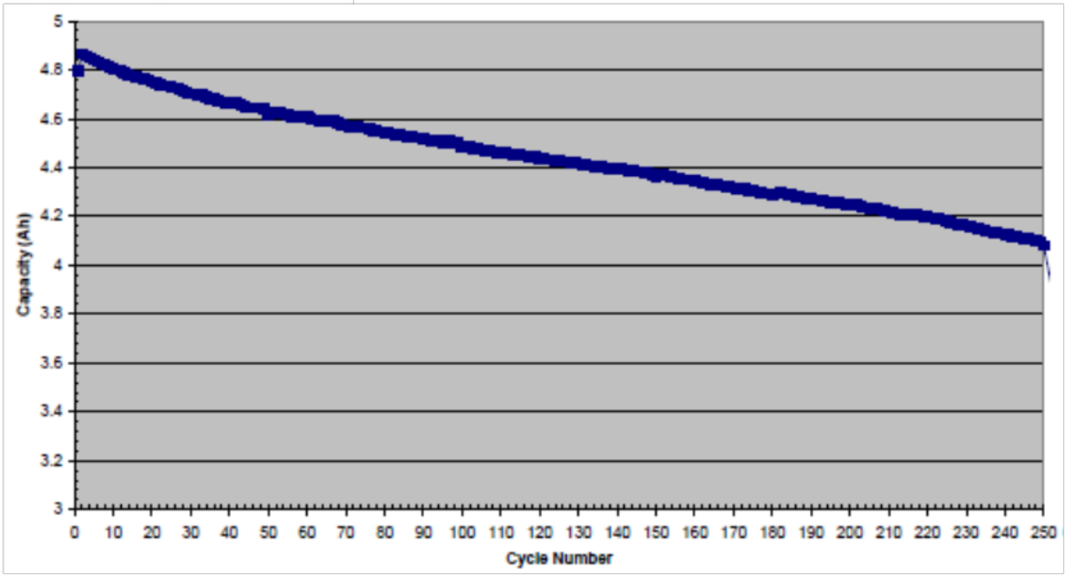


Wanma Performance Tests

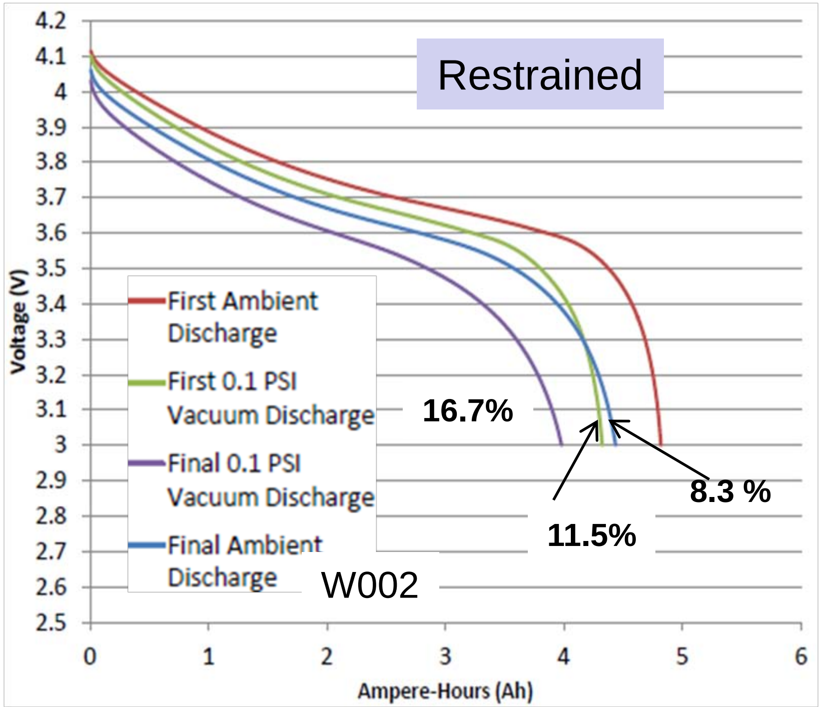


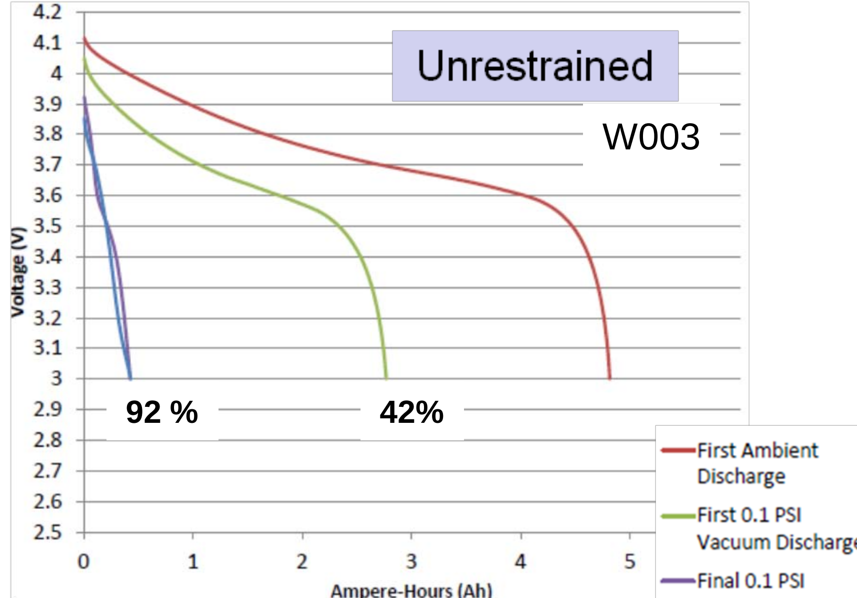
4.85 Ah Cycle 2
4.1 Ah Cycle 250

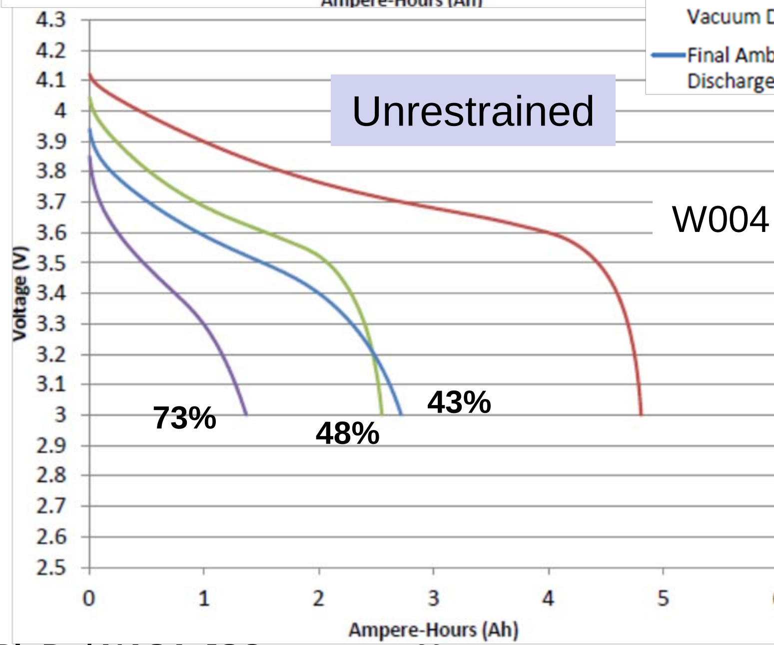
15.5% loss



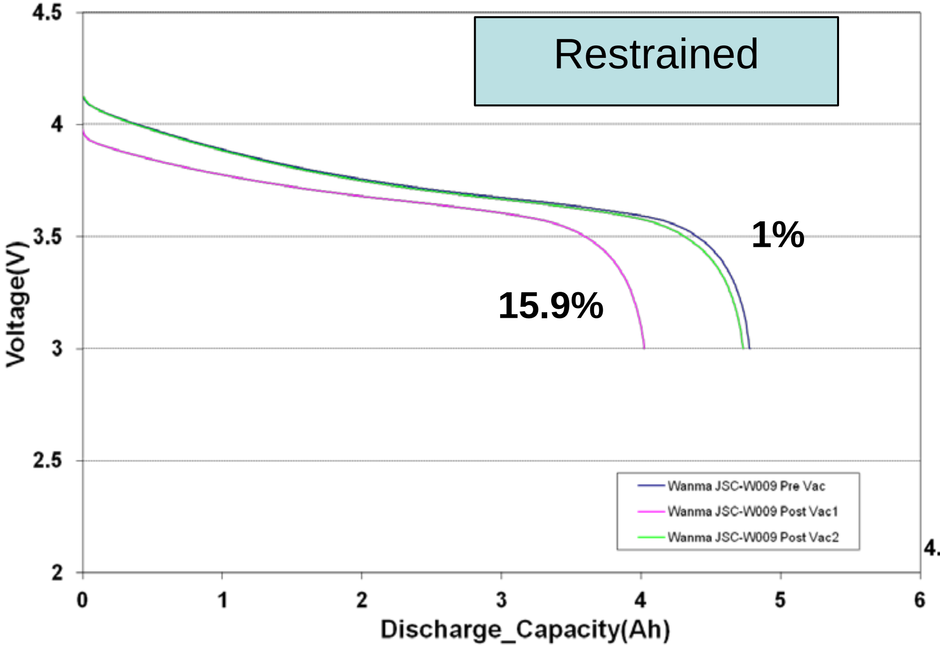
Wanma 5 Ah Li-ion Cell with Continuous Cycling Under Vacuum Environments

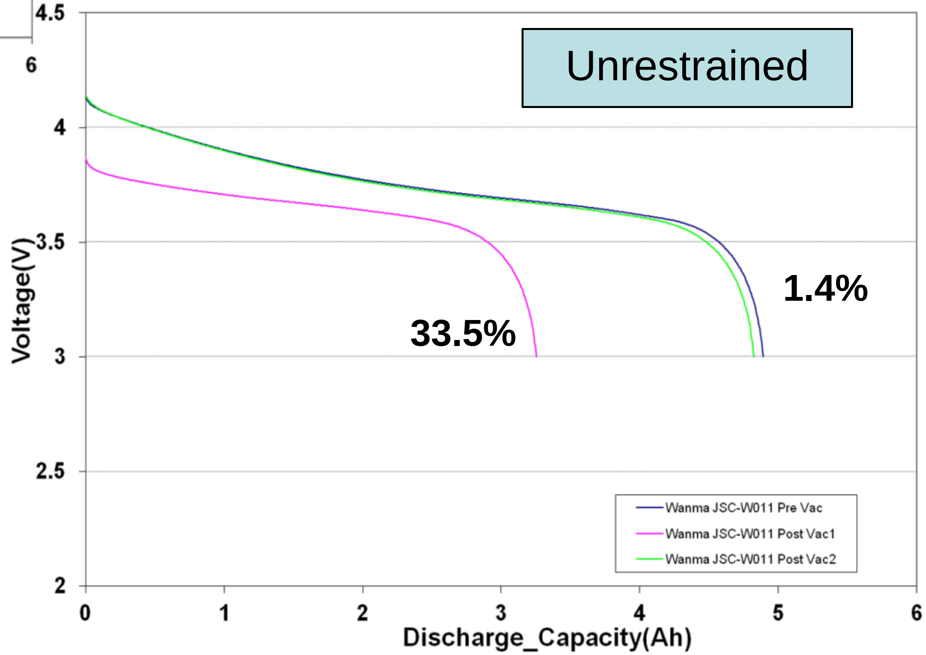




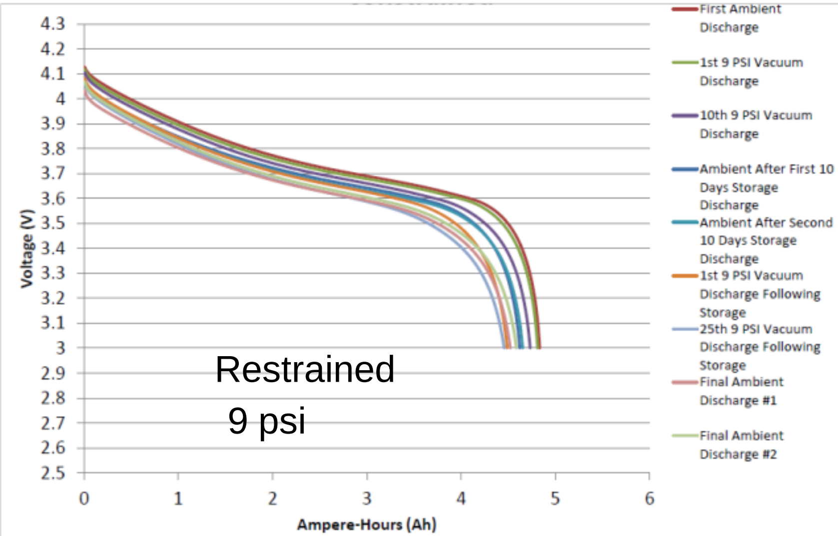


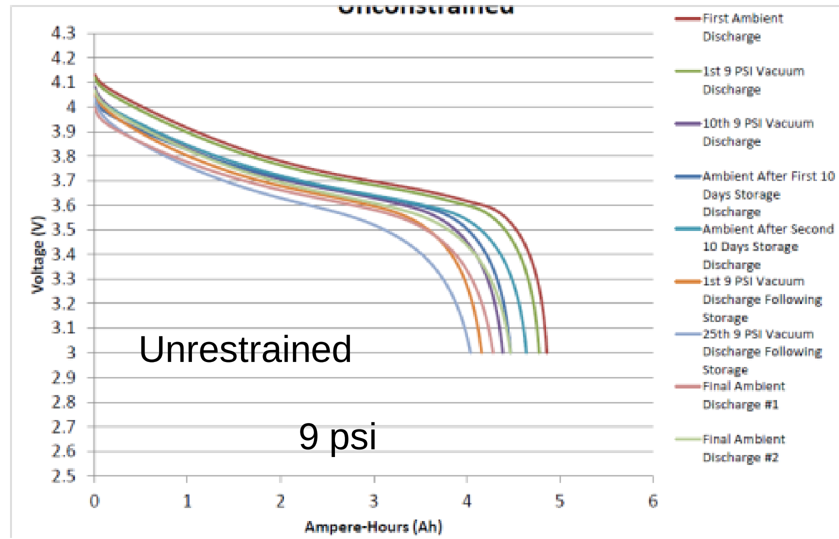
Wanma Li-ion Pouch Cell Charge under Vacuum With Storage under Ambient Pressure

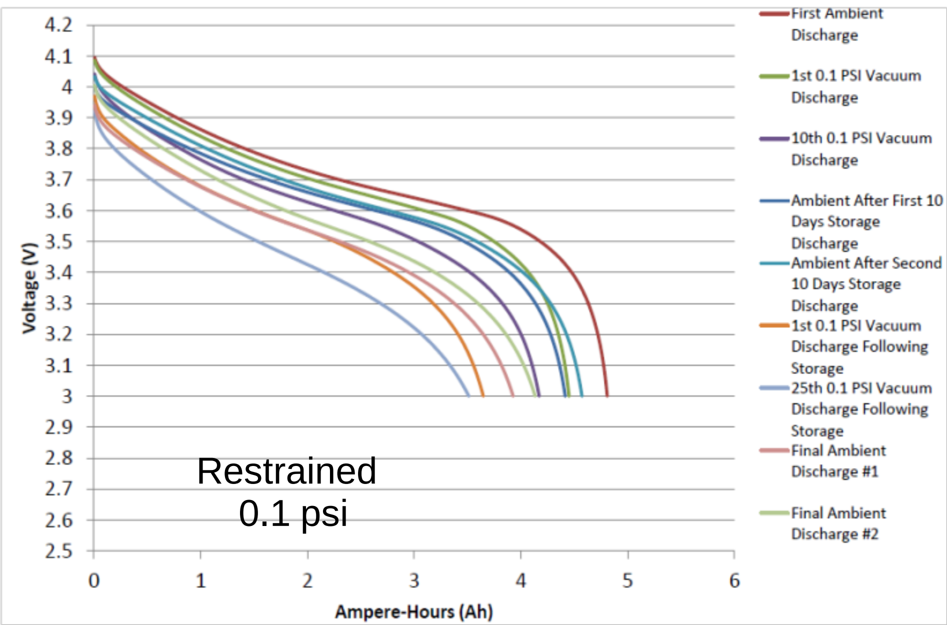


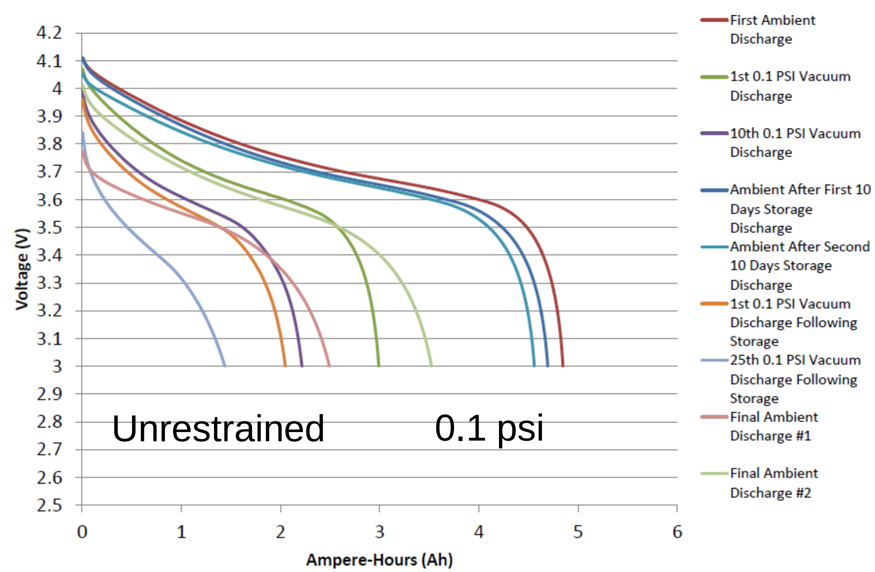


Wanma 5 Ah Li-ion Cell with Cycling Under Low Pressure or Vacuum Environments and Storage at Ambient



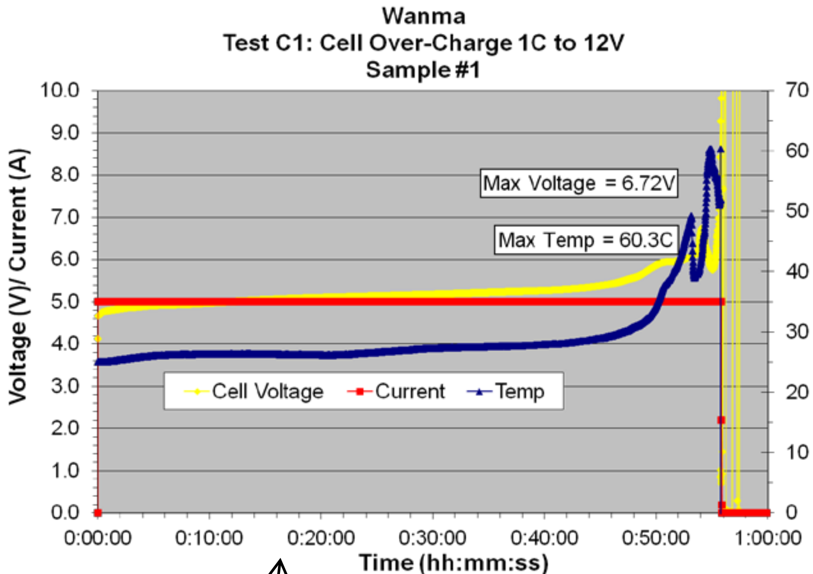


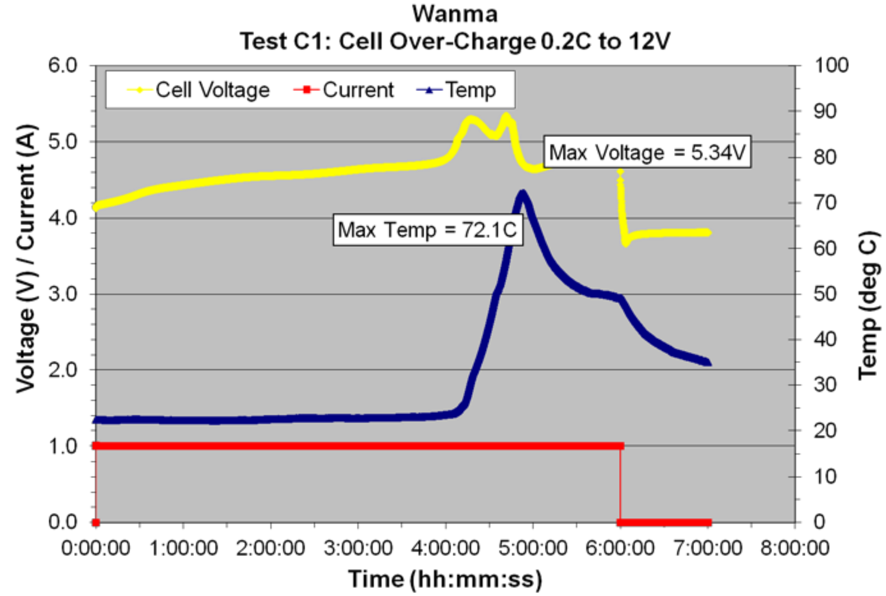




Vacuum exposure reduces performance tremendously
Compared to low pressure environments

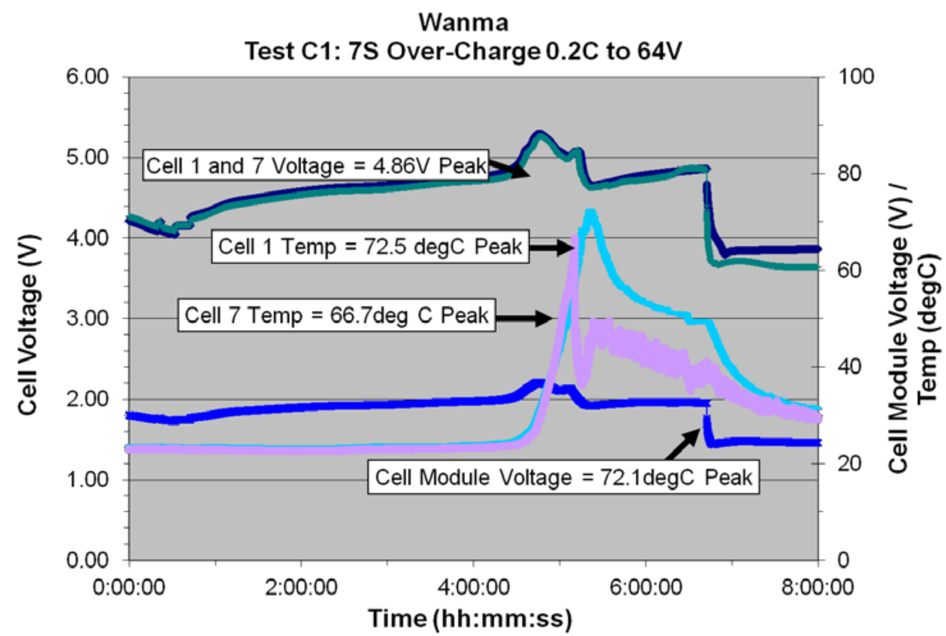
Overcharge Test on Wanma Li-ion Pouch Cell



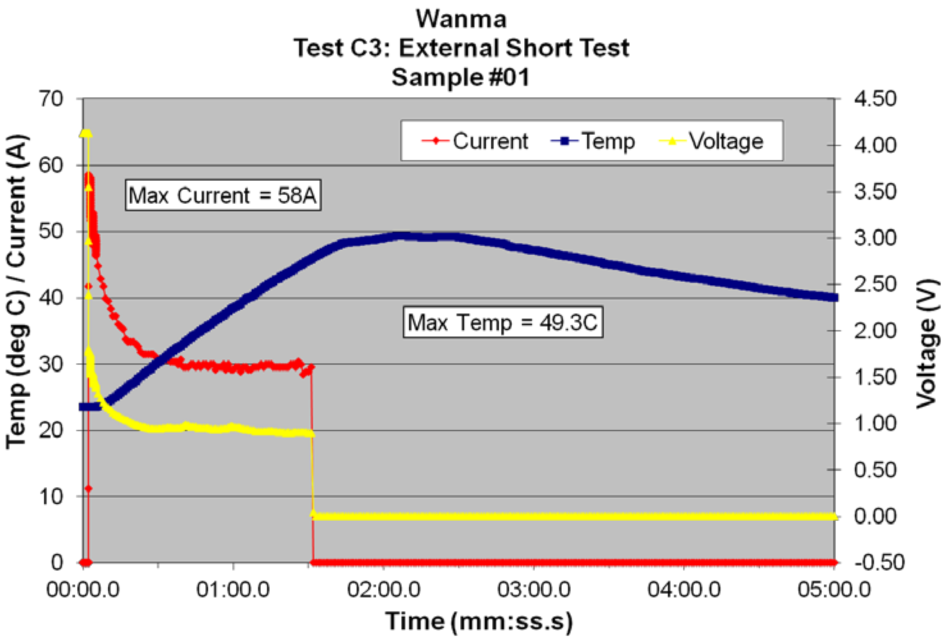


All 3 samples vented violently with fire and thermal runaway

Violent venting observed for 0.5 C overcharge at single Cell level

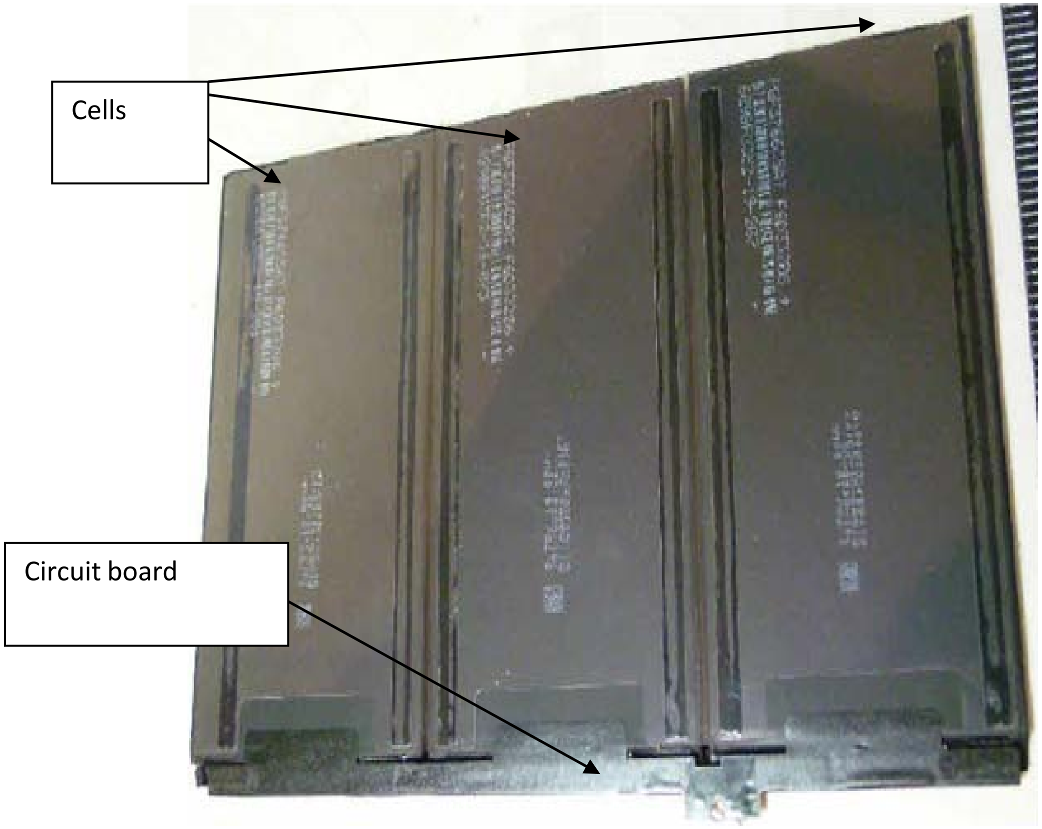


Wanma 5 Ah Li-ion Pouch Cell – External Short Test

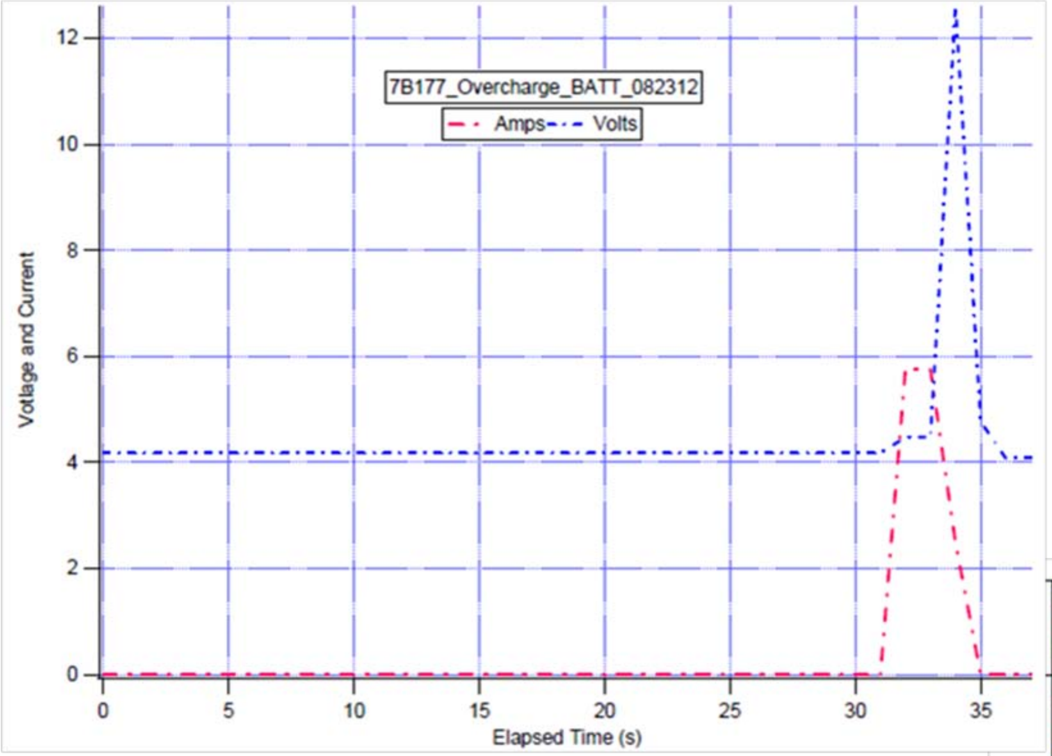


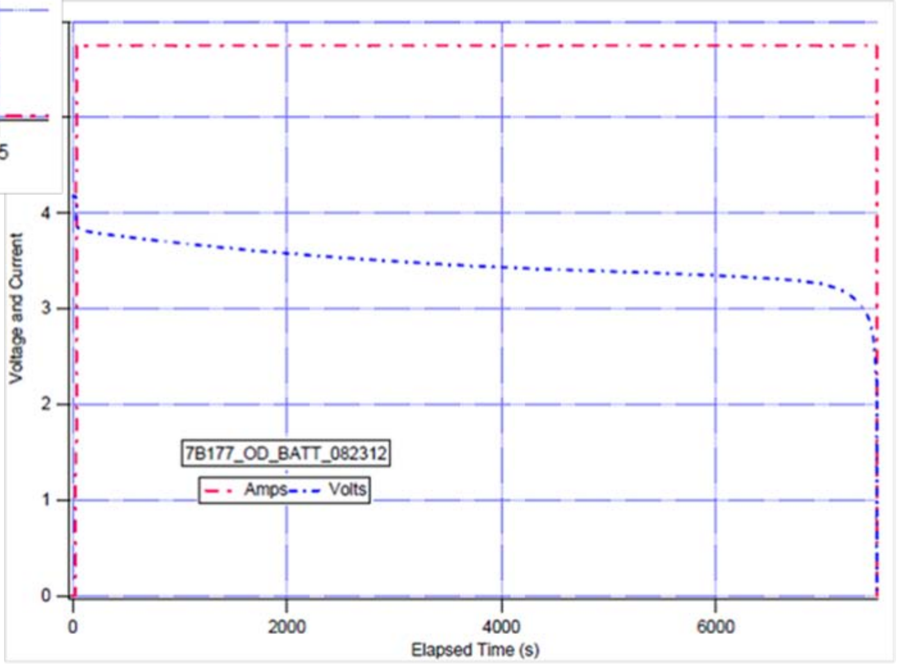
No venting or thermal Runaway was observed

iPad Li-ion Pouch Cell Battery

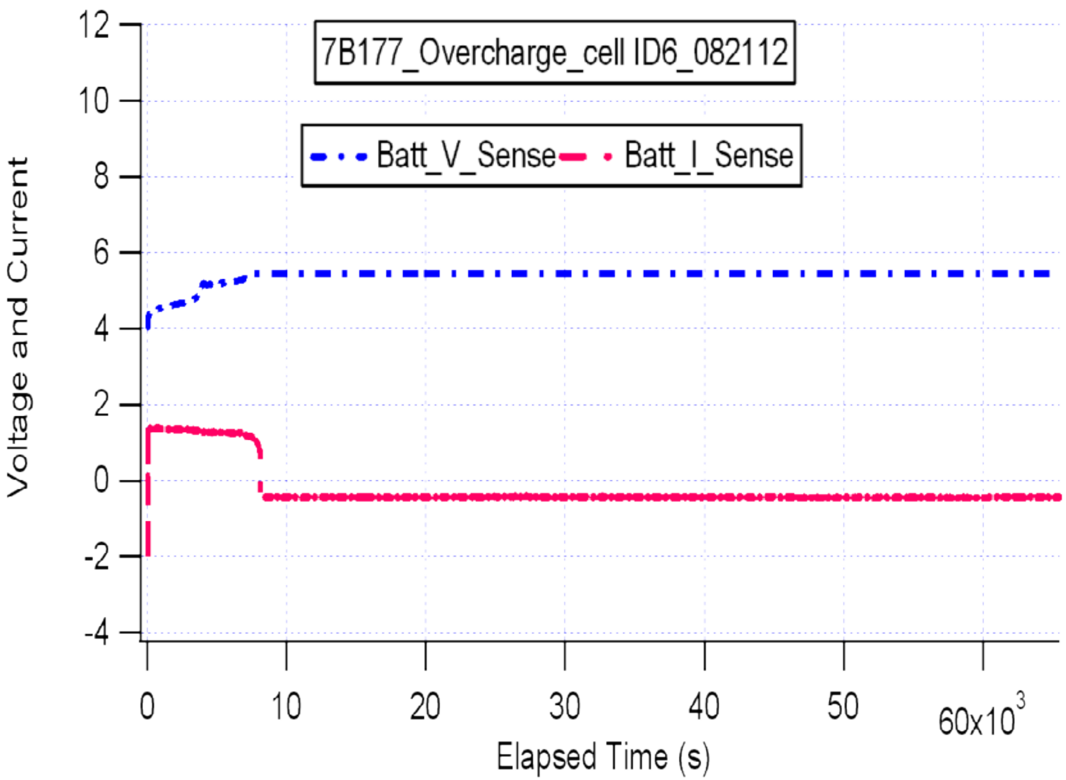


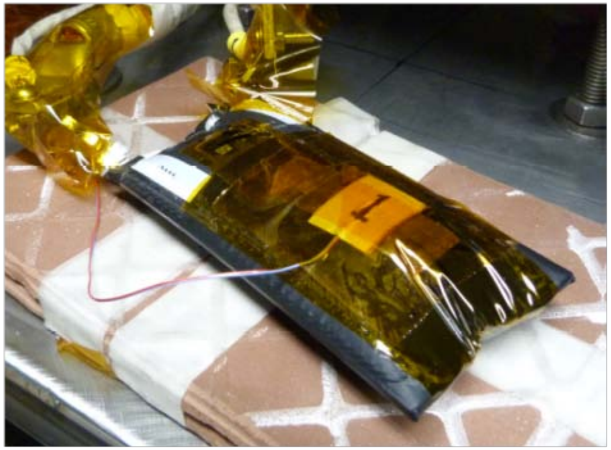
iPad Battery Level Overcharge and Overdischarge





iPad Cell Overcharge Test

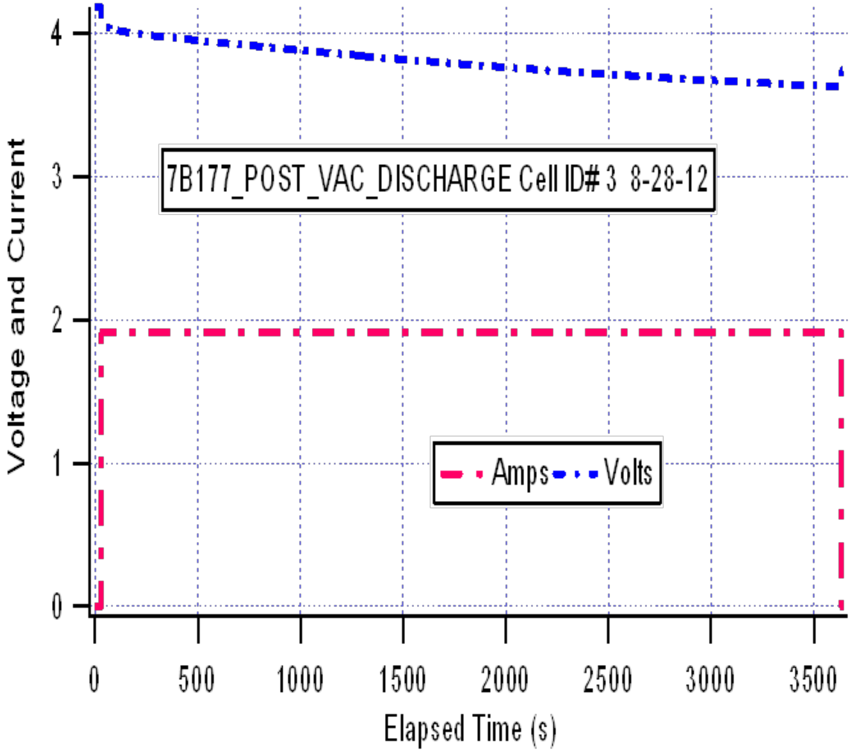


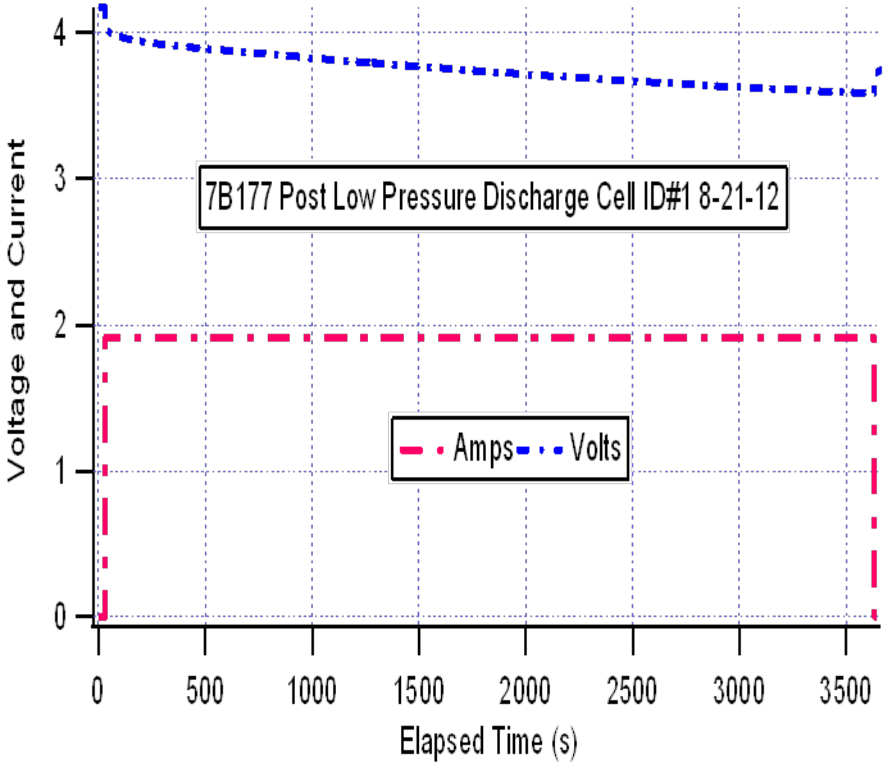


Max Temp 76 deg C

Cells did not show any swelling under overdischarge or external short conditions

iPad Li-ion Pouch Cells Under Vacuum and Reduced Pressure Conditions

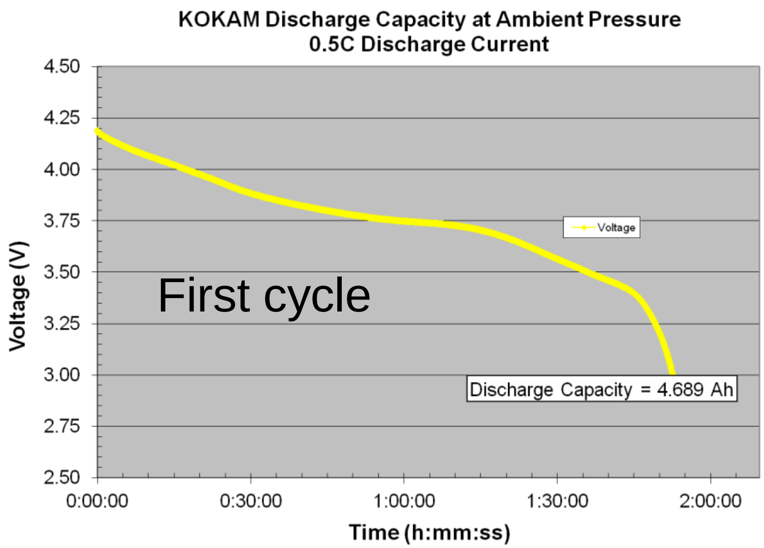


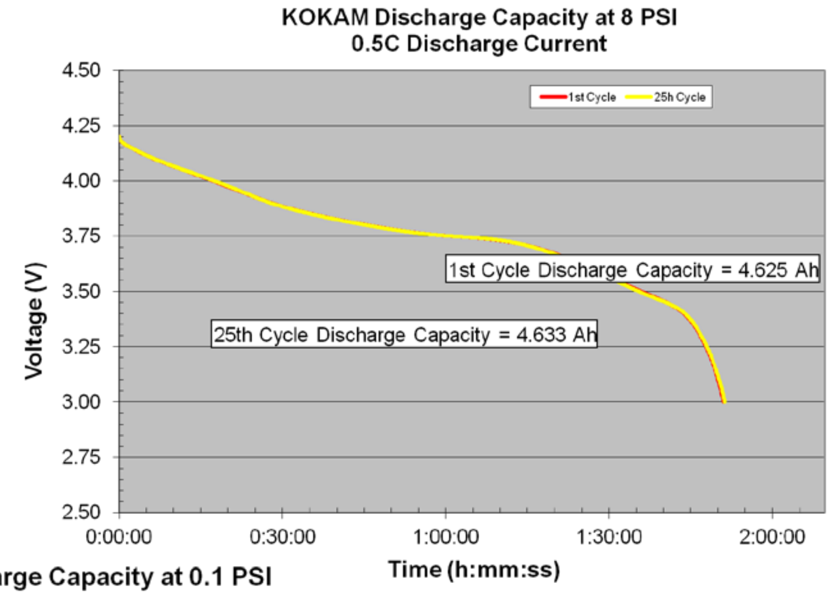


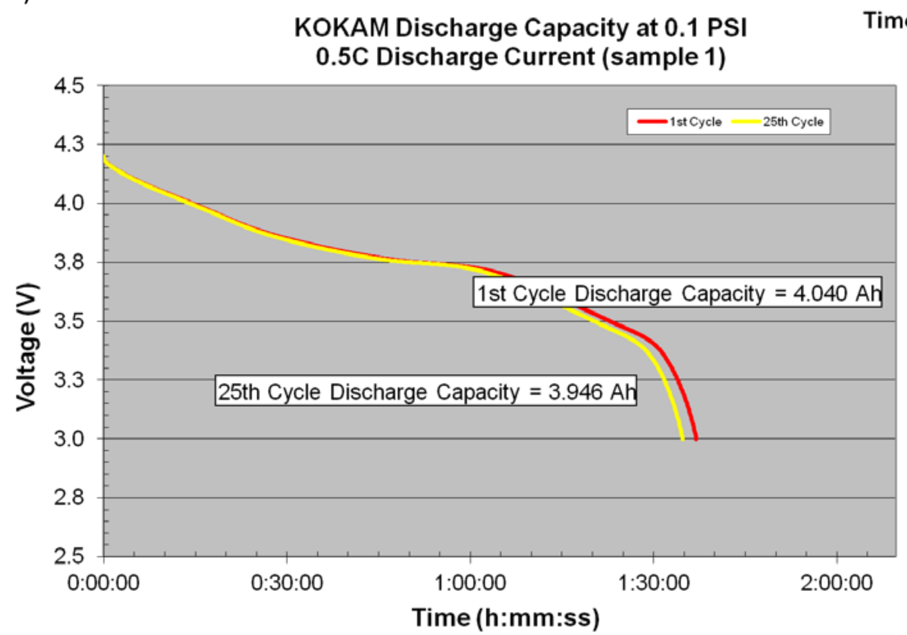
Vacuum exposure for 6 hours at 0.1 psi
1.94 Ah retained after vac exposure;
original capacity was 2.66 Ah (27% capacity loss);
No swelling was observed post-vacuum.

Low Pressure exposure for 6 hours at 9 +/0.5 psi.
1.91 Ah retained after low pressure exposure;
original capacity was 2.95 Ah (35 % capacity loss);
No swelling was observed post-vacuum.

Kokam 5 Ah pouch Li-ion cells under Vacuum and Reduced Pressure Environments

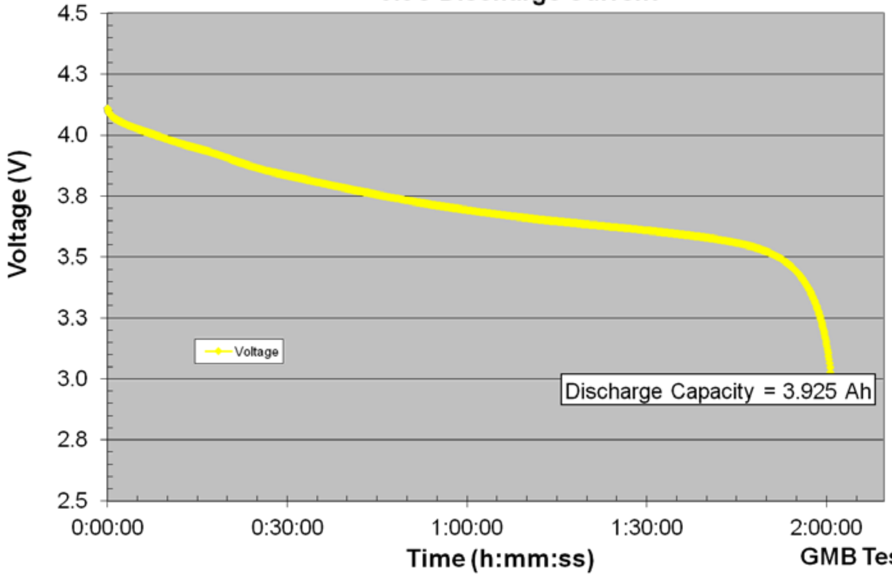




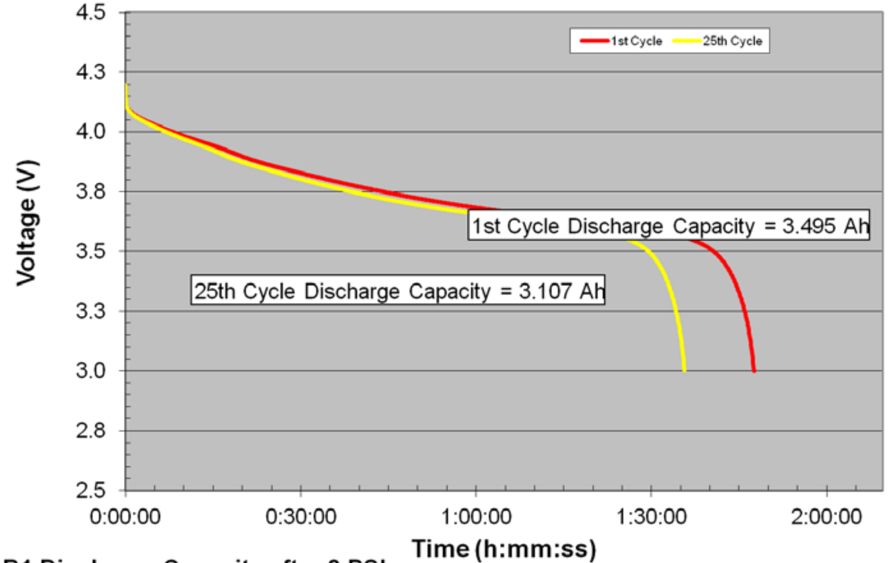


GMB 4.0 Ah Li-ion Pouch Cells under Ambient, Reduced Pressure and Vacuum Environments

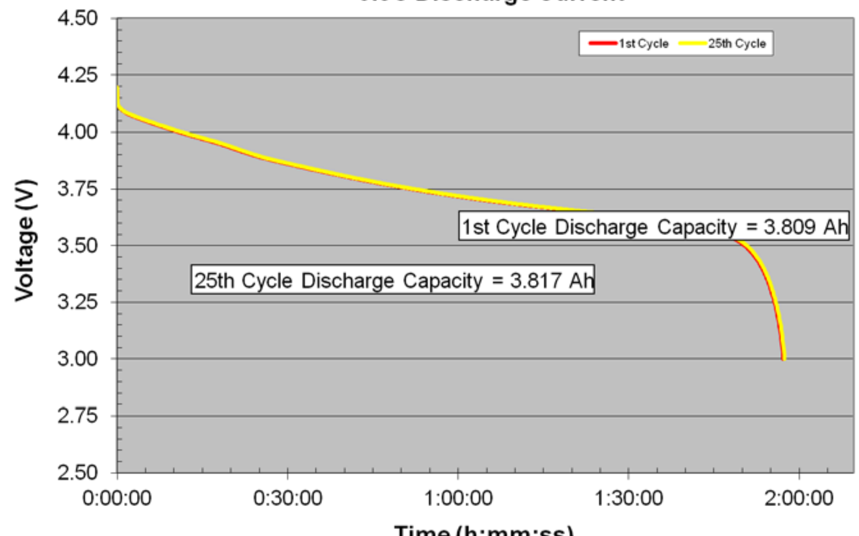
GMB Test B1 Discharge Capacity at Ambient Pressure
0.5C Discharge Current



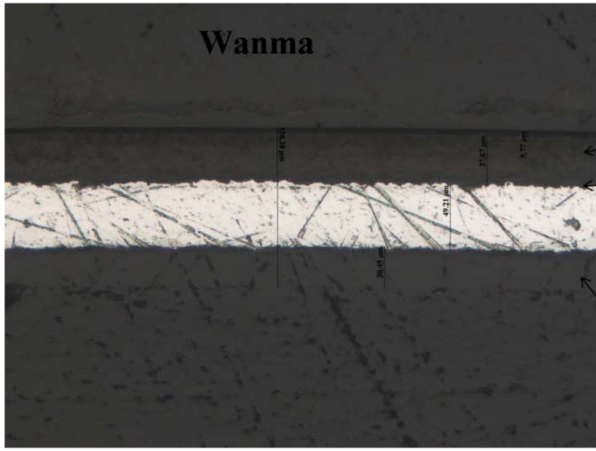
GMB Test B1 Discharge Capacity at 0.1 PSI
0.5C Discharge Current



GMB Test B1 Discharge Capacity after 8 PSI
0.5C Discharge Current

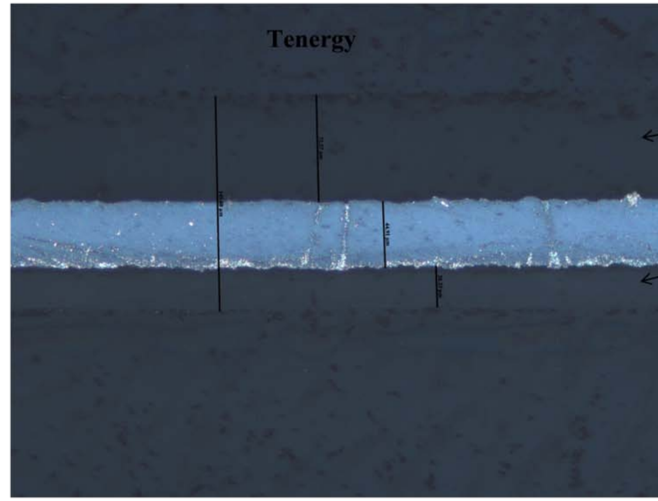


Analysis of Pouch Materials from the Different Manufacturers



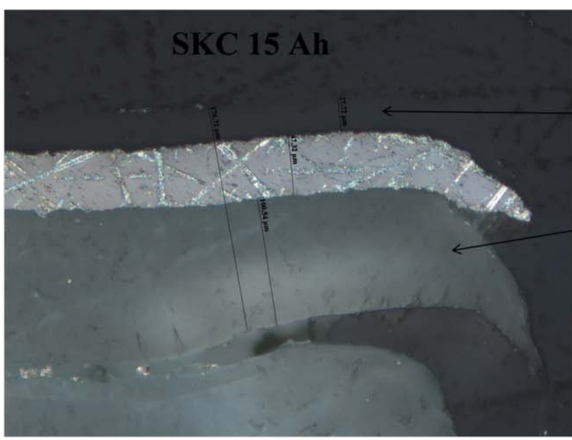
Outside:
Nylon 6 &
with a possible
Acrylic
adhesive

Inside:
Polypropylene



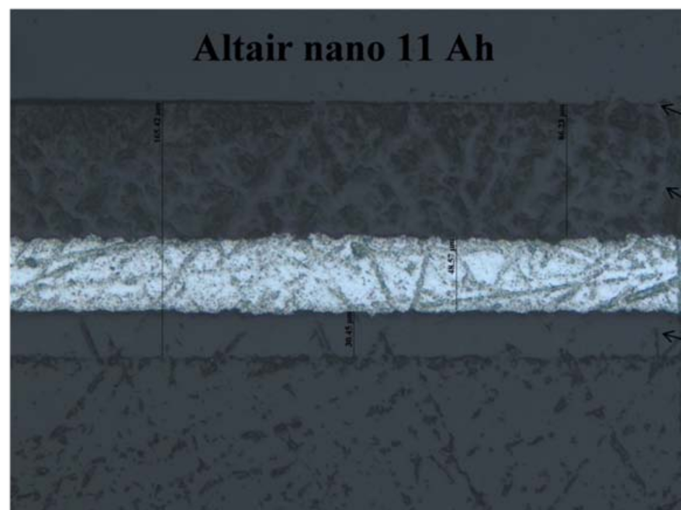
Outside:
Nylon 6

Inside:
Polypropylene



Outside:
Nylon 6

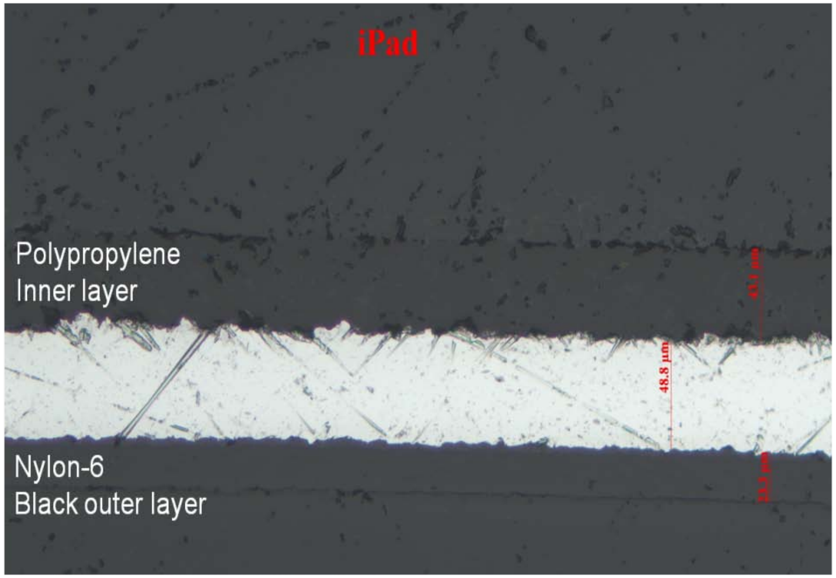
Inside:
Polypropylene

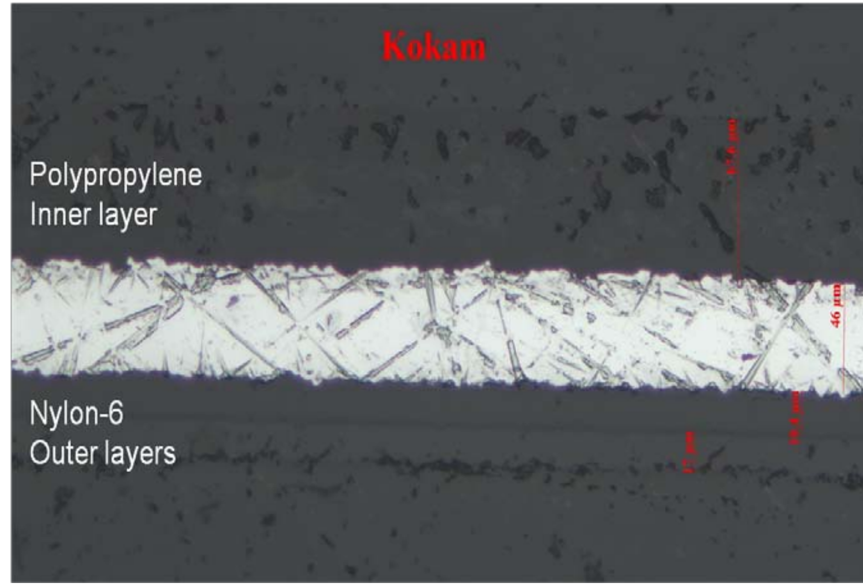


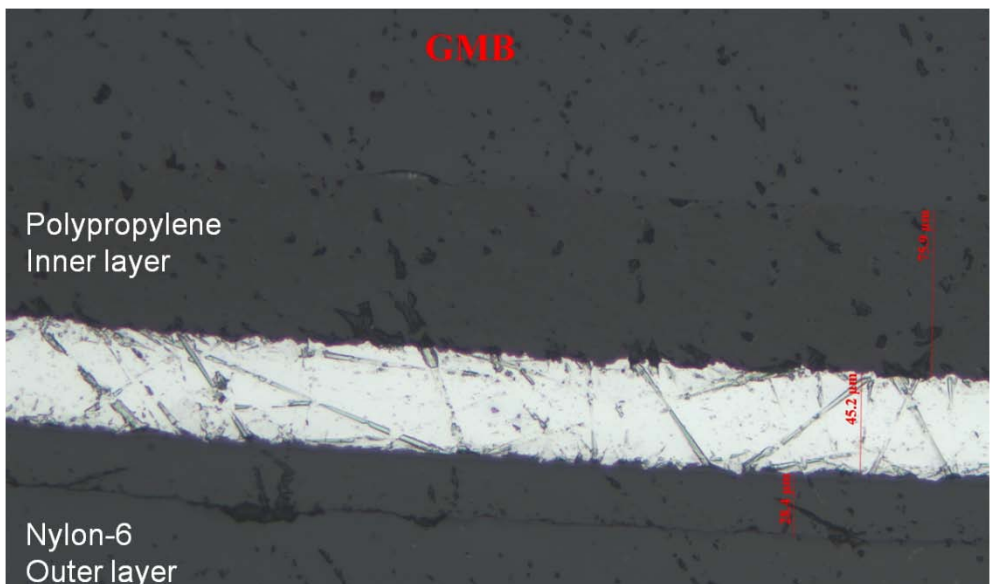
Outside:
Polyethylene
terephthalate &
Nylon 6

Inside:
Polypropylene

Analysis of Pouch Materials from the Different Manufacturers







Summary

- The li-ion pouch design cells exhibit similar behavior under off-nominal conditions as those in metal cans that do not have the internal safety devices.
  - Safety should be well characterized before batteries are designed.
- The li-ion pouch cell designs studied reacted most violently to overcharge conditions.
- Some pouch cell designs have higher tolerance to vacuum exposures than some others.
- A comparison of the pouch material itself does not show a correlation between this tolerance and the number of layers or composition of the pouch indicating that this is a property of the electrode stack design inside the pouch.
- Reduced pressure (8 to 10 psi) test environments show that the extent of capacity degradation under reduced pressure environments is less than that observed under vacuum conditions.

- Lithium-ion Pouch format cells are not necessarily true polymer cells

Acknowledgment

Test Team Members:

NASA-JSC: Bruce Duffield, Henry Bravo, Michael Andrews, Olga Vyshtykailo, Mike Salinas

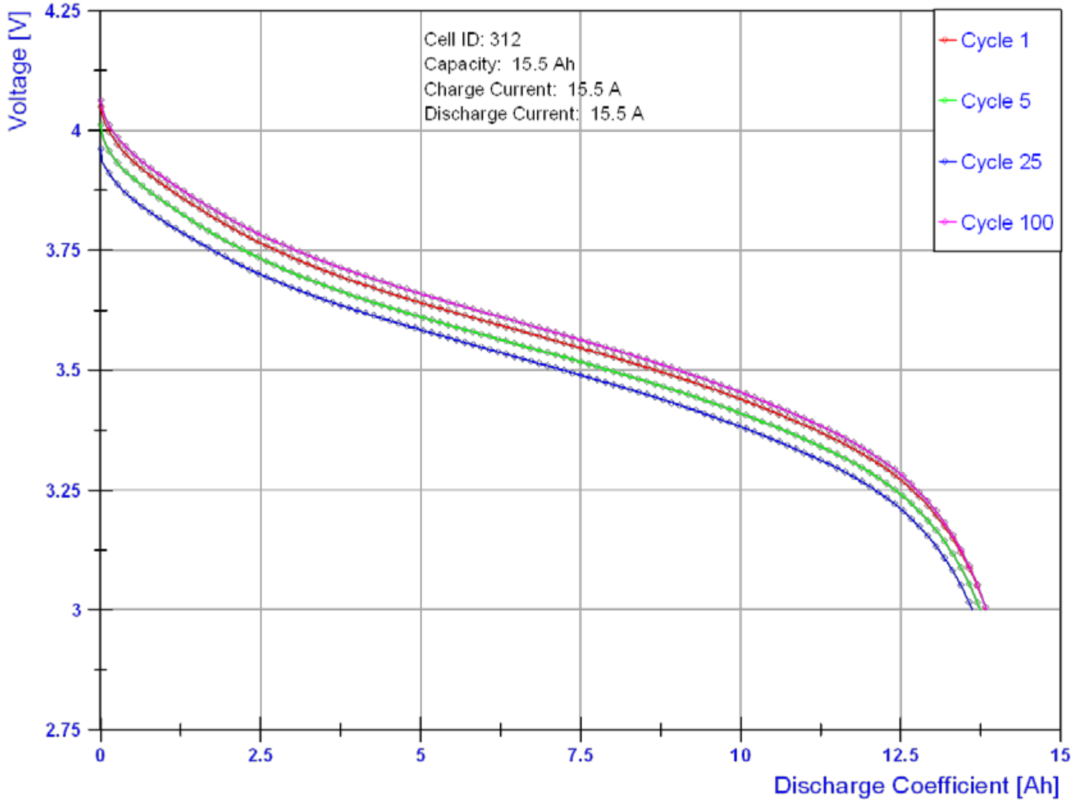
PC Test Engineering: Dr. Chung, James Park and Kwang Jung

Mobile Power Solutions : Dr. Andy Tipton and team

Space Information Labs: Jim Hammond and team

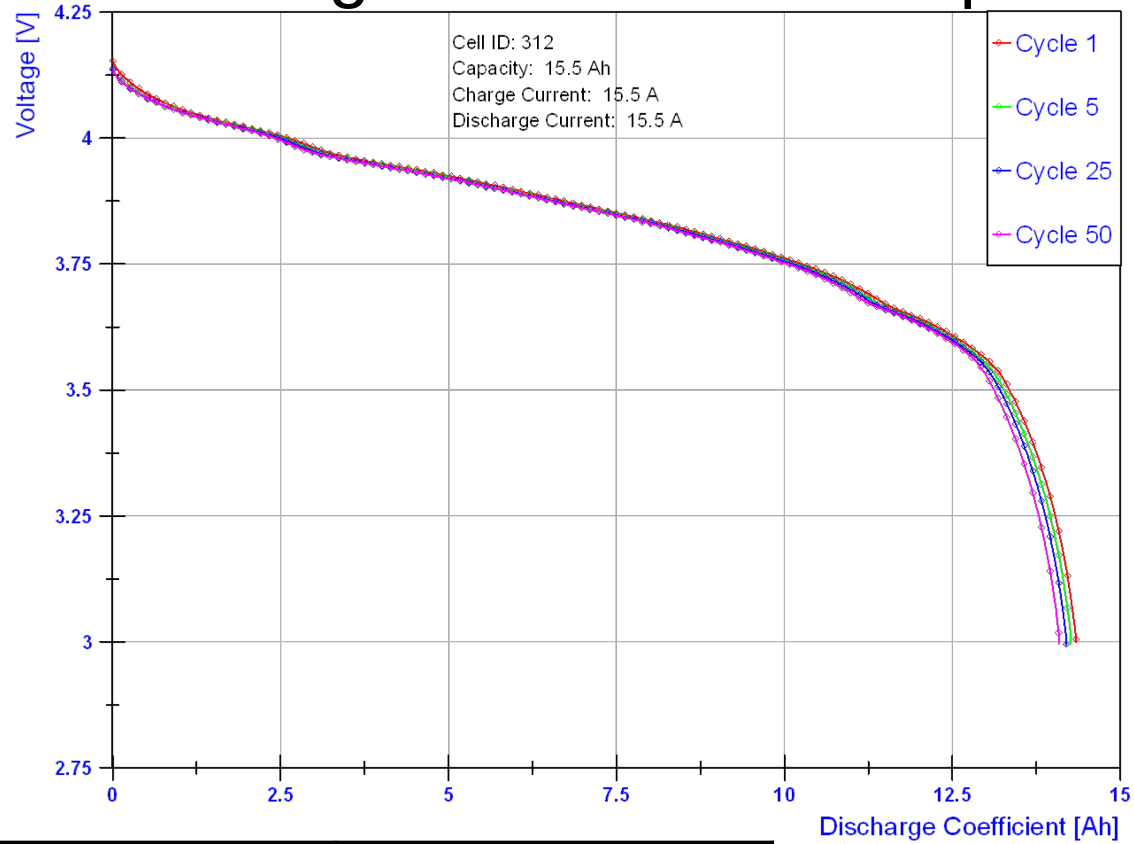
Back Up Slides

SKC 15 Ah Cell Cycling at 0 Deg C Discharge Charge at Ambient Temp

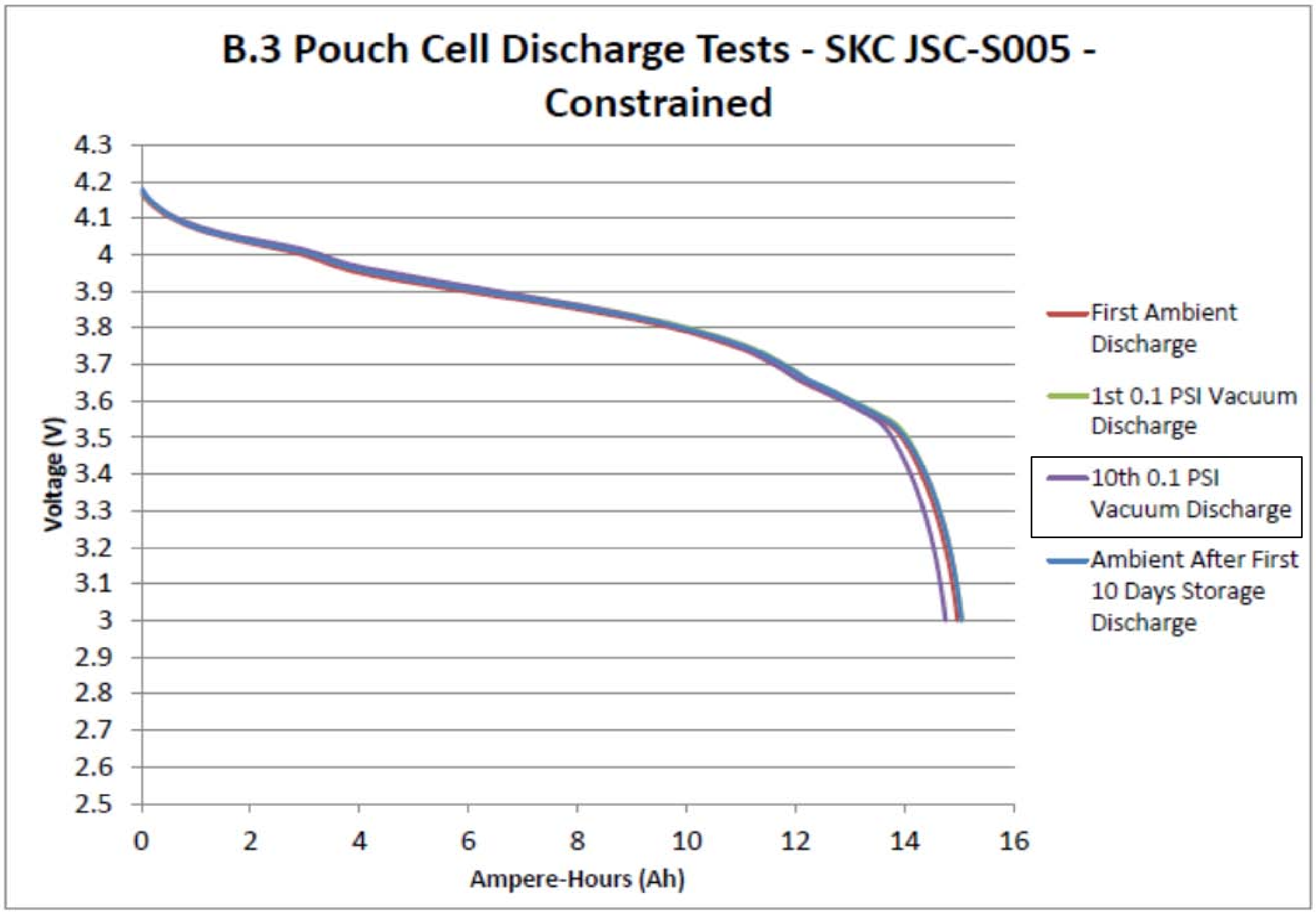


	SN 221	SN 312
Cycle	**Discharge Capacity**	**Discharge Capacity**
1	**13.89 Ah**	**13.82 Ah**
5	**13.89 Ah**	**13.74 Ah**
25	**13.89 Ah**	**13.61 Ah**
50	**13.89 Ah**	**13.83 Ah**

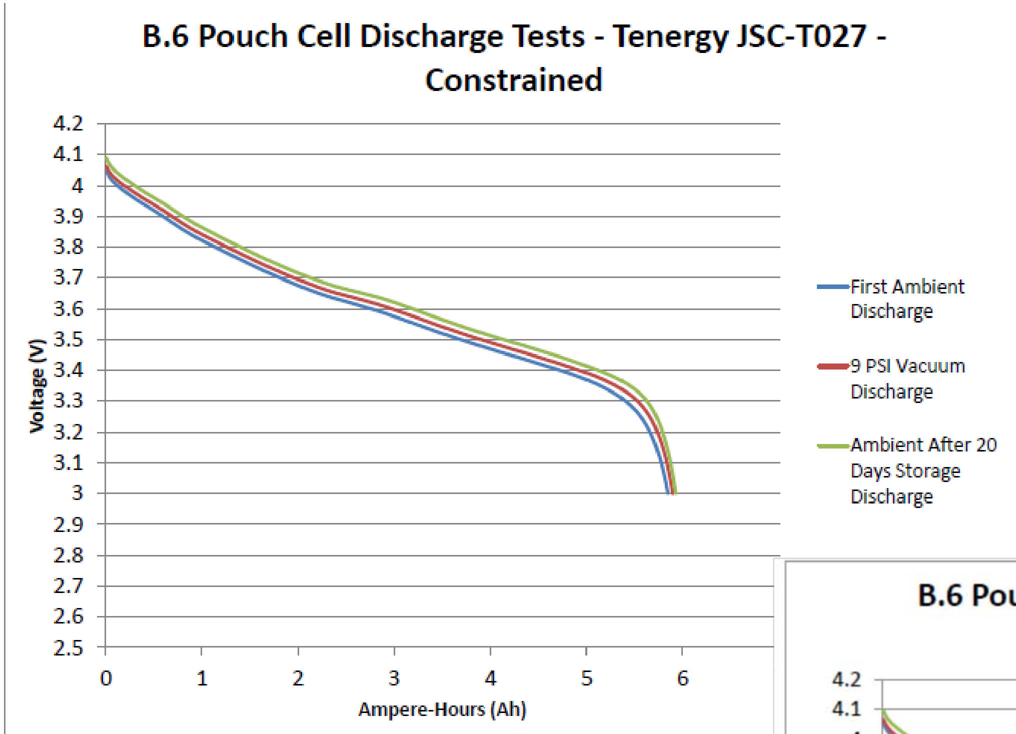
SKC 15 Ah Cell Cycling at 55 Deg C Discharge Charge at Ambient Temp



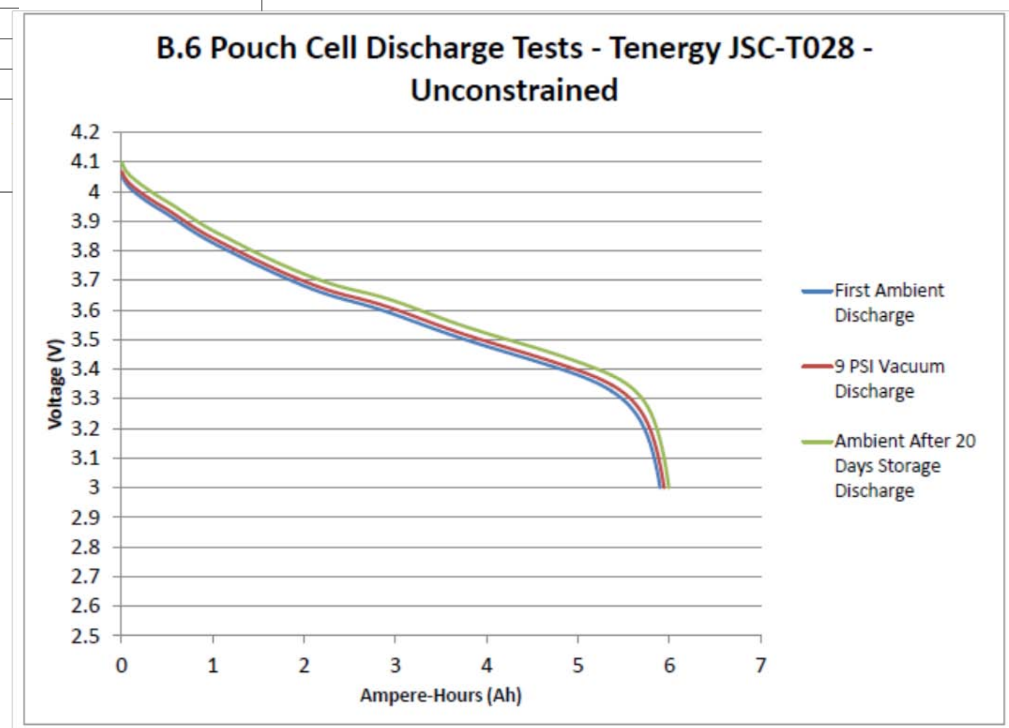
	SN 221	SN 312
Cycle	**Discharge Capacity**	**Discharge Capacity**
1	**14.34 Ah**	**14.34 Ah**
5	**14.23 Ah**	**14.26 Ah**
25	**14.17 Ah**	**14.19 Ah**
50	**14.06 Ah**	**14.08 Ah**

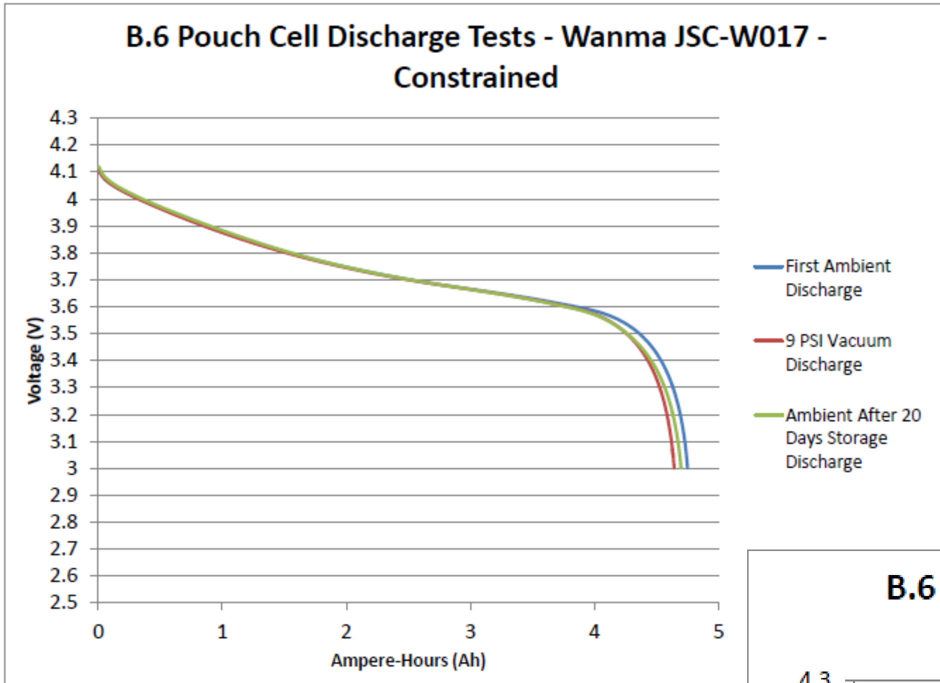


B.3 Pouch Cell Discharge Tests - SKC JSC-S005 - Constrained
Voltage (V)
4.3
4.2
4.1
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
0
2
4
6
8
10
12
14
16
Ampere-Hours (Ah)
First Ambient Discharge
1st 0.1 PSI Vacuum Discharge
10th 0.1 PSI Vacuum Discharge
Ambient After First 10 Days Storage Discharge



Reduced Pressure: 9 psi





Reduced Pressure: 9 psi