Performance and Safety of COTS 18650 Li-ion Cells from Various Manufacturers

J. Jeevarajan, Ph.D., NASA-JSC
B. Duffield, Jacobs Engg
Dr. J.-S. Chung, K. Jung, J. Park, PCTest Engg
B. Strangways, SRI
M. Claw, Element

The 2013 NASA Battery Workshop
Huntsville, AL
November, 2013
Outline

• Cell Characteristics
• Performance of Panasonic Cells
• Safety of Panasonic Cells
• Performance of Moli STOBA cells
• Safety of Moli STOBA cells
• Performance of LG cells at Different Temperatures
18650 Lithium-ion cells

Panasonic 3.1 Ah

LG 2.8 Ah

Moli STOBA 2.0 Ah
Panasonic 3.1 Ah Li-ion 18650 Cell

Performance and Safety Test Data
Panasonic 3.1 Ah Li-ion 18650 Cell

Ch: C/2
Disch: 1C
Cap. Change: -10.3%
Re Change: +0.88%

Sample 3
Cycle 1: 2.9 Ah
Cycle 300: 2.6 Ah
Cycle 1: 3.0 Ah
Cycle 250: 2.62 Ah

Cap. Change: -12.7%
Re Change: -1.5%

Cap. Change: -13.3%
Re Change: -5.8%

Sample 1
Ch: C/2
Disch: C/2
Cap. Change: -12.7%
Re Change: -1.5%

Cycle 1: 2.93 Ah
Cycle 300: 2.54 Ah
Cycle 1: 3.04 Ah
Cycle 150: 2.76 Ah

Cap. Change: -9.2%
Re Change: -14.5%
Panasonic 3.1 Ah Li-ion 18650 Cell

Cap. Change: -11.9%
Re Change: +0.54%

Sample 2
Ch: 1C
Disch: 1C
Cycle 1: 2.88 Ah
Cycle 300: 2.45 Ah

Cap. Change: -20.5%
Re Change: -1.8%

Sample 2
Ch: 1C
Disch: C/2
Cycle 1: 2.93 Ah
Cycle 300: 2.33 Ah
Panasonic 3.1 Ah Li-ion 18650 Cell

Performance Capabilities at 0°C

Cap Change: -5%
-15% of RT

Charge and Disch: C/5

Performance Capabilities at -20°C

Cap Change: -80%
-53% of RT

Charge and Disch: C/5

Performance Capabilities at -10°C

Cap Change: -54%
-21% of RT

Charge and Disch: C/5

Performance Capabilities at 30°C

Cap Change: -3.9%
3.5% of RT

Charge and Disch: C/5
Panasonic 3.1 Ah Li-ion 18650 Cell

Performance Capabilities at 40°C

Cap Change: -3.2%
4.5% of RT
Panasonic 3.1 Ah Li-ion 18650 Cell

Over-Charge at 1.0C Rate to 12 V
Fresh Sample #1

Over-Charge at 0.5C to 12 V
Fresh Sample #1

Over-Charge at 1.0C to 12 V
Cycled Sample #1

Max Temperature = 49.19 °C
Max Voltage = 5.37 V

Max Temperature = 44.95 °C
Max Voltage = 5.21 V

Max Temperature = 52.79 °C
Max Voltage = 5.05 V
Panasonic 3.1 Ah 18650 Li-ion Cell

Over-Charge 8 Series at 1 C current

Max Voltage = 41.13 V

Cell #1, #3, #5, #7 CID activated creating open circuit

Test C1: Over-Charge Test Cell 5 of 8 Cells in Series

Max Temp = 57.26 °C

CID activated

Max Voltage = 5.10 V
Panasonic 3.1 Ah Li-ion 18650 Cell

Over-Discharge to 0 V

Peak Temperature = 58.22 °C

Normal Cycle Charge

Normal Cycle Charge Failed

Discharge to 1 V

Discharge to 0 V

Current (A) / Voltage (V)

Temperature (°C)

Time (h:mm:ss)
Panasonic 3.1 Ah Li-ion 18650 Cell

External Short (10 mohms)

2 hours

Max Current = 76.48 A  
Max Temperature = 62.02 °C

4 hours

Max Current = 90.06 A  
Max Temperature = 72.82 °C

Current (A)

0.0  10.0  20.0  30.0  40.0  50.0  60.0  70.0  80.0  90.0  100.0

Time (s.s.)

5.2  5.4  5.6  5.8  6.0  6.2  6.4  6.6  6.8  7.0

Voltage (V)

0.0  0.5  1.0  1.5  2.0  2.5  3.0  3.5  4.0  4.5

Temperature (°C) / Current (A)

0  10  20  30  40  50  60  70  80  90  100

Time (h:mm:ss)
Panasonic 3.1 Ah Li-ion 18650 Cell Series String External Short (10 mohms)

<table>
<thead>
<tr>
<th>Cell #</th>
<th>Final Voltage (V)</th>
<th>External Resistance (mOhm)</th>
<th>Maximum Current (A)</th>
<th>Maximum Temp (°C)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.05</td>
<td>-</td>
<td>-</td>
<td>23.57</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>2</td>
<td>4.04</td>
<td>-</td>
<td>-</td>
<td>24.83</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>3</td>
<td>4.05</td>
<td>-</td>
<td>-</td>
<td>26.43</td>
<td>Smoked, no fire, burn mark on cathode tab</td>
</tr>
<tr>
<td>4</td>
<td>4.04</td>
<td>-</td>
<td>-</td>
<td>24.84</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>5</td>
<td>4.05</td>
<td>-</td>
<td>-</td>
<td>26.73</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>6</td>
<td>4.05</td>
<td>-</td>
<td>-</td>
<td>37.68</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>7</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>56.27</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>8</td>
<td>4.05</td>
<td>-</td>
<td>-</td>
<td>38.36</td>
<td>No vent or fire</td>
</tr>
<tr>
<td>Overall</td>
<td>-</td>
<td>9.7</td>
<td>92.13</td>
<td>-</td>
<td>No vent or fire</td>
</tr>
</tbody>
</table>
Panasonic 3.1 Ah Li-ion 18650 Cell

Simulated Internal Short with .125" Rod

Max Temp Prior to Fire = 44.15 °C

Voltage (V)

Time (h:mm:ss)

Voltage - Temperature

- Voltage
- Temperature
Panasonic 3.1 Ah Li-ion 18650 Cell
Moli STOBA 2.0 Ah Li-ion 18650 Cell

Performance and Safety Test Data
Moli STOBA 2.0 Ah Li-ion Cell

Cap. Change: - 6.3 %
Re Change: + 7.96%

Cap. Change: - 9.7 %
Re Change: +13.98%

Cap. Change: - 11.6 %
Re Change: +26.7%

Cap. Change: - 2.4 %
Re Change: 0%
Moli STOBA 2.0 Ah Li-ion Cell

- **C/5 Charge / 1C Discharge**
  - Cap. Change: -6.3%
  - Re Change: +11.2%

- **C/5 Charge / C/5 Discharge**
  - Cap. Change: -5.1%
  - Re Change: +1.5%

- **C/5 Charge / C/2 Discharge**
  - Cap. Change: -6.8%
  - Re Change: +10.5%

- **C/5 Charge / C/10 Discharge**
  - Cap. Change: -1.97%
  - Re Change: 0%
Moli STOBA 2.0 Ah Li-ion Cell

C/1 Charge / C/1 Discharge

Cap. Change: -8.8%
Re Change: 16.3%

1C Charge / C/2 Discharge

Cap. Change: -9.8%
Re Change: 11.23%
Moli STOBA 2.0 Ah Li-ion Cell

Performance Capabilities at 0°C

< 17.1% of RT

Performance Capabilities at -20°C

< 39.75% of RT

Performance Capabilities at -10°C

< 26.2% of RT

Performance Capabilities at 30°C

< 3.2% of RT
Moli STOBA 2.0 Ah Li-ion Cell

Performance Capabilities at 40°C

Capacity (Ah)

> 4.8% of RT

Cycle Number

Internal Resistance

Internal Resistance (mΩ)

Depth of Discharge (%)
Moli STOBA 2.0 Ah Li-ion Cell

**Overcharge (1C) Sample 01**

**Overcharge (1C) Sample P9-2**

**Fresh Cell**

**Cycled Cell**

**Overcharge (1C) Sample 01**

**Overcharge (1C) Sample P9-2**

**Fresh Cell**

**Cycled Cell**
Moli STOBA 2.0 Ah Li-ion Cell
Moli STOBA 2.0 Ah Li-ion Cell
Moli STOBA 2.0 Ah Li-ion Cell

Temp Ramp Rate: 1.5 deg C/min.
Moli STOBA 2.0 Ah Li-ion Cell

Vent and Burst Pressure Test Data

Sample 14 vent opened at a pressure of 155 psi.
Sample 15 vent opened at a pressure of 145 psi.

Sample 10 burst at a pressure of 859 psi. Failure around crimp seal.
Sample 11 burst at a pressure of 645 psi. Failure around crimp seal.
LG 2.8 Ah Li-ion 18650 Cell

Performance at Various Temperatures
LG 2.8 Ah Li-ion 18650 Cell

Discharge Capacity at 23 deg C: 1.53 Ah
Acknowledgments

• PCTest Engineering
• Symmetry Resources Inc.
• Element Inc.