Recent Advances with Lithium Carbon mono-fluoride Batteries for Portable Applications

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Topics

- Introduction to Li/CFx
- “Half-Sized” BA-5590 Li/CFx Battery Development
  - Phase I – Steel Cell Development and Limited Battery Testing.
  - Phase II – Aluminium Cell Development and Additional Safety and Battery Testing.
- Conclusions
Initial target is a D cell with 2X Specific Energy compared to the current Li/SO$_2$ and Li/MnO$_2$ batteries at the required 2A continuous discharge rate.

- **Li/SO$_2$**: 7.5 Ah, 0.96 kg
- **Li/MnO$_2$**: 10.5 Ah, 1.29 kg
- **Li/CF$_x$**: 15.5 Ah, 1.03 kg

**Half BA5590**

½ size / similar energy
Challenges

- Low temperature performance and heat management are recognized as the major challenges for this application.
- Significant improvements have been made in low temperature performance, but initial voltage delay still needs improvement for low temperature high rate applications.
- Heat management at the BA-5590 battery level is still a concern for high rate continuous operation.
- CFx material cost continues to be a concern for high volume applications.
Other Improvements

- Aluminium hardware provides an increase of >100 Wh/kg in specific energy density.
  - Reduction by 21% in weight.
- Welded design with rivet seal provides a robust design for high temperature operation.
- Extensive performance, safety and transportation testing has been successfully completed with this design.
- All UN transportation tests - 28 days desert cycle.

D cell with Al Hardware
Length = 54.6 mm
OD = 33.1 mm
## Baseline Phase I – Design Attributes

### Phase I – ½ Sized BA-5590 Li/CFx

- **Mild steel cell enclosure.**
- **Standard feed through and welding processes.**
- **Proof of Concept.**

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>200 Wh at SINCgars (30.5 hours)</td>
<td>170 Wh at SINCgars (26.2 hours) Ambient</td>
</tr>
<tr>
<td></td>
<td></td>
<td>184 Wh at 55°C</td>
</tr>
<tr>
<td>Weight</td>
<td>1.1 pounds (0.499 kg)</td>
<td>1.07 pounds (0.485 kg)</td>
</tr>
<tr>
<td></td>
<td>(400 Wh/kg)</td>
<td>(350 Wh/kg)</td>
</tr>
<tr>
<td>Dimensions</td>
<td>2.450” x 2.500” x 4.400”</td>
<td>2.435” x 2.490” x 4.390”</td>
</tr>
<tr>
<td>Voltage</td>
<td>16.8 V (10V cut-off)</td>
<td>16.5 V (10V cut-off)</td>
</tr>
<tr>
<td>Connector</td>
<td>BA-5590 Type</td>
<td>BA-5590 Type</td>
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<tr>
<td>Fuel Gauge</td>
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<td>Storage Temperature</td>
<td>-40°C to 70°C</td>
<td>-40°C to 70°C</td>
</tr>
<tr>
<td>Transportation and SAR</td>
<td>Required before FY09 Soldier use</td>
<td>UN Transportation Tests compliant; SAR testing is required for Phase II</td>
</tr>
</tbody>
</table>
Phase II – Changes/Challenges

Phase II – ½ Sized BA-5590 with Li/CFx Cells.

- Phase II was focused on additional testing of the battery to understand performance and safety.
- Outlined potential of Aluminium hardware as an option.
- Program refocused to Aluminium hardware development (LC-3155 Slim D).
- There were some design change issues which had to be addressed but the major issues were welding related.
- Phase II also carried out more testing according to that outlined in the First Article Tests and Safety Assessment Report, but not a full FAT/SAR.
Phase II – Cell Design Attributes

- Aluminium hardware provides a weight advantage but due to material selection there are some other concerns:
  - Rivet seal replaces a more conventional Glass to Metal seal.
  - Cell is 23% lighter when compared to the Phase I design.
  - Slim D cell has passed the UN Transportation requirements.
  - Slim D cell was tested for some FAT and SAR requirements.
Phase II – Cell Testing

- Cells tested under the SINCgars Protocol after 28 Day Desert Cycle lost 2.1%Wh and 1.2% Ah.

- SINCgars discharge protocol at 21°C provided.
Aluminium Cells passed the following abuse tests:

- **UN Transportation Requirements:**
  - T6 – Impact.
  - T8 – Forced Discharge.

- **Desert Cycle – Cell leakage.**

- **Cell Charging - 20 mA for 96 hours.**

- **Nail Penetration – 5 full penetration and 5 2/3 penetration**
  - Full maximum of 107°C.
  - 2/3 maximum of 137°C.

- **No fire or disassembly.**
Battery assembly was developed to deal with aluminium hardware.

Battery weight was reduced by approximately 19%.

Volume is 50% of the BA-5590.

Finished battery now weighs < 400g.

Weight is 41.1% of a BA-5590B/U
Under the I Test condition the battery delivered 164.6 Wh, 12.90-Ah and ran for 25.08 hours.
For the I Test 10 minutes FOD after 0V is required.
- Two of the batteries met this condition one did not.
- External Temperature reached a maximum of 134°F (56°C).
- Under the IT Test condition the battery delivered 164.9 Wh, 12.88-Ah and ran for 25.12 hours.
Under the H Test condition the battery delivered 181.9 Wh, 13.58-Ah and ran for 27.73 hours.
No FOD Requirement.
Maximum temperature reached was 146°F.
- Under the HT Test condition the battery delivered 179.8 Wh, 13.46-Ah and ran for 27.40 hours.
- Under the L Test condition the battery delivered 81.43 Wh, 7.07-Ah, 12.39 hours and 20 minute Voltage Delay.
- Under the LT Test condition the battery delivered 76.74 Wh, 6.65-Ah, 11.68 hours and 20 minute Voltage Delay.
### SINCGARS Performance – ½ Sized BA-5590
No Storage (I, L and H)

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Delay (min)</th>
<th>Min volt drop</th>
<th>Capacity (Ah)</th>
<th>Energy (watt-hrs)</th>
<th>Specific Energy (Wh/kg)</th>
<th>Energy Density (Wh/L)</th>
<th>Discharge time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-20</td>
<td>20</td>
<td>6.24</td>
<td>7.07</td>
<td>81.43</td>
<td>205.63</td>
<td>184.40</td>
<td>12.39</td>
</tr>
<tr>
<td>21</td>
<td>0.0</td>
<td>10.86</td>
<td>12.90</td>
<td>164.60</td>
<td>415.66</td>
<td>372.74</td>
<td>25.08</td>
</tr>
<tr>
<td>55</td>
<td>0.0</td>
<td>12.13</td>
<td>13.58</td>
<td>181.91</td>
<td>459.37</td>
<td>411.93</td>
<td>27.73</td>
</tr>
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</table>
## Phase II – Battery Testing

### SINCGARS Performance – $\frac{1}{2}$ Sized BA-5590
After 7 Days Desert Cycle Storage (LT, IT and HT)

<table>
<thead>
<tr>
<th>Temp (°C)</th>
<th>Delay (min)</th>
<th>Min volt drop</th>
<th>Capacity (Ah)</th>
<th>Energy (watt-hrs)</th>
<th>Specific Energy (Wh/kg)</th>
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<tr>
<td>-20</td>
<td>20</td>
<td>0.0</td>
<td>6.65 (94.1%)</td>
<td>76.74 (94.2%)</td>
<td>193.54</td>
<td>173.78</td>
<td>11.68</td>
</tr>
<tr>
<td>21</td>
<td>0.0</td>
<td>8.88</td>
<td>12.88 (99.8%)</td>
<td>164.92 (100%)</td>
<td>415.42</td>
<td>373.46</td>
<td>25.12</td>
</tr>
<tr>
<td>55</td>
<td>0.0</td>
<td>11.94</td>
<td>13.46 (99.1%)</td>
<td>179.80 (99.85)</td>
<td>452.91</td>
<td>407.16</td>
<td>27.40</td>
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## Phase II Performance versus Goals

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<td>200 Wh at SINCGARS (30.5 hours)</td>
<td>165 Wh at SINCGARS (25.08 hours 21°C) 182 Wh at SINCGARS (27.73 hours 55°C)</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>1.1 pounds (0.499 kg) (400 Wh/kg)</td>
<td>0.87 pounds (0.395 kg) (415 Wh/kg)</td>
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<td><strong>Dimensions</strong></td>
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High Energy D Size CFx cell has been developed with the energy and rate capability for the BA-5590 battery application

- 2X energy advantage over Li/SO₂ and Li/MnO₂.
- Significant improvements in low temperature operation.
- Aluminium hardware provides additional gain in specific energy.

Hybrid chemistry being developed by EPT Joplin offers the opportunity to expand technology to other applications

- Lower total battery material cost.
- Improves voltage delay and heat management for portable power.