Design and Manufacturing Criteria for High-Performance, Low-Cost, Large-Format, Bipolar Batteries

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Better Batteries, Better World©

• Advanced Battery Concepts, LLC is focused on advancing large-format energy to meet the ever growing energy needs of our world.

• Our first advancement is GreenSeal® bipolar, lead battery technology
  - Reduces weight by 35%
  - Reduces lead content by 46%
  - Increases cycle life by 300%
“Bipolar? I heard that doesn’t work”

• Technical Challenges
  ▪ Edge Seal Rupture
  ▪ Mechanical robustness
  ▪ Electro-chemical stability
  ▪ Thermal management

• Commercial Challenges
  ▪ Large format with standard size
  ▪ Globally available supply chain
  ▪ Compatibility with lead recycling loop
  ▪ At or below costs to existing lead battery costs
“GreenSeal®” Solves the Problems

• Suite of technology developed and designed for scale manufacturing.
  ▪ GreenSeal® bipolar electrode uses only common materials, is low cost & rugged, and 100% recyclable.
  ▪ SurePlate™ monopolar electrode integrates vent & terminal into single low cost plate.
  ▪ Bipolar+™ dual polar electrode allows for low-voltage, high capacity, standard size batteries to be built.
  ▪ PrecisionAM™ pasting technology ensures uniform weight, no edge cleaning, low-cost, high throughput production with no dust or waste.
  ▪ ViaLock™ assembly technology allows large batteries to be built.
  ▪ RapidSeal™ assembly technology ensure perfect seal and rugged case at production rates.
  ▪ SureFill™ technology ensures uniform fill with low cost (vacuum pump) equipment with no down draft tables needed.
  ▪ And much more.

14 issued or allowed patents
25 more pending patents
30 trade secrets
9 geographies
1 trademark
Building with “GreenSeal®”

- Greatly simplified and reduced unit operations.
- Uses globally available materials used in lead batteries today.
- Low cost capital costs to retro-fit existing lead battery production.
- Requires no changes to active material recipes.
- Improves quality and warranty.
- Improves safety.

GreenSeal® Battery Production Operations

- Mold frames
- Punch foil & AGM
- Assemble components
- Paste components
- Stack, cure and dry
- Overmold
- Fill & form
“GreenSeal®” Validation Study

- Assemble 82 12V 17Ah general purpose batteries using production ready processes to validate:
  - Production yield
  - Process control
  - Quality control

- Phases of Validation Study
  - Phase 0: Assembly
  - Phase 1: Quality Control Testing
  - Phase 2: Short term testing
  - Phase 3: Long term testing
Paste & Cure Results

- Paste Weights
  - PAM Weight = 171 +/- 0.99 gm
  - NAM Weight = 142 +/- 1.03 gm
- Yield > 99.9%
  - 2001 plate pasted
  - 2000 yielded
  - 1 lost due to operator insert error
  - No adhesion losses
- Porosimetry Normal
- Cleared & dried
Battery Assembly Results

- RapidSeal™ Assembly
  - Molded 82 Stacks
  - Yielded 79
  - Losses
    - 2 to operator loading error
    - 1 to short shot
- Pressure/Vacuum Check pre-formation
  - Yielded 78 out of 79
  - Lost 1 due to no chamfer in end-plate found via teardown of the battery – operator error during end plate assembly.
Filling Results

- Acid Final Wt QC Summary
  - #Filled: 78
  - # Pass: 78
  - %Yield: 100%
  - Avg Initial Fill: 178.7±2 gm
  - % Pyc volume: 98.4%
  - %Fill Variance: 2%
  - Avg Final Fill: 161 gm
  - %Final Variance: 1.7%
Formation Results

- Formed in four lots due to 20 battery string limit.
- Target 140 Ah/lb of PAM
- 78 out 78 batteries successfully filled and formed
  - No leaks or loss of voltage or high resistance
- Tear down showed good formation (XRD Intensity)
  - Alpha PbO$_2$ 8.8%
  - Beta PbO$_2$ 90%
  - PbSO$_4$ 1.2%
Quality Control Summary

• Final Weight QC Summary 100%
  ▪ Weight = 4852 gm +/- 0.4%

• Final Dims QC Summary 100%
  ▪ Height = 156.0 mm +/- 0.1%
  ▪ Length = 202.8 mm +/- 0.1%
  ▪ Depth = 83.8 mm +/- 0.4%

• High Rate dV QC Summary 100%
  ▪ Avg HRDVT = 8.69V +/- 2.2%

• Capacity QC Summary 100%
  ▪ 2A Cap = 13.87Ah +/- 3.7%

• OCV QC Summary 100%
  ▪ 2 Day OCV = 13.27V +/- 0.26%

• Final HRC QC Summary 98%
  ▪ 1 lost to operator error
  ▪ 1 lost to short shot (first OM’ed battery)

*excluding operator error
Short Term Testing

- GP12-17
  - EN 50342-1 C20 Capacity (25C) 17 Ah
  - EN 50342-1 Reserve Capacity Minutes (25C) 9 min
  - SAE J537 CCA Check (-18C) >7.2V after 30s at 30 A

<table>
<thead>
<tr>
<th>Battery Sample ID</th>
<th>EN50342-1 C20, Ah</th>
<th>EN50342-1 RCM, min</th>
<th>SAEJ537 CCA, V</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP050-09</td>
<td>17.07</td>
<td>12.35</td>
<td>7.70</td>
</tr>
<tr>
<td>TP050-12</td>
<td>17.46</td>
<td>12.53</td>
<td>7.78</td>
</tr>
<tr>
<td>TP051-01</td>
<td>16.67</td>
<td>12.22</td>
<td>7.49</td>
</tr>
<tr>
<td>TP051-10</td>
<td>17.16</td>
<td>11.25</td>
<td>7.05</td>
</tr>
<tr>
<td>TP050-05</td>
<td>17.12</td>
<td>12.84</td>
<td>7.63</td>
</tr>
<tr>
<td>TP050-08</td>
<td>17.11</td>
<td>13.01</td>
<td>7.70</td>
</tr>
<tr>
<td>Average</td>
<td>17.10</td>
<td>12.37</td>
<td>7.56</td>
</tr>
<tr>
<td>1-Sigma</td>
<td>0.25</td>
<td>0.62</td>
<td>0.27</td>
</tr>
</tbody>
</table>
Long Term Testing

- Over the past 5 years of development ABC has conducted numerous long term tests of GreenSeal® batteries to identify failure modes and improve quality.
- LTT falls into 4 categories
  - Cycle life
  - Vibration life
  - Stand life
  - Float life
- All LTT is performed on alpha-production ready batteries.

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Test Type</th>
<th>Test Temp</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 61056</td>
<td>Cycle Test</td>
<td>25 C</td>
<td>357 cycles</td>
</tr>
<tr>
<td>JIS D 5302</td>
<td>Cycle Test</td>
<td>40 C</td>
<td>15 Weeks</td>
</tr>
<tr>
<td>BCISO6 100% DOD</td>
<td>Cycle Test</td>
<td>25 C</td>
<td>780 cycles</td>
</tr>
<tr>
<td>ENS0342-1 Cycle Life</td>
<td>Cycle Test</td>
<td>25 C</td>
<td>180 cycles</td>
</tr>
<tr>
<td>SAE J2801 Life Test</td>
<td>Cycle Test</td>
<td>75 C</td>
<td>11 weeks</td>
</tr>
<tr>
<td>ABC 1C 100% DOD</td>
<td>Cycle Test</td>
<td>25 C</td>
<td>750 cycles</td>
</tr>
<tr>
<td>VDA 17.5% DOD</td>
<td>Cycle Test</td>
<td>25 C</td>
<td>18 weeks</td>
</tr>
<tr>
<td>SAE J537</td>
<td>Vibration</td>
<td>25 C</td>
<td>&gt; 40h</td>
</tr>
<tr>
<td>SAE J930 Level 2</td>
<td>Vibration</td>
<td>25 C</td>
<td>620h</td>
</tr>
<tr>
<td>SAE J930 Level 3</td>
<td>Vibration</td>
<td>25 C</td>
<td>&gt;360h</td>
</tr>
<tr>
<td>ENS0342-1 Float Test</td>
<td>Float</td>
<td>60 C</td>
<td>4 months</td>
</tr>
<tr>
<td>ENS0342-1 42 Day Water Loss</td>
<td>Float</td>
<td>60 C</td>
<td>&lt; 2 g/Ah</td>
</tr>
<tr>
<td>OCV Monitoring</td>
<td>Stand</td>
<td>25 C</td>
<td>&lt;0.5%/mo</td>
</tr>
<tr>
<td>150 Day Capacity</td>
<td>Stand</td>
<td>25 C</td>
<td>&lt;5% Fade</td>
</tr>
</tbody>
</table>
IEC 61056 Cycle Test

IEC 61056 Endurance Cycle

Avg of 3 samples

Cycle Testing Program
- DCH at 5x120 (4.25A) to 2H
- RCH at CC of 5A to 2.40 VPC
- RCH at CV of 2.40 VPC
- 6H Total RCH Time
- Every 50th Cycle Chk Capacity

Avg End of Life 357 Cycles

IEC 61056 Gas Recombination Efficiency > 99.8%
### Additional IEC 61056 Testing

#### IEC 61056 General Purpose Battery Testing

Scope: This part of IEC 61056 specifies the general requirements, functional characteristics and methods of test
- for either cyclic or float charge applications;
- in portable equipment, for instance, incorporated in tools, toys, or in static emergency or uninterruptible power supply and general power supplies

<table>
<thead>
<tr>
<th>Section</th>
<th>Section Name</th>
<th>Requirements</th>
<th>Result</th>
<th>Required</th>
<th>Pass or Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.2</td>
<td>Capacity Ca (actual capacity at the 20H discharge rate)</td>
<td>Sustain dch to 1.75 VPC for 20H at the MFG’s specified 20H rate (C20/20)</td>
<td>20.95H</td>
<td>20H</td>
<td>Pass</td>
</tr>
<tr>
<td>7.3</td>
<td>High Rate Capacity</td>
<td>Sustain dch to 1.6 VPC at 20*I20 for 20 minutes</td>
<td>27.3min</td>
<td>20min</td>
<td>Pass</td>
</tr>
<tr>
<td>7.4</td>
<td>Endurance in Cycles</td>
<td>Maintain end-of-discharge voltage above 1.65 VPC after discharge at 2H at the 5*I20 rate for 200 cycles</td>
<td>307 cycles (avg 3 bat)</td>
<td>200 cycles</td>
<td>Pass</td>
</tr>
<tr>
<td>7.5</td>
<td>Float Service Endurance</td>
<td>Maintain capacity &gt; 0.6<em>C20 tested at 5</em>I20 to 1.7V checking every six months after float at 25C for two years</td>
<td>Not Tested</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.6</td>
<td>Float Service Endurance at 40 C</td>
<td>Maintain capacity &gt; 0.6<em>C20 tested at 5</em>I20 to 1.7V checking every two months after float at 40C for 8.5 months</td>
<td>Not Tested</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.7</td>
<td>Charge Retention</td>
<td>After 120 days of storage at 25C the battery shall have a discharge time &gt; 15 hours discharging at the C20 rate to 1.75 VPC</td>
<td>19.2H</td>
<td>15H</td>
<td>Pass</td>
</tr>
<tr>
<td>7.8</td>
<td>Max. Permissible Current</td>
<td>A battery should be able to sustain a 150s discharge to 1.34VPC at 40<em>I20 after being discharged for 300sat 40</em>I20, charged, discharged for 5s at 200*I20 and charged</td>
<td>600s</td>
<td>150s</td>
<td>Pass</td>
</tr>
<tr>
<td>7.9</td>
<td>Charge Acceptance after Deep Discharge</td>
<td>A battery should maintain &gt; 0.75<em>C20 tested at 120 to 1.75VPC after being connected to a resistor load (40</em>I20) for 360H, recharged at constant voltage for 48 hours at 6*I20 or</td>
<td>16.1Ah</td>
<td>12.75Ah</td>
<td>Pass</td>
</tr>
<tr>
<td>7.10</td>
<td>Gas Emission Intensity constant current</td>
<td>Constant current charge battery for 24H and then collect gas for 5 hours at 0.1*I20. Record gas volume and calculate recombination efficiency which shall not be less than</td>
<td>&gt;99.8%</td>
<td></td>
<td>Pass</td>
</tr>
<tr>
<td>7.11</td>
<td>Vibration resistance characteristics</td>
<td>Measure OCV after vibrating battery with 4 mm amplitude wave at 16 to 7 Hz for 1 H in each direction. OCV should remain above 2V VPC with no leakage or damage to case</td>
<td>Used SAE J930 Instead</td>
<td></td>
<td>Pass</td>
</tr>
<tr>
<td>7.12</td>
<td>Shock Resistant Characteristics</td>
<td>OCV shall remain above 2V VPC with no visual damage after 3 drops from a height of 20 cm onto a flat hardwood floor at least 10 mm thick (battery bottom downward)</td>
<td>No damage, 13.2V</td>
<td>No visible damage</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Motorcycle Battery Life Test (40C)

JIS D 5302 Shallow Cycle Life Test at 40C
DCH at -5A for 1H
RCH at CC of 1.25A for 5H, no lid
After 25x cycles DCH to 10.2V
CHA same, then repeat
Capacity at 5A every 25th cycle < 40% C/10
Goal 14 Loops

% of C/10 Capacity on Cycle Loop vs Cycle Loop Count (# Weeks)
BCIS 06 Cycle Test

BCIS-06 Cycle Life (100% DOD at 2h Rate)

- Identified Failure Mechanism.

- Dual-Purpose AGM* 70 Cycles
- TPPL AGM* 250 Cycles
- Trojan AGM* 337 Cycles
- GreenSeal® Bipolar AGM 780 Cycles!!

*Data from Trojan Overdrive AGM Brochure

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SAE J930 Level 3 Vibration

- Completed 10 units (360h) PASS
- No evidence of fade
- Testing stopped due to cost
- Standard VRLA is less than 162h
Outstanding Stand Loss

- One year of stand with < 0.5% voltage loss/month and stable impedance
EN50342-6 Corrosion Test

- Aggressive test to monitor corrosion
- Float 14V 60C 13 Days
- Rest OCV 60C 13 Days
- High rate Discharge

EN50342-6 Corrosion EODV GP-12-17-1M

<table>
<thead>
<tr>
<th>EN50342-1 §5.7 Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of batteries</td>
</tr>
<tr>
<td>Test Conditions</td>
</tr>
<tr>
<td>1 Fully charge the battery</td>
</tr>
<tr>
<td>2 Place battery in 60C Water bath &amp; Float</td>
</tr>
<tr>
<td>3 Keep in 60C remove from float &amp; stand</td>
</tr>
<tr>
<td>4 Remove battery and cool to 25C</td>
</tr>
<tr>
<td>5 Recharge battery</td>
</tr>
<tr>
<td>6 Rest battery</td>
</tr>
<tr>
<td>7 Discharge at 0.6Icc at 25C 30s</td>
</tr>
<tr>
<td>Repeat steps 1-7</td>
</tr>
<tr>
<td>Discharge at 0.6*Icc at 25C 30s</td>
</tr>
<tr>
<td>Goal</td>
</tr>
</tbody>
</table>
GreenSeal® Golf Cart Batteries

- ABC is now producing field ready golf cart sized batteries.
  - Same weight higher energy
  - Lower production costs
- Initial results
  - All unit operations specified
  - 52 Wh/kg C20 energy density
  - Superior cycle life to today’s premium AGM GC batteries
- Field trials anticipated this summer.
GreenSeal® GC Battery Stand Life

GreenSeal® GC2 24V 55Ah Battery

Voltage per Cell, V

Days on Stand at 25°C

Rel. Impedance

0.49% dV/month

LABAT June 2017
Advanced Battery Concepts, LLC
“GreenSeal®” is Ready

- Secured licenses with 3 large, global lead battery manufacturers
  - Includes JCI & Trojan
  - In negotiations with multiple others
- Battery Engineering & Manufacturing Development Center (BEMDC)
  - Advanced research of battery materials
  - Engineering process development
  - Prototype production line for small lots, fieldable, advanced batteries. (2018)
- Fielding GC’s 2H 2017 and developing G31’s for field trials 1H 2018.
- Scale production anticipated 2019
THANK YOU

www.advancedbatteryconcepts.com