Advanced Battery Technology Programs

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Advanced battery technology programs focus on selection and procurement of state-of-the-art commercial off-the-shelf (COTS) and custom-made cells – delivered by Small Business Innovative Research (SBIR) program companies – for testing and inclusion in the existing Johnson Space Center cell database. COTS procurement allows for ease of selection, and the use of custom-made cells allows for quick-turnaround projects requiring power for government-furnished equipment (GFE) and payload hardware. This article describes the results of a few cell studies.

In the early stages of the exploration technology development program (ETDP), we studied primarily lithium polycarbonmonofluoride ($Li(CF)_x$) cells to improve their rate capability. As part of this effort, our laboratory characterized COTS $Li(CF)_x$ coin cells under different discharge rates and temperatures. These data formed a baseline for comparison with cells made with material improvements. We found that these state-of-the-art cells provided excellent performance at room temperature at very low discharge rates of capacity C/100 to C/200 (C refers to the current-equivalent rate based on capacity; for example, 1C rate for a 1 Ah cell is 1A). The voltage delay (observed as an initial drop) that occurs with this chemistry was negligible at room temperature (figure 1). However, at temperatures of –40°C, the performance drops significantly and the voltage delay is also pronounced (figure 2).

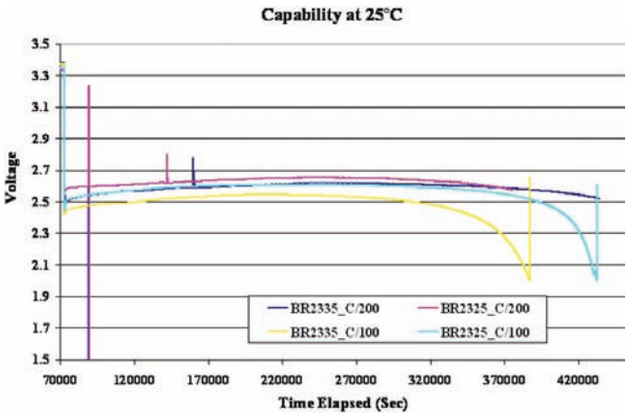

Fig. 1. *$Li(CF)_x$ COTS coin cell discharge at room temperature.*

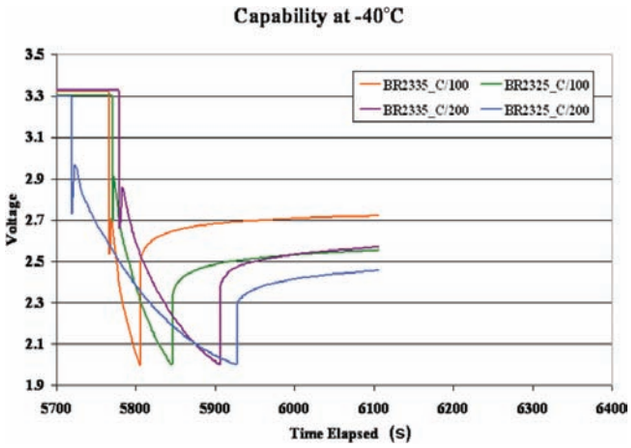

Fig. 2. *$Li(CF)_x$ COTS coin cell discharge at –40°C.*

In parallel with this study, an SBIR program involved the development of novel electrolytes for low-temperature performance of $Li(CF)_x$ cells. Covalent Associates, Inc., Corvallis, Ore., synthesized the low-temperature ionic liquid electrolytes and Quallion, LLC, Sylmar, Calif., manufactured the cells containing this electrolyte. We tested cells of different sizes (from coin to AA-size cells) at different temperatures. Laboratory cells performed at temperatures as low as –98°C (figure 3) and AA-size cells at temperatures as low as –70°C.

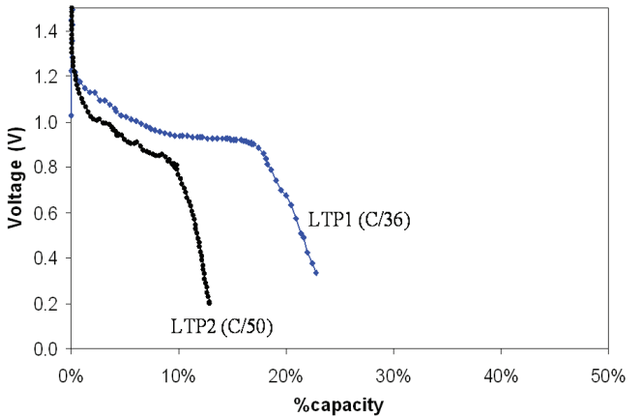

Fig. 3. *Performance at –98°C and at different rates of $Li(CF)_x$ coin cells with low-temperature electrolyte.*

Cell studies conducted under the GFE advanced technology program include performance and safety testing of the Altairnano lithium-ion 11-Ah high-rate polymer cell. The Altairnano (Reno, Nev.) cell has a traditional lithium cobalt oxide cathode and a nanotitanate anode. Due to the nature of the anode, the overall operating voltage of the cell falls to about 2.3V instead of the standard 3.6V obtained with a carbon-based anode. Although the cell can discharge under a continuous current load of 20 C (220A), only discharge rates up to 5 C (~50A) were carried out due to a lack of test equipment capability. The Altairnano cell provided excellent performance under these conditions with as many as 500 cycles.

A set of Altairnano cells underwent abuse testing under conditions of overcharge, overdischarge, external short circuit, and heat-to-vent. When single cells were overcharged at a 1-C rate with a 12V limit, they swelled up and, in some cases, caused the cell seals to open (figure 4). When we overcharged eight cells in a series configuration at a 1-C rate to 48V, one cell was charred externally (figure 5) by the burning of expelled electrolyte liquid and vapors. Charring was also observed when the cells were exposed to high temperatures under the heat-to-vent test. When the Altairnano cells were subjected to an overdischarge test, no catastrophic events occurred. The maximum temperature observed was 70°C.

NASA scientists also determined the characteristics of COTS cylindrical lithium-ion cells under a vacuum condition. Tests included overcharge and external short circuit in multicell configurations. These scientists determined that the overcharge test was benign due to a lack of rapid propagation of heat between the failed cell and the other cells, but the external short-circuit test proved catastrophic (figures 6 and 7) as the heat failed to dissipate fast enough either to the neighboring cells or to the environment.

Fig. 4. *Overcharge of a single Altairnano cell.*

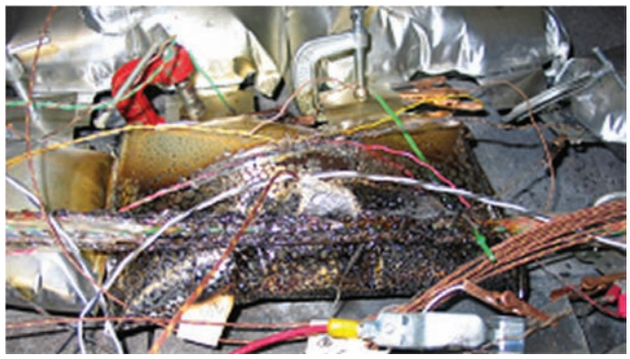

Fig. 5. *Overcharge of 8-series-connected Altairnano cells.*

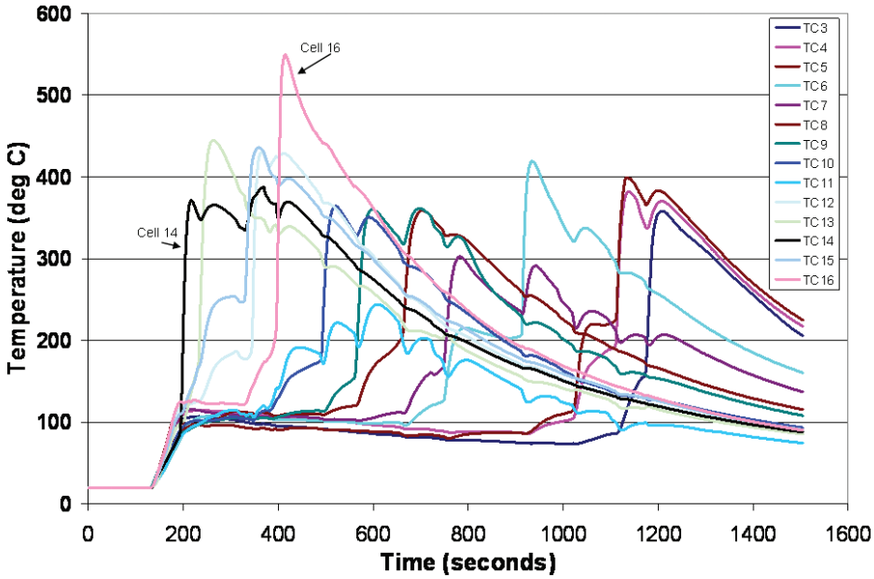

Fig. 6. *Temperatures observed during an overcharge test on a 14-series string in vacuum.*

Fig. 7. *Cells from the overcharge test on the 14-series string in vacuum conditions showing expulsion of cell contents and melted metal.*

Our laboratory evaluated an advanced cell chemistry – lithium-sulfur (Li-S). We compared baseline state-of-the-art cells provided by Sion™ Power Corporation, Tucson, Ariz., to cells (also provided by Sion™ Power Corporation) with an improved cathode and anode that increased the cycle life stability. We cycled these cells under three different rates as well as under vacuum conditions and safety tests that included overcharge, overdischarge, and external short. The excellent performance of the improved cells under vacuum conditions for the 25 cycles studied (figure 8) was comparable to that of the cells under ambient environmental conditions. The baseline cells fell in capacity to 1.7 Ah at about 45 cycles, whereas the improved cells provided as many as 65 cycles before the capacity fell to the earlier value. If the cycle life of the Li-S chemistry is improved further, it will produce a rechargeable battery with the highest energy density available in the market today.

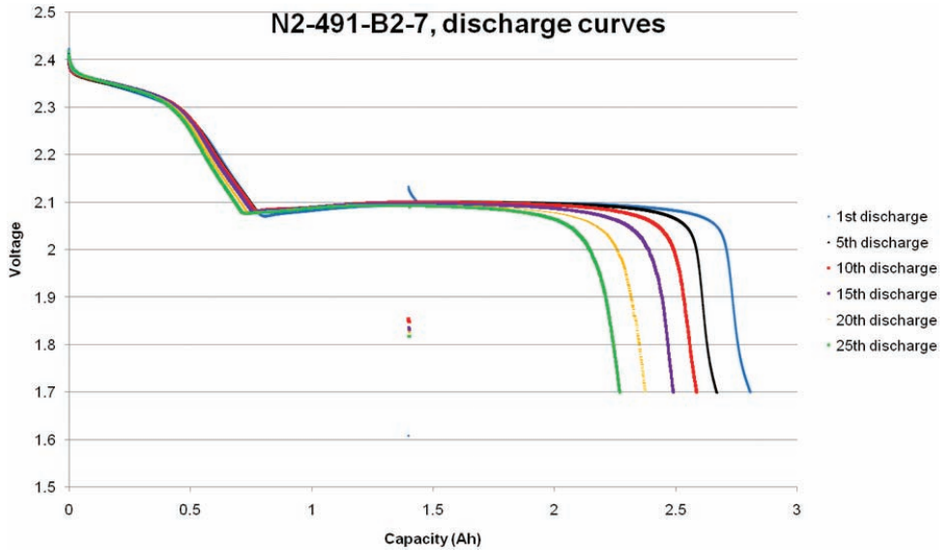

Fig. 8. *Discharge curves for the Li-S cells in a vacuum condition (315 mA charge and 250 mA discharge currents).*

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