PERFORMANCE AND SAFETY OF LITHIUM-ION POLYMER POUCH CELLS

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ABSTRACT

Lithium-ion cells, currently, provide the highest energy density and cycle life of rechargeable battery systems. Of all the available design formats for lithium-ion cells, those that are manufactured in a pouch provide a higher gravimetric energy density, compared to those in metal containers. The lithium-ion polymer cells in the pouch format perform under nominal and off-nominal conditions in a manner similar to cells in metal containers. However, the pouch design has its limitations. The pouches swell under various conditions including vacuum environments. Results of the performance and safety of lithium-ion polymer cells found in pouch designs from several manufacturers and in various environments of space are included in this paper.

INTRODUCTION

Lithium-ion (li-ion) cells in the pouch format are often referred to as 'lithium-ion polymer' cells or 'lithium-polymer' cells, both of which are, in a majority of cases, a misnomer. Li-ion polymer cells are those of a pouch format design with a true polymer electrolyte and/or polymer-added electrodes and wetted with a liquid electrolyte. Although the li-ion pouch cells are frequently referred to as lithium polymers, these are, in actuality, lithium-ion cells with a liquid electrolyte and may or may not contain a polymeric additive in their components (cathode, anode or electrolyte). Li-ion pouch cells that are commonly referred to as 'lithium-polymer' cells are sold at significantly low cost for use in portable electronic equipment and remote-controlled airplanes and toys. However, there are several manufacturers of li-ion polymer cells that offer cells in a pouch format of high quality and long endurance and consequently of higher cost.

For more than two decades, commercial-off-the-shelf (COTS) cells have been tested at NASA-JSC, to determine the state-of-the-art characteristics with respect to both performance as well as safety. The cells are tested as a subset of the flight battery certification process as well as stand-alone cells obtained from cell manufacturers. [1] In recent years, NASA has flown several portable electronic equipment and experiments that have used li-ion polymer cells in the pouch format. Although they do provide an advantage in gravimetric energy density the cells designs often require restraints of the flat surfaces in order to provide performance comparable to li -ion cells that utilize the metal can designs. And the hazards associated with the li-ion polymer pouch cells are very similar to those found in a metallic container designed without the internal protective features.

As part of the NASA human-rated space flight acceptance test process, all batteries, including button cells, are subjected to a leak check that is typically a six-hour vacuum exposure test. This vacuum can range from 0.1 psi down to 10^{-5} Torr, depending on the environment they are to be used in. The former is used for all hardware that is used in an in-cabin (Intravehicular Activity [IVA]) environment whereas the latter is used for those applications that need to be used in a deep space environment as during an Extravehicular Activity (EVA). As the number of portable applications using li-ion polymer pouch cells has increased, and as the vacuum exposure test is used as a leak check on all flight batteries, it was imperative to carry out a test program to determine the tolerance of these pouch cell designs to various pressure conditions.

Cells manufactured by SKC, Altairnano, Tenergy, Wanma, Kokam, GMB, Varta as well as cells from the iPad were tested under this program. The SKC and Altairnano cells were of high rate capability with the latter containing a nanotitanate anode that reduces the nominal voltage of the cell to 2.3 V. The other cells were chosen due to their high gravimetric energy density or use in a space-application.

In this study, li-ion polymer cells in the pouch format were subjected to various nominal and off-nominal conditions. Apart from this, several of these were subjected to cycles under various pressure environments as well as placed under various storage protocols to understand their characteristics in a true usage environment that has a mix of cycle life and storage conditions.

EXPERIMENTAL

Performance studies on li-ion polymer cells in the pouch format included testing of SKC 15 Ah, Tenergy 6 Ah, Wanma 5 Ah, Altairnano 13 Ah [2] and Varta1.2

Ah [3]. The tests included rate capability determination at various rates of charge and discharge for 300 to 500 cycles, internal resistance measurements and in some cases, performance at various temperatures. The safety and abuse tests consisted of overcharge at various rates at the single cell and string levels, overdischarge at the cell level, external short at the cell and string level, heat-to-vent, simulated internal short and pouch burst pressure determination. The li-ion polymer cells from SKC, Tenergy, Wanma, GMB (3.9 Ah), Kokam (5Ah), Varta and the iPad (3.8 Ah) were also tested under vacuum (~0.1 psi), reduced pressure (8 to 10 psi) and in some cases deep vacuum conditions (10^{-3} Torr instead of typical 10^{-5} Torr due to reduced environmental chamber capabilities).[2]
All these tests included cells that were restrained and unrestrained. The pressure used to restrain the cells was dependent on the manufacturer's recommendation and typically lexan end plates were used as restraints. The tests under the various pressure conditions included the following:
a. Continuous charge and discharge for a maximum of 30 cycles (50 cycles for Varta cells) at 0.1 psi or 8 to 9 psi followed by one or two ambient capacity cycles.
b. One charge under reduced pressures (0.1 psi, 9 psi or 10^{-5} Torr) followed by storage for 20 days and then one ambient capacity cycle test.
c. Charge and discharge (10 cycles) at 0.1 psi, 9 psi or 10^{-5}Torr, followed by storage at full charge under ambient pressure for 20 days; 25 cycles at the same reduced pressures (0.1 psi, 9 psi or 10^{-5} Torr); then cycled twice for capacity checks to determine reversible capacity.
The iPad li-ion cells and battery pack (3 cells in parallel) underwent a different set of tests. They included the following:
1. One charge and discharge cycle, store at full charge for 2 months with mass measurements once a week; capacity cycle at the end of two months (one pack and three single cells).
2. Charge and discharge cycle (one pack), mass measurements under ambient pressure, expose fully charged pack to 0.1 psi for 6 hours, store for 6 months, repeat charge and discharge cycle and mass measurements.
3. Charge and discharge cycle and mass measurements under ambient pressure, expose fully charged pack to 0.1 psi for 6 hours, store at ambient for 2 months, carry charge/discharge cycles with one cycle per day for 30 days.
4. Repeat test 3 on one pack and 3 cells, at 8 psi pressure instead of 0.1 psi.
5. 10 cycles at 0.1 psi and 10 cycles at 8 psi.

The performance and safety tests had a sample number of 3 while each of the tests under the various pressure conditions had two cells with restraints and two cells without restraints.

The cross sections of the pouches were carried out and analyzed using scanning electron microscopy (SEM). Analysis of the pouch materials using energy dispersive spectroscopy (EDS) and chemical methods were also carried out to determine the composition of the various layers used in the pouch. The internal construction of the cell/electrode winding was also studied.
All the details of the test results for this entire program are not discussed in this paper due to the extensive nature of tests and results. The author can be contacted to obtain more information.

RESULTS AND DISCUSSION

A. Performance and Safety Tests:

The SKC li-ion polymer cells performed extremely well under different rates with the maximum capacity loss of 4 % occurring at 1C discharge rate for the 500 cycles tested (Fig. 1). The SKC li-ion cells exhibited only swelling under the off-nominal safety tests except for the heat-to-vent test that showed complete charring due to the pouch opening up and burning of electrolyte.

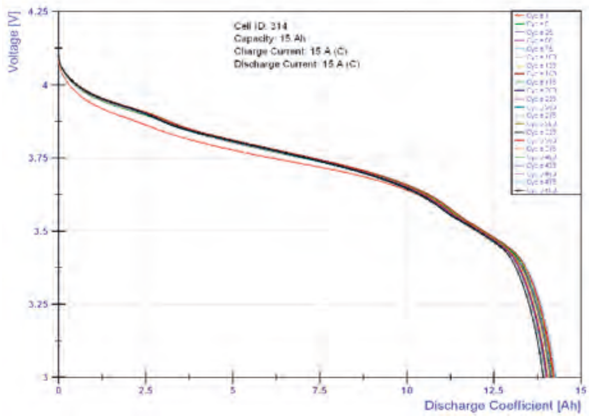

Figure 1. Capacity Trend for SKC li-ion pouch cells at 1 C charge and discharge rate for 500 cycles.

The Altairnano cells performed extremely well exhibiting 14 Ah capacity (8% higher than rated) at a 1C discharge rate and the rated capacity of 13 Ah at 5C discharge rate with no degradation of capacity for a cycle life of 100 and 200, respectively. The capacities obtained at the 10 C rate of discharge was about 72% of the capacity obtained at a 1 C discharge rate but the loss in capacity for 25 cycles was negligible (Fig. 2).
The Altairnano cells were also subjected to charge and discharge cycles at various temperatures and it was determined that the capacity was, less than 50% at -30 °C, ~15% capacity at 0 °C, greater than 4% at 40 °C and ~6% greater at 60 °C, compared to that obtained at room temperature (25 °C).