A Novel Lithium-ion Laminated Pouch Cell Tested For Performance And Safety

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ABSTRACT

A new Li-ion 4.0 Ah pouch cell from GS Yuasa has been tested to determine its performance and safety. The cell is of a laminate pouch design with liquid electrolyte. The rate, thermal and vacuum performance capabilities have been tested to determine the optimum parameters. Under vacuum conditions, the cells were cycled under restrained and unrestrained configurations. The burst pressure of the laminate pouch was also determined. The overcharge, overdischarge into reversal and external short circuit safety tests were also performed to determine the cell's tolerance to abuse.

Key Words: Li-ion, safety, vacuum test, abuse, COTS batteries, rate capability

INTRODUCTION

Lithium-ion batteries have been used for space applications (Orbiter and International Space Station) by NASA for about eight years starting with the Canon battery for the camcorder.[1] Most of these are commercial-off-the-shelf (COTS) batteries for portable electronic equipment.[2-5] Extensive studies have also been carried out to obtain baseline data on the performance and safety of state-of-the-art li-ion cells.[6-11] In this paper, we discuss the results of one such study on a laminate pouch cell with the traditional liquid li-ion cell electrolyte.

The laminated pouch li-ion cell with liquid electrolyte was manufactured by GS Yuasa with a capacity of 4 Ah and a high rate capability.

EXPERIMENTAL

The li-ion cell was tested under different test conditions. The tests carried out on the cells included rate capability, performance at different temperatures, cycling under vacuum condition, and abuse tests of overcharge, overdischarge and external short circuit. The rate capability, thermal performance and vacuum tests were carried out at Symmetry Resources, Inc. in Arab, AL using Maccor Series 4000 and Maccor 29481 for cycling and a Tenney chamber for the thermal tests. The abuse test program was carried out at NASA-JSC in the Energy Systems Test Area using a BT 2000 series of the Arbin Test Station.

The nominal charge/discharge protocol included charging using a constant current/ constant voltage protocol with a current of C/2 to 4.1 V and a taper current limit of C/40. The discharge was performed using a constant current of C/2.

The rate capability tests included C/2 charge and discharges at C/2, 1C and 2.5C rates (Set 1); 1C charge and discharges at C/2, 1C and 2.5C rates (Set 2); charge at C/2 and discharges at 5C, 7.5C and 10C rates (Set 3). Sets 1 and 2 underwent 200 cycles. Set 3 had a temperature limit of 60 °C as the criteria for test completion and underwent nominal rate capacity checks every 25 cycles. At the time of paper writing, not all the protocols were completed as required.

The thermal performance tests included cycling at C/2 rates for charge and discharge at temperatures of 0 °C, 10 °C, 25 °C, 40 °C and 55 °C. Ten cycles were performed at each temperature with pulses at every 10 % depth-of-discharge (DoD) during the discharge phase of each cycle. The pulses were of 10 sec duration but data collected at 10 sec and 100 msec was used to calculate the internal resistance (R_e) values. The trend in R_e versus the DoD and cycle number at each temperature was determined. In this paper, only the trend observed with the 100 msec pulses is discussed.

For the vacuum tolerance test, three cells were placed in a vacuum chamber and exposed to a vacuum of approximately 0.1 psi. Ten cycles were performed under vacuum conditions using a C/4 charge and discharge rate with a constant current /constant voltage protocol for charge. A 6.0 A pulse for 100 msec at 50 % DoD was performed. One cycle was performed at ambient environments before and after the vacuum exposure.

The overcharge test was performed on a fully charged cell with a current of 2 A for 6 hours with a 12 V limit. The overdischarge test was carried out on a fully charged cell using a 2 A current and removing an additional 150% of the capacity after the cell reached 0 V. The external short test was performed on a fully charged cell with a load of 50 mohms. A fast data collection of 1 kHz was used for the first three seconds of the test.

RESULTS AND DISCUSSION

The results of the performance and abuse tests are discussed in this Section.

a. Rate Capability:

The cells were charged and discharged at different rates as mentioned in the Experimental Section. Figures 1, 2 and 3 provide the trend observed for the cells that were cycled using the protocols in Sets 1, 2 and 3 respectively.

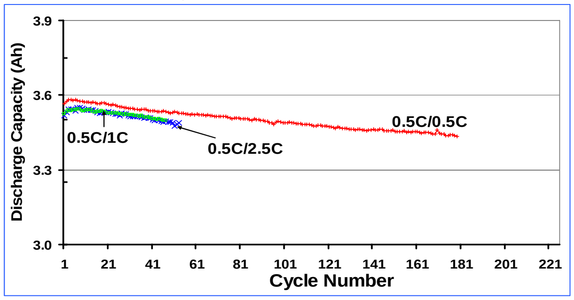

Figure 1: Capacity Trend for Cells Charged at a C/2 Rate and Discharged at Different Rates.

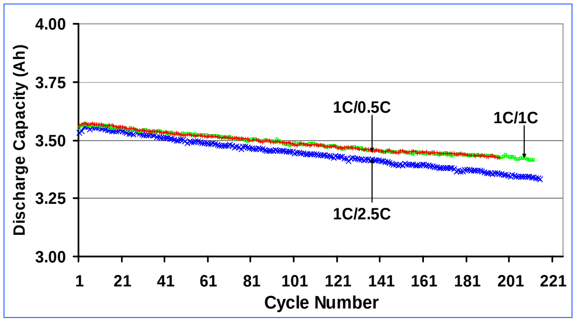

Figure 2. Capacity Trend for Cells Charged at a 1C Rate and Discharged at Different Rates.

Table 1 lists the capacity changes for the first and last cycle tested during this time period. For the Sets 1 and 2, the change in capacity was not much whereas for Set 3 at the highest rate of 10C discharge, the capacity drops faster. However, when discharges with 0.5C current were performed at 25 cycle intervals, higher capacities were obtained showing that the cells do recover in performance even after undergoing high rate discharges (Figure 3).

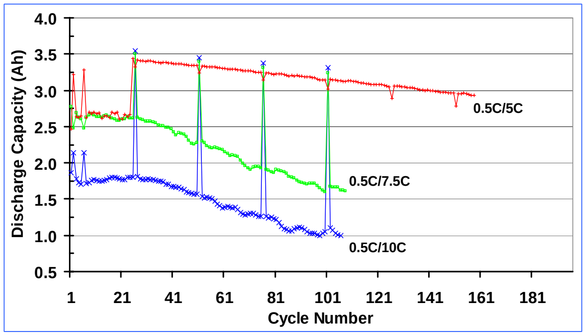

Figure 3. Capacity Trend for Cells Charged at C/2 Rate and Discharged at Different Rates.

Figure 4 shows a comparison of the discharge characteristics for cells discharged at 40 A current rates. The temperature of the cells for the 100 cycles studied remained below 60 °C.

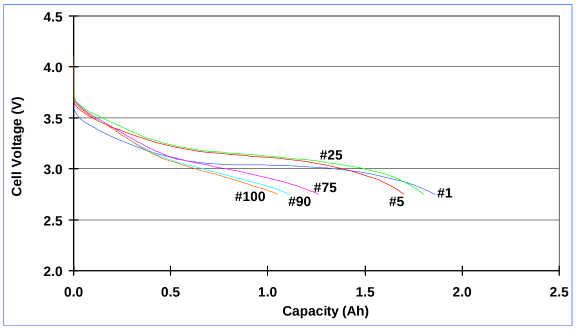

Figure 4. Trend in Discharge Profiles With Cycle Life for Cells Discharged at the 10C Rate.

Table 1. Discharge Capacity Trend Using the Various Charge/ Discharge Protocols

Protocol	Init. Cap (Ah)	Final Cap. (Ah)
0.5C/0.5C	3.57	3.43 (#175)
0.5C/1C	3.52	3.49 (#43)
0.5C/2.5C	3.52	3.49 (#49)
1C/0.5C	3.56	3.42 (#192)
1C/1C	3.55	3.42 (#200)
1C/2.5C	3.53	3.35 (#200)
0.5C/5C	3.22	2.93 (#158)
0.5C/7.5C	2.77	1.61 (#108)
0.5C/10C	1.86	1.0 (#106)

(Numbers in parenthesis give the cycle number for the capacity listed.)

b. Performance at Different Temperatures:

At 0 °C, the cells gave a capacity of 3.44 Ah on cycle 2 and 3.51Ah on cycle 10. The R_e (for 100 msec pulses) varied from 30 mohms for 10 % DoD to 31.9 mohms at 90 % DoD. During the ninth cycle, the R_e decreased slightly and ranged from 28.6 mohms to 30 mohms for the same DoD range. Figure 5 shows the discharge characteristics with the pulse performances, temperature and trend in R_e for cycles 2 and 9.

At 10 °C, the laminate pouch cells provided a capacity of 3.53 Ah and 3.55 Ah for the first and tenth cycles respectively and the R_e varies from 19.8 mohms to 18.6 mohms from 10 % to 90 % DoD without much change for the 9th cycle.

At 25 °C, the cells show a capacity of 3.55 Ah and 3.57 Ah for the first and tenth cycles respectively and the R_e varies from 10.6 mohms to 9.2 mohms from 10 % to 90 % DoD with an average decrease of 4 % for the 9th cycle.

At 40 °C, the cells provide a capacity of 3.54 Ah for the first and tenth cycles respectively and the R_e varies from 6.00 mohms to 5.30 mohms from 10 % to 90 % DoD with an average of 7 % decrease for the 9th cycle.

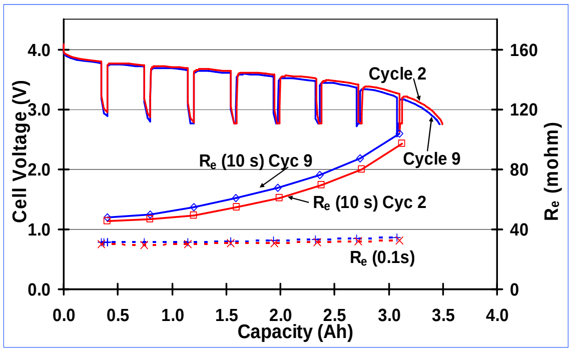

Figure 5. Discharge and R_e Characteristics at 0 °C for Cycles 2 and 9.

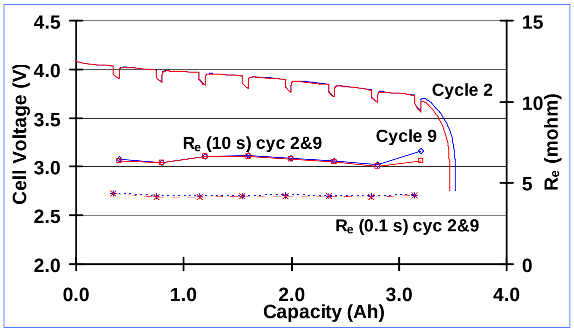

Figure 6. Discharge and R_e Characteristics at 55 °C for Cycles 2 and 9.

At 55 °C, the cells provide a capacity of 3.53 Ah and 3.47 Ah for the first and tenth cycles respectively and the R_e varies from 3.60 mohms to 2.50 mohms from 10 % to 90 % DoD with almost no change from 10 % to 80 % DoD and a fall of 44 % at 90 % DoD for the 9th cycle compared to the 2nd cycle.

A 3% drop in performance was observed for the 0 °C thermal environment compared to that obtained at 25 °C.

c. Vacuum Test:

Three of the laminated pouch cells were cycled under vacuum environments. The capacity trend (Figure 7) shows that there is a drop during vacuum exposure which can be explained by the observation of a slight swelling of the pouches. The capacity obtained in cycle #1 before placement under a vacuum environment is 3.54 Ah and for cycle #2 (the first cycle in a vacuum environment) is 3.39 Ah, a drop of 4 % capacity. Cycle #11 which is the 10th cycle under vacuum conditions provided a capacity of 2.85 Ah and cycle #12 which was performed at ambient environmental conditions provided 2.99 Ah which is a 4.9 % recovery in capacity. A 16 % drop in capacity is obtained between cycle #2 and cycle #11. Tests performed with restraints on the pouches have not been completed.

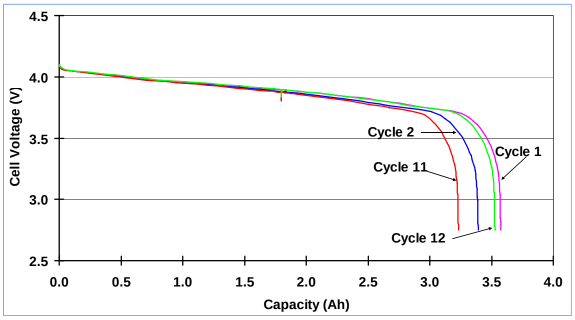

Figure 7. Discharge Characteristics of the Laminate Pouch Cells under Ambient and Vacuum Environments.

d. Overcharge:

The results of the overcharge test are provided in Figure 8. The cells showed tolerance to the charge current for the six hours tested. The voltage plateaus at about 5.5 V and the maximum temperature recorded was 70 °C.

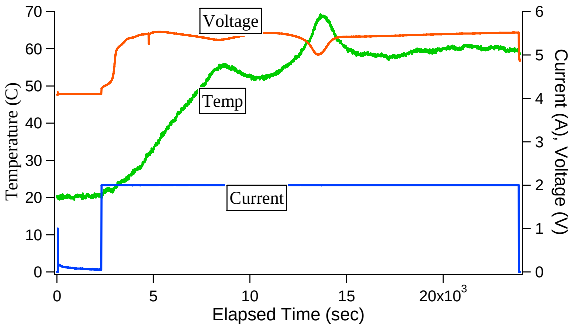

Figure 8. Overcharge Test on GS Yuasa laminate pouch cell with 2 A for 6 hours.

The cells were cycled using the nominal charge/discharge protocol and they did not accept charge and were unable to be discharged. Although the cells showed puffing (Figure 9), they did not exhibit any venting or electrolyte leakage.

Figure 9. Laminate Pouch Cell Showing Expansion After Completion of Overcharge Test.

e. Overdischarge:

The overdischarge test was performed on the cells as described in the Experimental Section. The maximum temperature recorded during this test was 30 °C (Figure 10). The cells did not accept charge after this test but did not vent (Figure 11), burst or leak electrolyte.

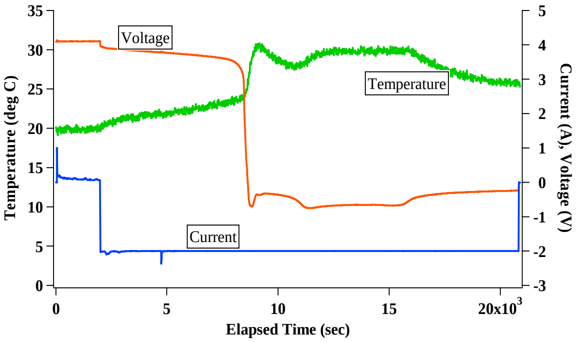

Figure 10. Overdischarge-into-Reversal Test for the Laminate Pouch Cells.

Figure 11. Laminate Pouch Cell after Overdischarge-into-Reversal Test.

f. External Short Circuit:

For the short circuit test, the maximum current spike recorded within the first few milliseconds was about 50 A. The maximum temperature obtained during this test was 27 °C (Figure 12). No venting or leakage of the cells was observed but the cells were non-functional after the test.

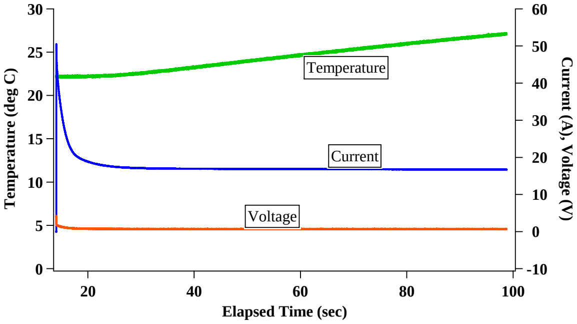

Figure 12. External Short Circuit for the Laminate Pouch Li-ion Cell with a Load of 50 mohms.

CONCLUSIONS

The GS Yuasa laminate pouch cells with liquid electrolyte provided remarkable performance under the conditions tested especially those at higher discharge current rates. The cells show excellent performance even at low temperatures with only a 3 % drop in capacity at 0 °C compared to that obtained at 25 °C. The tests under vacuum conditions indicate that the cells should be restrained in a vacuum environment for consistent performance. Although the cells were not usable after all the abuse conditions tested, they did not any hazardous results of electrolyte leakage, venting or fire.

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