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LOT ACCEPTANCE, ABUSE AND LIFE TESTING OF VARTA LITHIUM POLYMER POUCH CELLS

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ABSTRACT

The aim of this paper is to describe the qualification, characterisation and acceptance testing performed on Varta Lithium Polymer cells in order to assess their suitability for LEO cube-sat and small satellite applications.

Verification of battery operational performance and safety is a multi-layered process that involves continuous assessment of cell parameters at cell, battery and system level from initial cell selection through to final battery configuration.

The tests performed involved assessing individual cell performance relating to capacity under a variety of environmental conditions as well as establishing cell safety via abuse testing for small satellite systems.

1. INTRODUCTION

The Varta cell is a COTS lithium ion polymer cell format which offers high volumetric energy densities in a rectangular form factor. The rectangular footprint makes the cell ideal for mounting in stacked PCB configurations and gives a flexible starting point for modular battery configurations ranging from 10Whr packs to 150Whr and beyond.

Clyde Space has extensive experience in designing and testing batteries based on lithium ion polymer pouches for LEO applications [1].

Consistency of cell build quality and performance was assessed via the lot acceptance process. Beyond this the cell responses to external and internal fault conditions as well as capacity retention with continuous cycling was characterised.

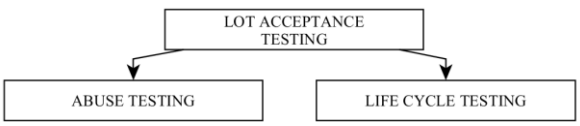

Figure 1. Test Overview for Cell Acceptance and Characterisation

2. LOT ACCEPTANCE TESTING

The lot acceptance testing was performed in accordance with Clyde Space's previously established test flow for cell lot acceptance procedures which was co-developed with ESA support. This testing comprises tests to characterise cell performance as well ensure build quality and consistency across the entire batch.

A total of 36 cells were randomly allocated from the lot for acceptance testing.

2.1 Physical Characteristics

The randomly selected cells were photographed and had their physical characteristics recorded and were visually inspected in order to flag any defects or build inconsistencies prior to further test. No concerns or abnormalities were identified at this stage and all initially selected cells progressed to active cycle testing.

Figure 2. Individual Varta Lithium Polymer Pouch Cell

2.2 Cell Discharge Capacity Assessment

Prior to further testing each individual cell was cycled at C/5 under ambient conditions in order to provide a representation of the expected capacity distribution for the entire lot. Each cell was charged via constant current to at C/5 to 4.2V and then charged at constant voltage until meeting a 10mA cut off. Discharge was performed by applying a constant current load of C/5 until reaching a programmed cut-off voltage of 3.0V.

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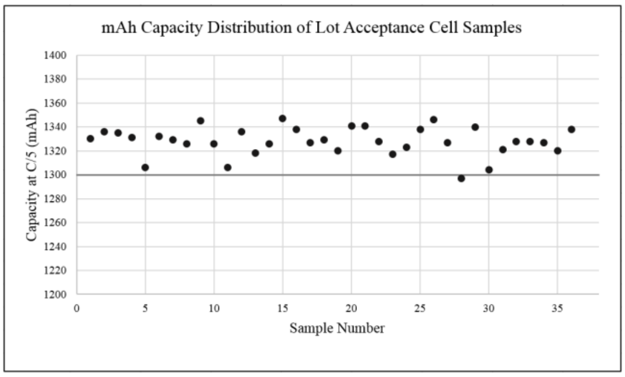

Figure 3. mAh Capacity Distribution of Lot Acceptance Cell Samples

The manufacturer's rated nominal capacity for the cells was 1300mAh at C/5, with a nameplate minimum capacity of 1250mAh. Any cells found to be outside these rated margins would be discarded and not used as part of the lot acceptance testing.

The results for the allocated lot acceptance samples gave a good grouping of recorded discharge capacity with all cells performing within the expected range.

2.3 Discharge Capacity Assessment versus Operational Temperature

Sixteen cells were allocated for testing of extractable cell capacity versus various environmental temperatures. For each of the test points given below the cell under test was subjected to three capacity cycles under a fixed discharge rate and temperature as described in Tab 1.

Test No.	Test Conditions (Discharge Rate, Temperature)	Measured Capacity Cycle 1 (mAh)	Measured Capacity Cycle 2 (mAh)	Measured Capacity Cycle 3 (mAh)
1	C/2, +40 °C	1303	1306	1298
2	C/2, +22 °C	1265	1257	1255
3	C/2, +0 °C	1196	1196	1194
4	C/2, -20 °C	865	832	796
5	C/5, +40 °C	1344	1338	1340
6	C/5, +22 °C	1329	1338	1335
7	C/5, +0 °C	1286	1292	1290
8	C/5, -20 °C	1135	1132	1128
9	C/10, +40 °C	1385	1383	1382
10	C/10, +22 °C	1342	1342	1342
11	C/10, +0 °C	1295	1294	1293
12	C/10, -20 °C	1183	1193	1193
13	C/15, +40 °C	1342	1340	1338
14	C/15, +22 °C	1349	1348	1345
15	C/15, +0 °C	1309	1309	1305
16	C/15, -20 °C	1208	1210	1217

Table 1. Measured Capacity versus Fixed Discharge Rate and Temperature

A graphical representation of the cell output voltage versus state of charge is given in Fig 5, Fig 6, Fig 7 and Fig 8.

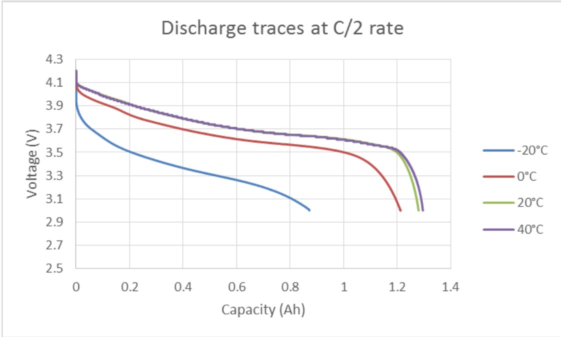

Figure 4. Discharge Slopes at -20degC, 0degC, 20degC and 40degC for a C/2 Discharge Rate

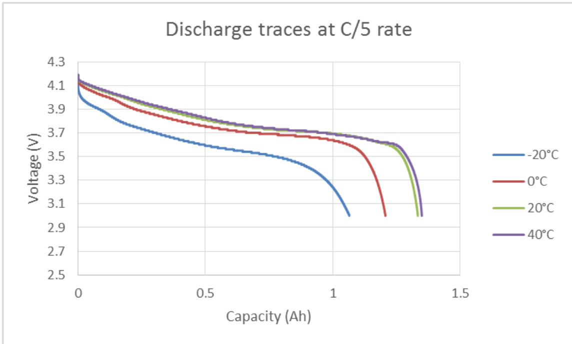

Figure 5. Discharge Slopes at -20degC, 0degC, 20degC and 40degC for a C/5 Discharge Rate

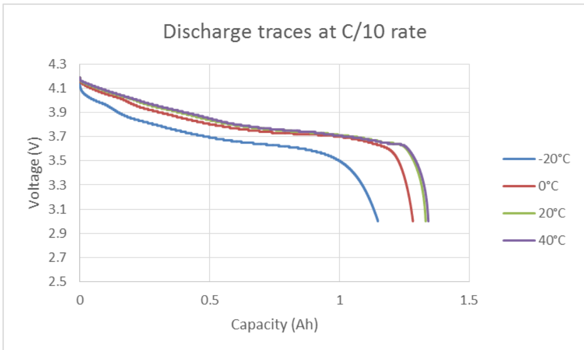

Figure 6. Discharge Slopes at -20degC, 0degC, 20degC and 40degC for a C/10 Discharge Rate

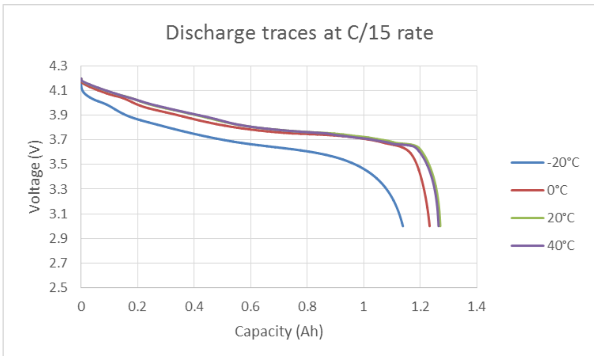

Figure 7. Discharge Slopes at -20degC, 0degC, 20degC and 40degC for a C/15 Discharge Rate

It can be seen that the cells exhibited very consistent

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output voltages for a given C rate across the range of temperatures under test.

Of particular interest are the experimental results for the cells cycled at -20°C conditions. This is known to be an operational region where cell capacity is poor for lithium ion cells due to several rate-limiting factors [2]. For cells tested at a discharge rate of C/5 or lower at -20°C the Ahr capacity was over 85% the nominal capacity available under ambient conditions.

For the cell cycled at C/2, -20 °C there is a perceptible reduction in cell capacity per additional discharge cycle even for the low amount of cycles performed.

Despite the reduced impact on usable capacity per cycle at higher discharge rates, due consideration to permanent cell lifetime will still have be given when discharging cells at high C rates – this has yet to be characterised.

3. ABUSE TESTING

The abuse testing performed was in order to support qualification of the cell to levels suitable for stowage on the ISS. This comprised tests of the cell-based electronic protection circuitry as well as forcing physical fault conditions within the cell itself. Fifteen cells were selected from the same lot as LAT testing.

Test Name	Description	Cell Allocation
External Short	Application of 10 mΩ load to cell for three hours to confirm short circuit protection.	3
Overcharge	Application of overcharge fault to cell to confirm safe activation of protection circuit.	3
Overdischarge	Overdischarge of cell at 1C to 0V to confirm safe overdischarge capability.	3
Simulated Internal Short Test	Physical crushing of cell along longitudal axis to generate internal short.	2
Heat-To-Vent	Cell temperature increased to 150°C and periodically ramped until thermal runaway.	2

Table 2. Cell Allocation for Abuse Testing

3.1 External Short, Overcharge and Overdischarge Tests

These tests were performed in accordance with NASA work instruction EP-WI-032 [3] with no catastrophic events. In all cases for the samples tested the electronic protection circuit cleanly activated when a fault condition was applied.

3.2 Simulated Internal Short Test

Each of the cells allocated for this test were compressed along the main body of the pouch between two flat plates in 2KN increments until a fault condition could be observed. For applied forces of up to 70KN both cells remained intact with no deviation in output voltage or pouch rupture.

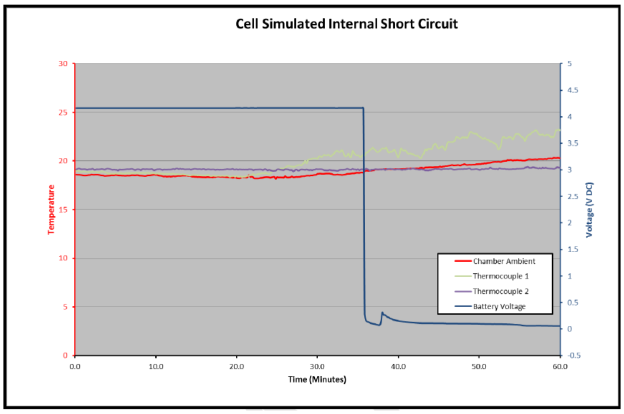

Figure 8. Internal Short Circuit for Sample 10

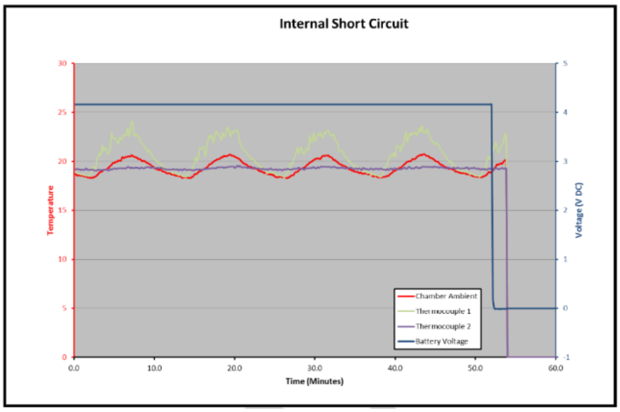

Figure 9. Internal Short Circuit for Sample 11

3.3 Heat-to-Vent

The allocated cells were placed within a thermal chamber with the chamber temperature adjusted every 30 minutes increasing the temperature increments from 66°C to 70°C then in steps of 5°C to 100 °C, the steps were then changed to 10°C steps until the cell under test went into thermal runaway (approx. 150°C) with resultant rupture and venting.

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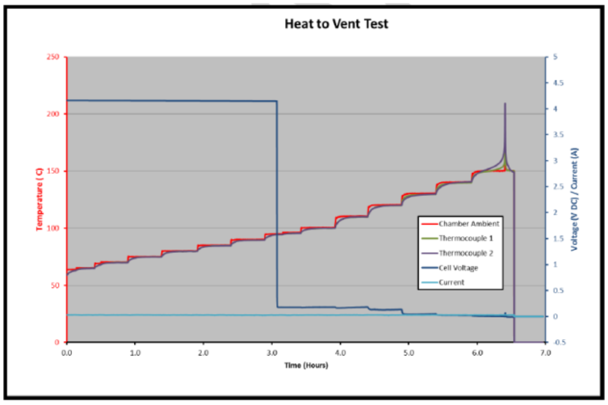

Figure 10. Heat to Vent for Sample 12

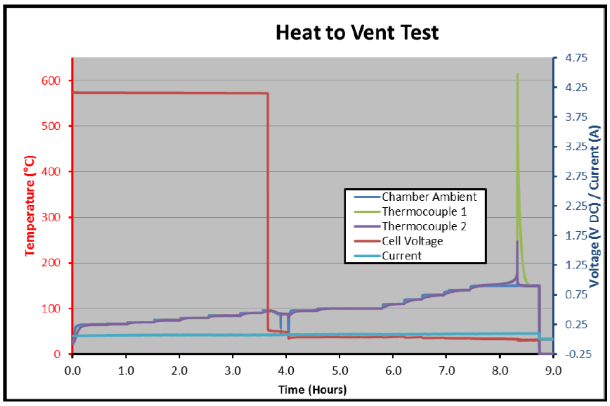

Figure 11. Heat to Vent for Sample 13

Both samples tested exhibited similar responses to the over temperature conditions. Not graphed above is the drop-out of the cell voltage from 4.2V to 0V for both samples at approximately 90°C. From the physical position of the cell fuse with respect to the cell tabs and cell voltage sense points this is believed to be caused by the low-side fuse melting and disconnecting the negative terminal at high temperatures.

Further physical analysis on the samples will be performed to confirm this.

4. LIFE CYCLING

Life cycling of the Varta cell is currently ongoing internally at Clyde Space in order to assess permanent capacity fade of the cells under continuous cycling conditions representative of typical depths of discharge, frequency and ambient temperatures for cubesat applications.

This is comprised of two parts; partial depth of discharge cycling representative of LEO conditions and full depth of discharge cycling to baseline the cells performance with respect to the manufacturer's datasheet parameters.

4.1. Full depth of Discharge Cycling

The cycle protocol consists of an alternating charge/discharge cycle operating between 0% and 100% depth of discharge at C/5. 100% depth of discharge is defined as the point at which the cell voltage reaches the lower 3V threshold.

For this test four cells were selected with varying initial capacities in order to assess if rate of capacity fade was tied to this parameter.

Cell	Initial Discharge Capacity (Ahr)	Initial Discharge Capacity (Whr)	Initial Charge Capacity (Whr)
CS105021	1.424	5.410	5.251
CS105025	1.384	5.184	5.314
CS105027	1.219	4.520	5.303
CS105059	1.272	4.903	5.228

Table 3. Cell Allocation for Full Depth of Discharge Cycling

At present the continuous full depth of discharge cycling has reached cycle 90. Fig. 12 shows the measured relationship between cell discharge capacity and cycle number; the results that widely deviate from the main trends are due to interruptions in the data collection.

This has been plotted versus the predicted capacity fade for this cell type.

The predicted capacity fade has been generated from the manufacturers datasheet which states an expected discharge capacity of >70% of C capacity after 500 cycles at C/5 and an expected discharge capacity of >80% of C after 300 cycles.

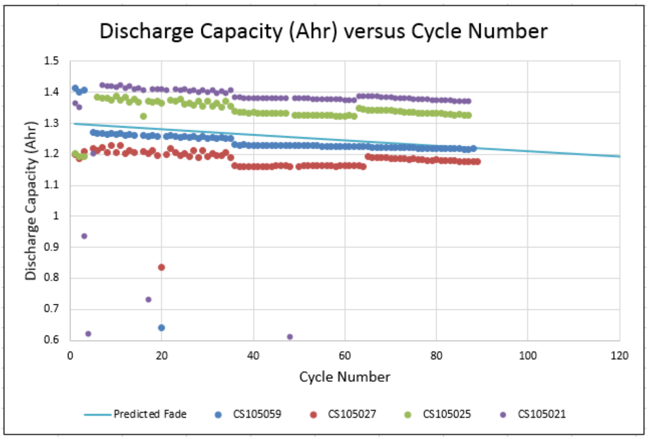

Figure 12. Discharge Capacity (Ahr) versus Cycle Number

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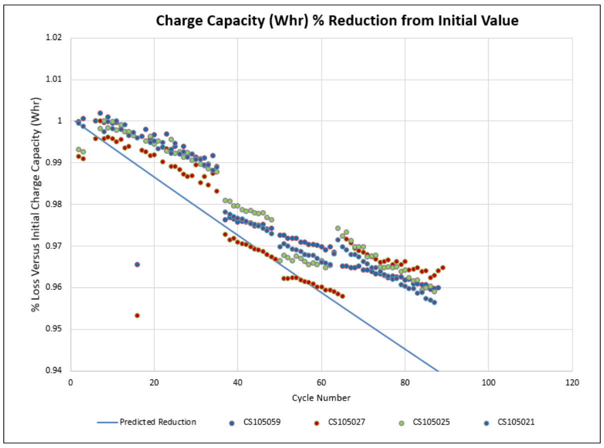

Figure 13. Percentage of Charge Capacity (Whr) Reduction versus Cycle Number

Fig. 13 shows the measured Whr charge capacity per cycle as a percentage of the initial Whr charge capacity for each cell. This is to compensate for the initial variation in cell capacities and assess the rate of change independent of initial capacity.

The "stepping" observed between cycle 40 and cycle 60 is due to an alteration in test setup which resulted in an additional voltage drop in the sense points used to calculate cell capacity. This did not alter the rate of capacity fade however did decrease the measured capacity with respect to the original value.

Outside of this the behaviour of the cells with respect to capacity fade was consistent despite the +/-10% variation in initial capacity for the cells tested. For the first 40 cycles and final 20 cycles the percentage loss per cycle is almost independent of the actual cell capacity.

Fig. 14 shows the change in voltage profile for CS105021 after 87 complete cycles to 100% DoD. The discharge curve for the final cycle with respect to the first exhibits an additional ohmic drop for the entire duration of the discharge period but otherwise the cut-off voltage of 3.0V is reached in a similar amount of time. This indicates that the measured capacity loss is mostly due to an increase in the internal cell resistance with depletion of active materials within the cell not yet playing a major part to capacity loss.

The cycle profile used for this test is to a much deeper depth of discharge than typical applications for these cells. Typically the target design maximum depth of discharge is 20% - the rate of capacity fade is therefore higher than for the cells in the full depth of discharge testing than is expected in a system designed with appropriate depth of discharge limitations.

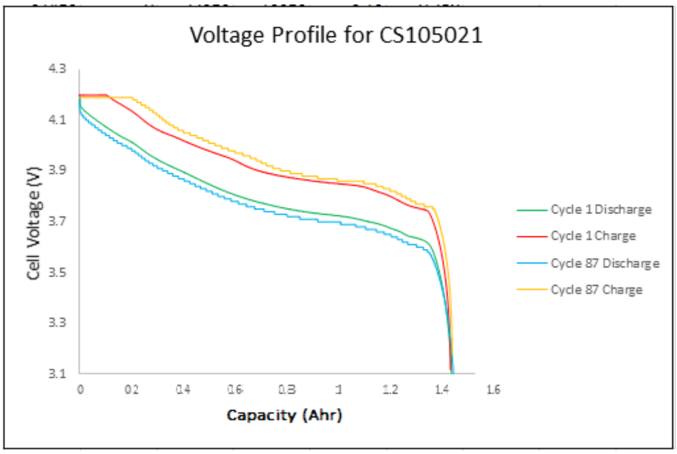

Figure 14. Comparison of Charge and Discharge Voltage Profile for CS105021 for Cycle 1 and Cycle 87

4.2. Partial Depth of Discharge Cycling

The partial depth of discharge testing is yet to commence but the method is included for reference purposes.

The cycle protocol consists of an alternating charge/discharge cycle operating between 0% and 20% depth of discharge at C/5. The 20% depth of discharge point is initially set by the nominal watt hour rating of the cell and will be fixed through the life cycle testing. Of particular interest is the drift with end of discharge voltage with continuous cycling.

Every 250 cycles a full charge and discharge cycle is performed to 100% DoD in addition to a resistance check performed via the current interruption method in order to assess the impact on overall cell capacity and quantify the cell internal resistance.

To provide a representative sample six cells will be cycled under identical conditions.

Item	Mechanical Configuration	Depth of Discharge Cut-Off	Discharge Rate	Ambient Temperature
1	Unconstrained 1s1p cell	20%	C/5	20°C
2	Unconstrained 1s1p cell	20%	C/5	20°C
3	Unconstrained 1s1p cell	20%	C/5	20°C
4	Unconstrained 1s1p cell	20%	C/5	20°C
5	Unconstrained 1s1p cell	20%	C/5	20°C
6	Unconstrained 1s1p cell	20%	C/5	20°C

Table 4. Cell Allocation for Partial Depth of Discharge Cycling

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5. CONCLUSION

Characterisation of the Varta cells capacity fade with response to continuous cycling is still ongoing at this time however a body of experimental data for cell performance as well as response to external and internal fault conditions has been generated.

The lot acceptance testing has shown good cell build consistency with respect to manufacturer's parameters as well as promising cell performance at low ambient temperatures.

The abuse testing shows that the cell-level protection circuit can reliably inhibit versus electrical fault conditions; this is of paramount importance for applications involving manned flight. Response to over temperature conditions show that the temperature required to trigger a thermal runaway and cell rupture scenario is well in excess of the cells operational maximum temperature of +50°C.

At present the individual cells have been utilised in a range of battery configurations from bespoke designs to modular cubesat variants.

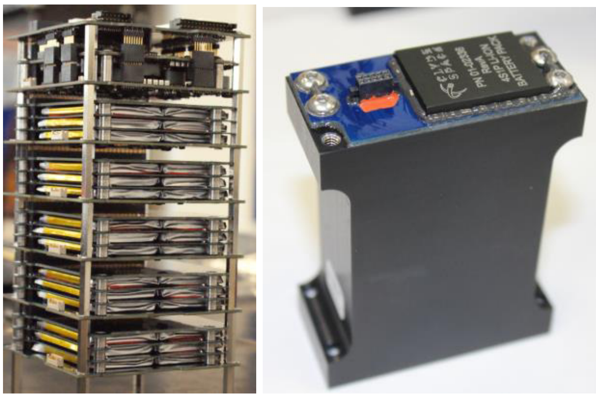

Figure 14. 150Whr Battery in 3s10p configuration (left). 20Whr Module in 4s1p configuration (right).

6. REFERENCES

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