ELSEVIER

Journal of Power Sources 80 (1999) 116–118

JOURNAL OF POWER SOURCES

Electrical and electrochemical performance characteristics of large capacity lithium-ion cells

G. Nagasubramanian [a,*], D. Ingersoll [a], D. Doughty [a], D. Radzykewycz [b], C. Hill [b], C. Marsh [c]

[a] Lithium Battery Research and Development Department 1521, Sandia National Laboratories, Albuquerque, NM 87185-061, USA
[b] Air Force Research Laboratory, Phillips Research Site, Kirtland Air Force Base, Albuquerque, NM 87117, USA
[c] Yardney Technical Products, 82 Mechanic Street, Pawcatuck, CT 06379, USA

Received 23 November 1998; accepted 1 December 1998

Abstract

We are currently evaluating large capacity (20–40 Ah) Bluestar (cylindrical) and Yardney (prismatic) lithium-ion cells for their electrical and electrochemical performance characteristics at different temperatures. The cell resistances were nearly constant from room temperature down to −20°C, but increased by over 10 times at −40°C. The specific energies and powers, as well as the energy densities and power densities are high and did not reach a plateau even at the highest discharge rates tested. For example, the prismatic lithium-ion cells gave close to 280 Wh dm^{-3} from a 4 A discharge and 249 Wh dm^{-3} at 20 A, both at room temperature. For the same current range the specific energy values were 102 Wh kg^{-1} and 91 Wh kg^{-1}. Cycle life and other electrical and electrochemical properties of the cells will be presented. © 1999 Elsevier Science S.A. All rights reserved.

Keywords: Lithium-ion rechargeable cells

1. Introduction

Since Sony Energytec introduced the first commercial lithium-ion cell in 1991, the rechargeable lithium-ion battery market has been increasing at an accelerating rate. Because of the high energy (~120 Wh kg^{-1}, ~380 W dm^{-3}) lithium-ion batteries are finding widespread use in a variety of devices including computers, cellular phones, etc. and are being proposed for use in military, space and electric-vehicle applications. At Sandia National Laboratories we have currently an active programme to evaluate small capacity lithium-ion cells for different applications including robotics [1]. Encouraged by the recent advancements made by the USABC and PNGV (partnership for the new generation of vehicles) in the area of large lithium-ion cells for automotive applications, the US military and NASA (National Aeronautics and Space Administration) are jointly developing large capacity lithium-ion cells for aircraft and spacecraft applications. Together with the Air Force Philips Laboratory, Sandia is evaluating the energy and power characteristics of the lithium-ion cells that we are receiving from the contracts.

2. Experimental

Before welding tabs to the cells for electrical connections, both their weights and physical dimensions were measured. These weights and the computed cell volumes

Table 1
Lithium-ion cells and their physical characteristics

Cell type	Number tested	Weight (g)	Volume (dm^3)
Cylindrical (Bluestar)/Design 1	2	771	0.4
Cylindrical (Bluestar)/Design 2	5	1192	0.55
Prismatic (Yardney)	5	943	0.34

* Corresponding author. Tel.: +1-505-844-1684; Fax: +1-505-844-6972; E-mail: gnagasu@sandia.gov

PII: S0378-7753(98)00255-9

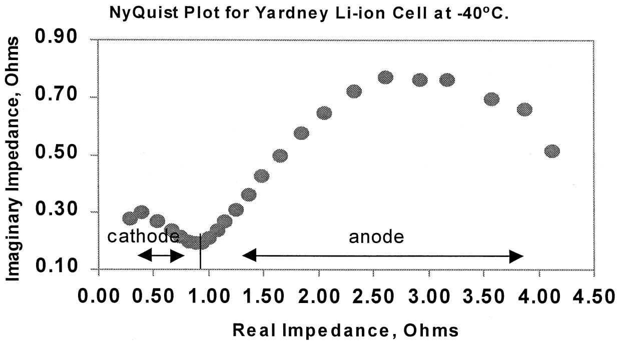

Fig. 1. NyQuist plot for Yardney lithium-ion cell at −40°C.

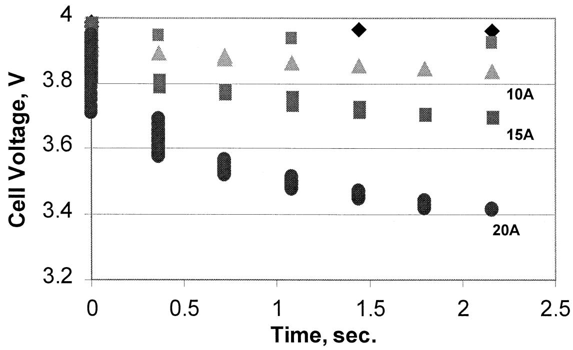

Fig. 3. Voltage drop at 0°C as a function of time for different pulse currents.

are listed in Table 1. PAR electrochemical impedance spectroscopy instrumentation and software (Model 273A potentiostat, FRA 1255 and M398 software) was used to collect impedance and pulse discharge data, and an Arbin battery cycler (Model BT2042, College Station, TX) was used to cycle the cells either galvanostatically (constant charge/discharge currents) or potentiostatically. Cell temperatures during tests were controlled with a Tenney Jr. temperature chamber (benchtop model, Union, NJ). The energy and power (for Ragone data) were computed from the discharge data as follows.

Every discharge curve has over 2000 points. Each point corresponds to a voltage. To obtain energy, each voltage is multiplied by the product of discharge current and the time before the voltage jumps to the next voltage. This procedure is repeated for each voltage and the results are summed together. This gives the total delivered energy during discharge. For discharge power, the voltage is multiplied by the discharge current and the results are summed together and averaged over the number of points.

3. Results and discussion

In Table 1, the type and number of cells used in this study are given, along with their respective weights and volumes. In Fig. 1 is shown a NyQuist plot for the Yardney prismatic lithium-ion cell at −40°C. The loop in the high frequency regime belongs to the cathode and the one at the lower frequency regime is attributed to the anode [2,3]. The plot shows that the contribution to the total cell impedance from the anode and in particular the solid electrolyte interphase (SEI) layer on the carbon anode is significant [4]. Christie et al. [4] have shown that the impedance of the passivating layer on a coke surface increases from 20 Ω (at room temperature to 100 (at 0°C). The effect of this observation on practical applications is that at low temperatures the impedance of the SEI layer may limit the performance of the lithium-ion cell. Similar results were obtained for the Bluestar lithium-ion cells.

Fig. 2 plots power density against energy density for at different temperatures and charge/discharge currents. As expected, the energy decreases with decreasing temperature and at −20°C the cell delivers very little energy during 16 A and 20 A discharges. The Bluestar cells showed similar behaviour. In Fig. 3 are shown the voltage drops for different pulse-currents for Yardney cells at 0°C, while Fig. 4 are the drops at −20°C.

The plots in Figs. 3 and 4 show that the voltage drop increases with pulse current amplitude, and at −20°C the

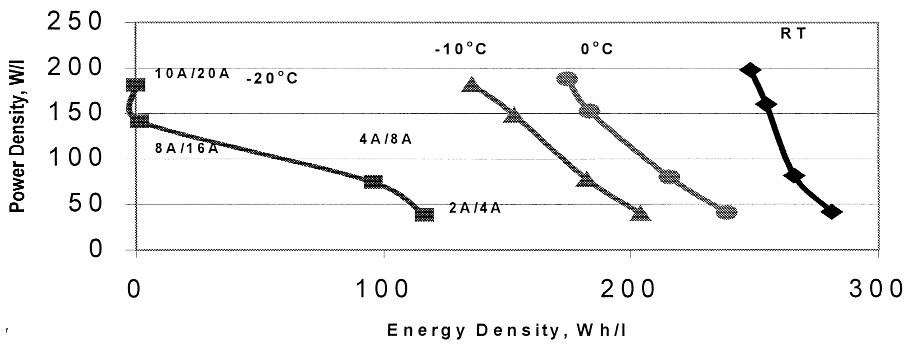

Fig. 2. Ragone data for Yardney lithium-ion cell at different temperatures.

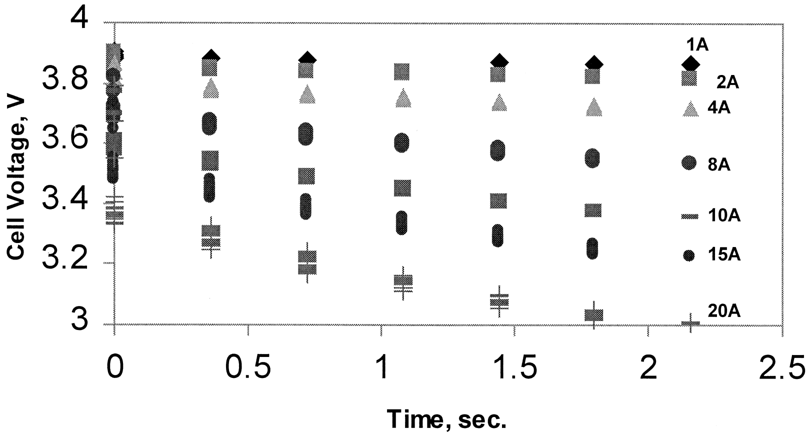

Fig. 4. Voltage drop at -20°C as a function of time for different pulse currents.

Table 2
Impedances of the BlueStar (Design 1) 22 Ah cells

Temperature (°C)	Total cell impedance a.c. (mΩ)	Total cell impedance from volts drop (mΩ)	Ohmic resistance from a.c. (mΩ)
−40	502	505	193
−30	195	197	85
−20	50	68	40
−10	47	43	30
0	30	36	19

voltage drop is higher than at 0°C for the same value of current. For example, at 0°C and a 20 A pulse the voltage drop at 2.25 s is around 0.6 V, whereas the voltage drop at -20°C is about 1 V for the same current and time. These plots also indicate that the polarization resistance (proportional to the slow voltage decay) is non-trivial. This observation is in line with the impedance results discussed above.

In Table 2 is given the resistances obtained from both a.c. and voltage drop measurements for Bluestar (Design 1) 22 Ah cells at different temperatures. The total impedance values obtained from a.c. and voltage drop measurements are comparable.

4. Conclusions

Electrochemical and electrical performance characteristics have been measured for large capacity cylindrical (Bluestar) and prismatic (Yardney) lithium-ion cells at different temperatures. The cell impedance increases at lower temperatures. The room temperature performance of the cells is respectable. However, at sub-ambient temperatures the delivered energy decreases and at -20°C the discharge energy is negligible. Generally, the cell resistance computed from the voltage drop is comparable to the total cell resistance obtained from the a.c. impedance measurements, both at ambient and sub-ambient temperatures.

Acknowledgements

Sandia National Laboratories is a multiprogram laboratory operated by Sandia, a Lockheed Martin, for the United States Department of Energy under contract DE-AC04-94AL85000. We are grateful to D.R. Bradley for performing the electrochemical measurements.

References

[1] G. Nagasubramanian, R. Jungst, J. Power Sources 72 (1998) 189.
[2] K. Ozawa, Solid State Ionics 69 (1994) 212.
[3] M.J. Isaacson, M.E. Daman, R. Hollandsworth, Proc. 32nd Intersociety Energy Conversion Engineering Conference 1 (1997) 31.
[4] L. Christie, A.M. Christie, C.A. Vincent, 9th International Meeting on Lithium Batteries, Edinburgh, UK, 1998, p. 80.