Available online at www.sciencedirect.com
SCIENCE DIRECT®
Journal of Power Sources 136 (2004) 317–321
JOURNAL OF POWER SOURCES
www.elsevier.com/locate/jpowsour

Performance and electrochemical characterization studies of advanced high-power bipolar nickel/metal hydride batteries

Martin Klein [a], Michael Eskra [a], Robert Plivelich [a], Alvin J. Salkind [b,*], J. Ockerman [b]

[a] *Electro Energy Inc., 30 Shelter Rock Road, Danbury, CT 06810, USA*
[b] *School of Engineering, Center for Energy Storage Materials and Engineering, Rutgers University, 98 Brett Road, Piscataway, NJ 08854, USA*

Available online 4 June 2004

Abstract

This paper addresses recent activities relating to energy storage systems capable of delivering very high power. Specific power in the range of 2.0–2.2 kW/kg and power density in the range of 5.0–6.5 kW/l were obtained at current densities of 0.43–0.86 A/cm^2 (400–800 A/ft^2). The designs incorporate the use of thin, plastic bound electrodes laminated to nickel foil substrates. The units tested were nominal 28 V, 24 Ah batteries, as well as individual cells.
© 2004 Published by Elsevier B.V.

Keywords: Applications; Hybrid vehicles; Space vehicles; Nickel; Metal hydride batteries

1. Introduction

Studies of EEI advanced bipolar nickel/metal hydride batteries previously reported [1,2] discussed the fabrication, design, and testing for performance, life cycling, and electrochemical dynamic properties at intermediate power levels. These mainly related to hybrid vehicle and aerospace pulse power applications. These designs have successfully completed over 30,000 deep cycles and the equivalent electrical circuit models were determined using ac impedance spectroscopy and fuzzy logic modeling techniques [3].

The EEI bipolar nickel/metal hydride battery design incorporates the use of thin, plastic bound, electrodes laminated to nickel foil substrates as a departure from classical cylindrical or prismatic electrode packaging techniques. A sketch of this design is shown in Fig. 1.

Individual flat wafer cells are constructed with outer contact faces, containing one positive electrode, a separator and one negative electrode. The contact faces serve to contain the cell and make electrical contact to the positive and negative electrodes. The contact faces are sealed around the perimeter, with an insulating seal, to contain the potassium hydroxide electrolyte. To fabricate a multi-cell battery, identical cells are stacked one on top of each other such that the positive face of one cell contacts the negative face of the adjacent cell making a series connected battery. The current is collected at the ends of the cell stack. Structural integrity for the cell stack is obtained by housing the stack in an outer container, which holds the cells in compression.

This battery design has several advantages. The need for conventional terminals, tabs, current collectors, and cell containers is eliminated. Use of available space is maximized, and the headspace for tabs and terminals required in conventional cells is eliminated. The current path in the electrodes and from cell to cell is minimized, since the current flows normal to the plane of the electrodes. Battery impedance is reduced, making this design particularly effective for high rate, power applications.

The wafer stack design has excellent thermal conductivity in the planar direction due to the metal foils in the wafer cell that aid thermal management. Compared to conventional cylindrical and prismatic packaging designs, the use of plastic bonded electrodes offers considerable reduction potential in cost and volume.

2. Design and data

Several cells were produced under a DOE pulse power program (SNL series). The cell electrode area was 6″ × 12″

* Corresponding author. Tel.: +1-732-445-6858; fax: +1-732-445-1669.
E-mail address: salkind@rci.rutgers.edu (A.J. Salkind).

0378-7753/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.jpowsour.2004.03.044

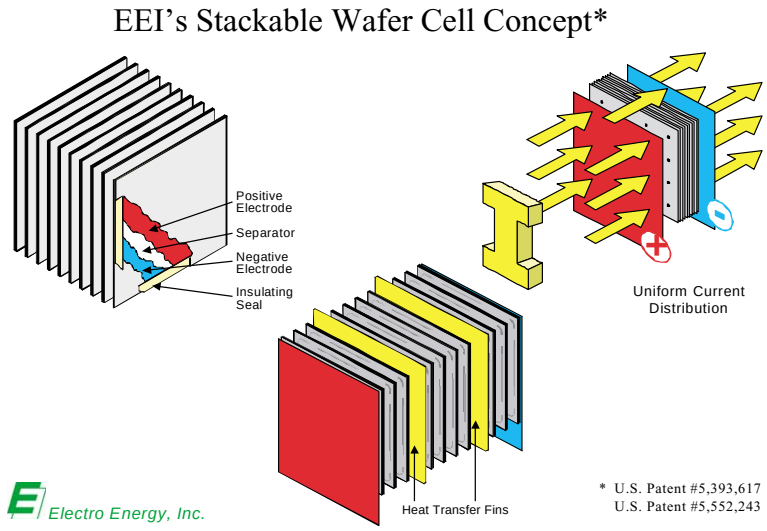

Fig. 1. Schematic depicting a battery constructed of bipolar wafer cells.

(approximately 150 mm × 300 mm), and the theoretical capacity was 6.48 Ah. All cells were tested in a sealed configuration at 50% SOC. The test for high discharge power capability at various current densities (ranging from 200 to 1000 ASF) was conducted in the following way:

- Discharge of the cell at C/3 rate to 0.8 V.
- Charge of cell to 50% SOC (3.24 Ah charge input).
- 3 h stand.
- Discharge of cells at various currents to a discharge cut-off of 0.6 V (for most testing), or 0.3 V (for 450, 500 A tests).

3. Pulse testing results

The cells were consistently able to sustain a 10 s discharge at currents up to 300 A (Fig. 2).

Discharges up to about 450 A for 1 s to 0.6 V appear to be possible. In terms of specific power, levels up to 2 kW/kg were observed with 10 s data, while the maximum 1 s power density appears to be about 2.2–2.4 kW/kg (Figs. 3–6).

On a volumetric basis, this corresponds to 5.0–6.5 kW/L. This power level occurs at discharge currents of 300–400 A. The specific energy figures were calculated on a basis of 125 g per cell weight, and cell dimensions of 6 in. × 12 in. × 0.037 in. (152 mm × 305 mm × 0.95 mm).

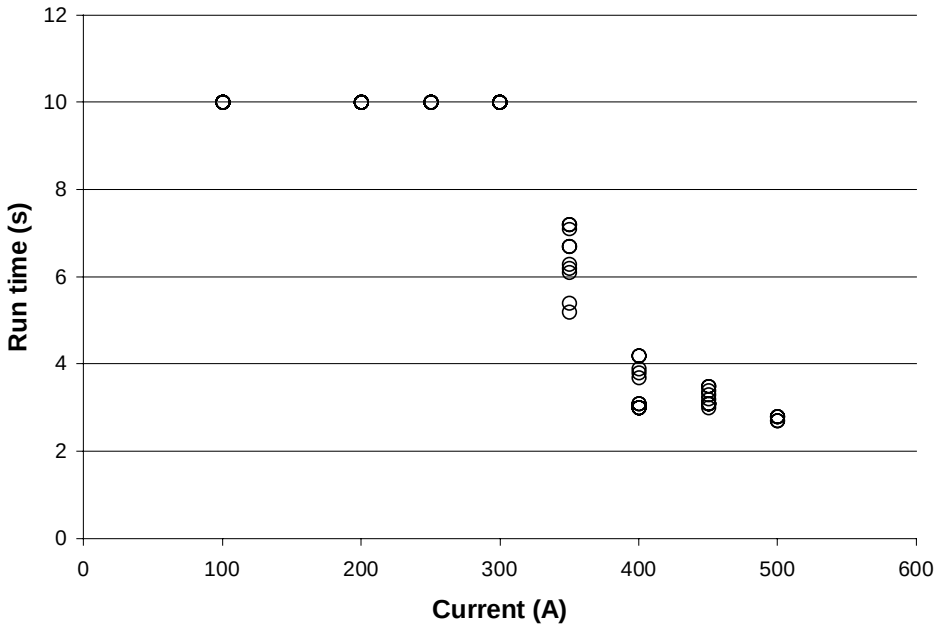

Fig. 2. Total runtimes (450 and 500 A runs are to 0.3 V, others are to 0.6 V) at various discharge currents. Starting SOC was 50%.

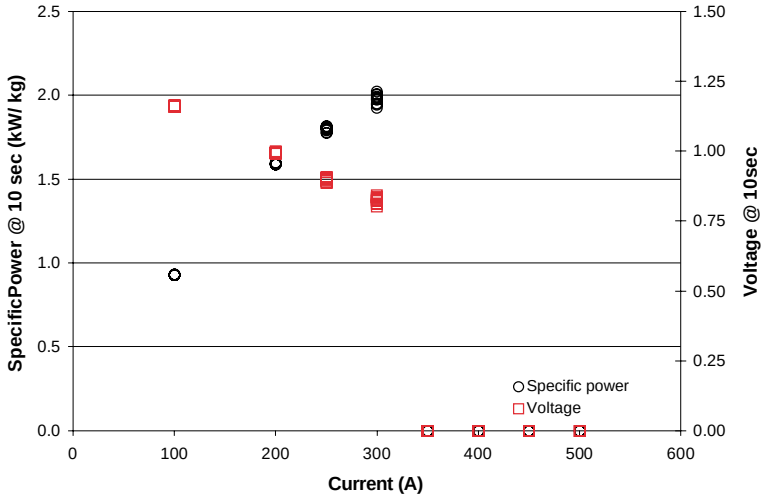

Fig. 3. Power capability at the end of a 10 s discharge on a gravimetric basis. Starting SOC was 50%.

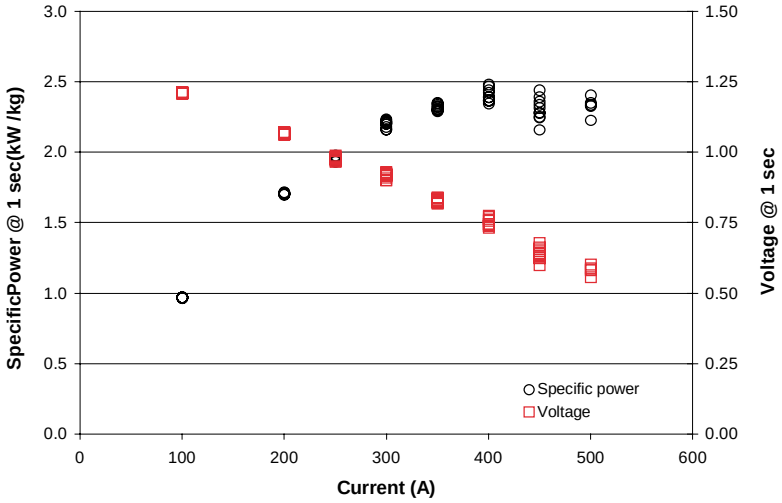

Fig. 4. Power capability at the end of a 1 s discharge on a gravimetric basis. Starting SOC was 50%.

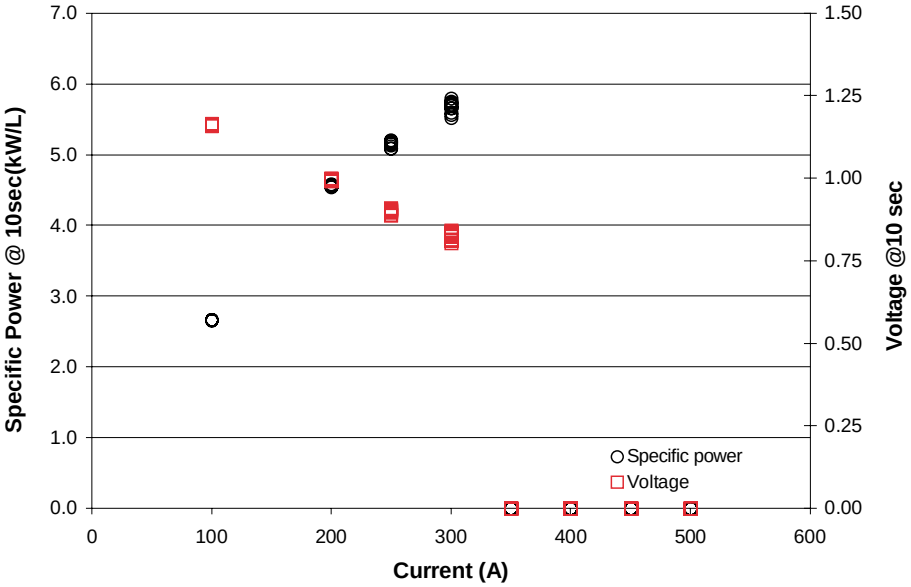

Fig. 5. Power capability at the end of a 10 s discharge on a volumetric basis. Starting SOC was 50%.

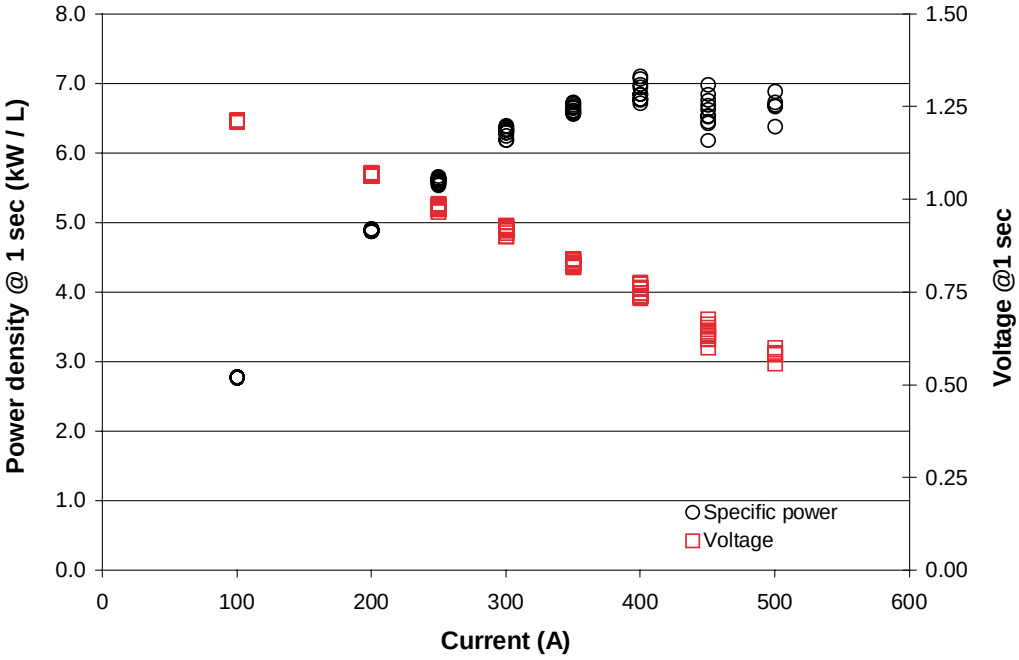

Fig. 6. Power capability at the end of a 1 s discharge on a volumetric basis. Starting SOC was 50%.

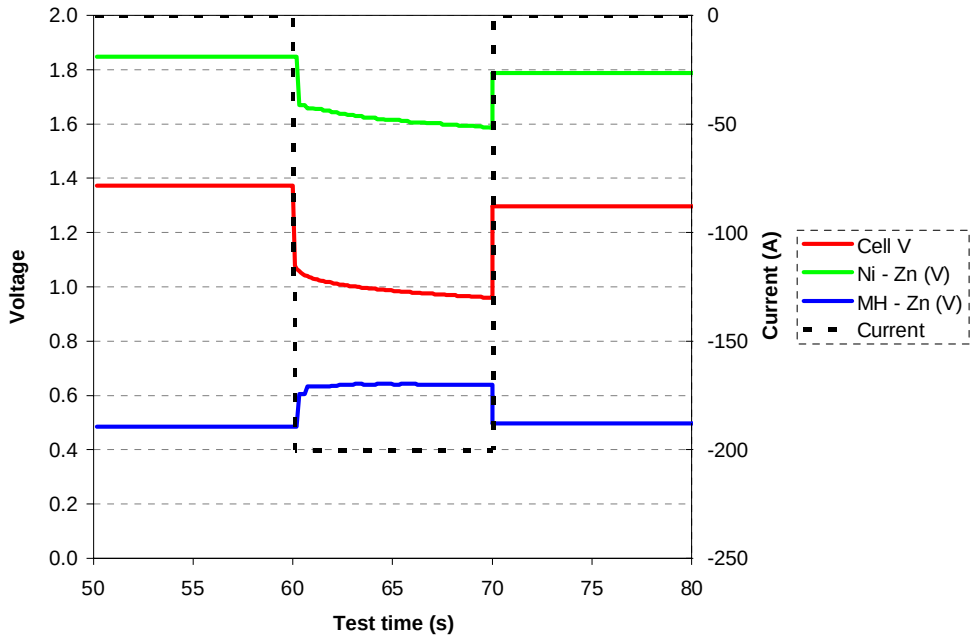

Fig. 7. 200 A discharge data (flooded configuration) using a zinc reference.

4. Reference electrode diagnostics

It is of interest to identify which of the electrodes is limiting under these discharge conditions. Fig. 7 is a plot of a 200 A/50% SOC discharge conducted in a flooded configuration using zinc metal as a reference. The plot shows that the nickel oxide electrode is primarily responsible for the observed polarization, the metal hydride versus zinc trace is relatively flat during the discharge. This suggests to us that to obtain even greater power, one must either reduce the overall cell ohmic resistance, or reduce the polarization in the nickel electrode (that is, non-ohmic polarization in the negative electrode does not seem to be a problem in this design).

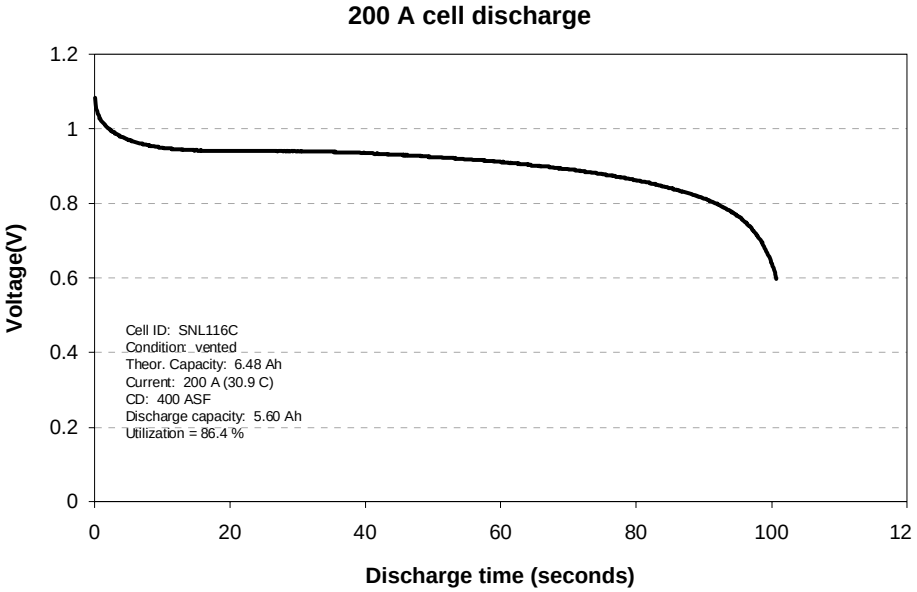

Fig. 8. 200 A discharge data (flooded configuration) starting at 100% SOC.

5. Deep discharge behaviour at high powers

Additionally, it is conceivable that deep discharge applications may arise at high power levels. Fig. 8 shows the discharge of a cell in the flooded configuration starting fully charged. The current used was 200 A (about 31 C based on a theoretical capacity of 6.48 Ah), and a utilization of 86% of theoretical was measured.

6. Summary

This work presents data that shows that the EEI bipolar wafer cell construction is capable of high power. Data related to both pulsing loads as well as deep discharges were presented. Future work will focus on scaling the single cell results to multicell batteries.

Acknowledgements

The authors would like to thank the generous support of the US Department of Energy for the work described herein.

References

[1] R. Plivelich, M. Eskra, Pulse Power Nickel Metal Hydride Battery, in: Proceedings of the Conference of the 2002 Power Systems Society of Automotive Engineers, Coral Springs, FL, October 2002.
[2] M. Klein, S. Viswanathan, in: Proceedings of the 38th Power Sources Conference of BiPolar Nickel Metal Hydride BB390/A, Cherry-Hill, NJ, June 1998, pp. 106–110.
[3] A.J. Salkind, C. Fennie, P. Singh, T. Atwater, D. Reisner, Determination of state-of-charge and state-of health of batteries by fuzzy logic methodology, J. Power Sources 80 (1999) 293–300.