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High Performance Lithium Ion Aircraft Battery for DoD Platforms

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ABSTRACT

This paper describes a development project at Electro Energy designed to develop a high performance aircraft battery which will be suitable for use in many DoD aircraft platforms. The goal is to provide a safer high energy and power battery for aircraft energy storage systems. Aircraft batteries used on military aircraft battery platforms have a low reliability and require significant maintenance and as a result have significant costs associated with them beyond the initial procurement cost. It is desirable to develop state of the art aircraft batteries which have high reliability and minimal maintenance costs. Lithium ion cells can be employed to produce a lithium ion aircraft battery which will have significant advantages over the present nickel cadmium and lead acid aircraft batteries. The lithium ion battery will have higher specific energy, increased energy density, improved cycle life, and lower maintenance requirements. Prior projects with Electro Energy Inc. have shown increased low temperature performance and better capacity per unit volume and weight.

The relationship between electrode parameters and the discharge performance of high rate batteries has been discussed previously in characterizing the rate capability of the $LiCoO_2$ electrode by Abraham et al (Discharge Rate Capability of the LiCoO2 Electrode", J. Electrochem. Soc., 145, 482, 1998). The cathode material $LiNi_{0.33}Mn_{0.33}Co_{0.33}O_2$ (NMC) has been identified as an excellent candidate for development of a robust positive electrode. NMC has the potential to provide a superior safe high rate cathode compared to $LiCoO_2$. The proper parameters to achieve optimum compaction for the electrode while leaving adequate porosity in the electrode structure for electrolyte penetration and wetting is also critical to the development of a high performance lithium ion aircraft battery. This development project includes a review of anodes, cathodes, electrolytes, additives, compositions and manufacturing processes in a wafer cell battery configuration to meet the performance requirements of DoD aircraft batteries. Cathode materials were evaluated from three different suppliers and particle sizes from 4 to 10 microns were tested for energy storage and power density. Investigations were conducted on the effects of particle size of the electrode materials and thickness of the electrode on rate capability. An initial design for a 28 volt module and 270 volt aircraft battery has been developed. Test data shows that it will be possible to achieve the initial technical objective of this effort which is to develop a lithium ion cell that will meet the aircraft battery requirements, including fast discharge and recharge over the DoD operating temperature range.

INTRODUCTION

Batteries are used as a DC power source for various functions aboard the military aircraft, such as auxiliary power unit for starting, canopy operation, refueling operations, lighting, emergency power, fight control backup or a combination of functions. There is always a demand to reduce weight on the aircraft while not sacrificing performance. To meet the demands of aircraft applications, EEI has begun to develop an aircraft battery that is smaller, lighter, more powerful, has increased life, has uncompromised safety characteristics and is competitively priced compared to today's battery technology[1,2,3,4]. In this effort, EEI has sought to improve all aspects of a standard Li-ion cell, and battery module and pack design.

EEI'S HIGH POWER CELL

High power Li-Ion cells, which exceed 120 Wh/kg at the cell level have been constructed. Cells are constructed with a $LiNi_{0.33}Co_{0.33}Mn_{0.33}O_2$ (NMC) cathode and a meso carbon micro bead (MCMB) graphite anode. These cells demonstrated continuous discharge power up to the 30 C-rate with >75% capacity utilization, and the ability for >50 C-rates pulse discharges. Typical discharge curves are presented in Figure 1.

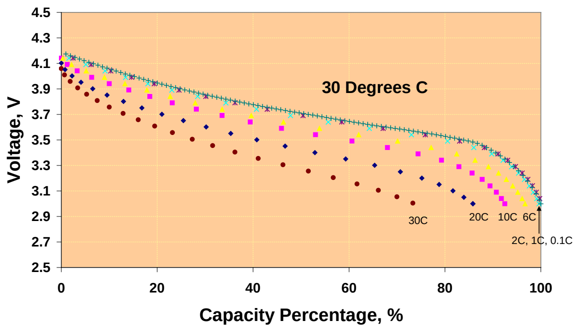

Figure 1. Discharge curves for a high power Li-Ion wafer cell with NMC cathode at different C-rates.

The rate capability of EEI's 5 Ah Li-Ion cell is compared in Figure 2 with high power commercial 26650 Li-Ion cells based on the $LiMn_2O_4$ and $LiFePO_4$ cathodes (3,4). EEI's cell has demonstrated power densities of 1-3 kW/kg with specific energies 70–125 Wh/kg. The performance of EEI's cell exceeds that of commercial cells.

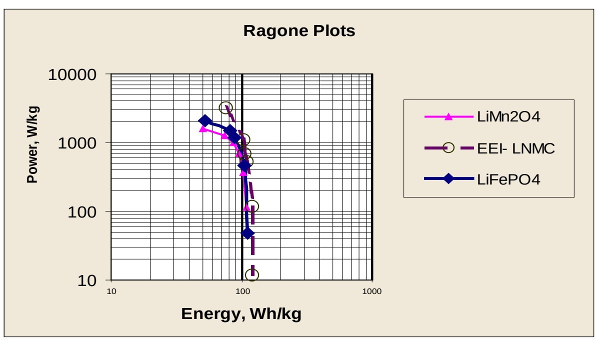

Figure 2. Ragone plots for EEI's 5 Ah NMC cell and commercial 26650 cells with LiFePO4 and $LiMn_2O_4$ cathodes. The data represent continuous discharges

Figure 3 depicts the cycle life of the wafer cells. The cells cycling at room temperature demonstrated more than 1500 cycles at full depth of discharge. A wafer cell utilizing NMC has significantly higher thermal stability, and as a result better safety characteristics and longer cycle life than cells made with conventional lithium cobalt oxide.

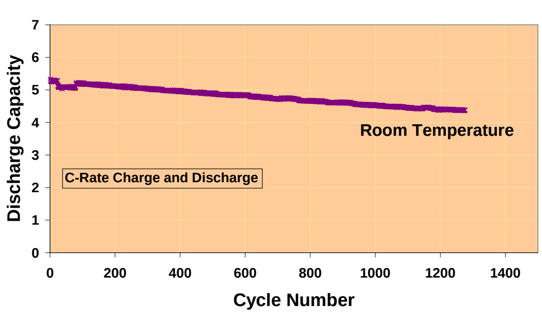

Figure 3. Cycle life of EEI Li-ion cell cycled at C- rate and room temperature

EEI has also begun to look at shallow cycling of its high power wafer cells (Figure 4) The 1.5 Ah cell is cycling at room temperature at 30% DoD with a charge voltage limit of 4.2V.

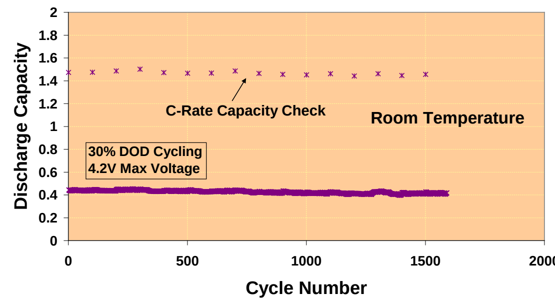

Figure 4. Cycling of EEI's high power wafer cell at 30 % DOD

In an effort to extend cycle life further, EEI has begun to study the failure mechanism impeding long term cycling. The graphitic anode contributes largely to the overall cycle life of Li-ion cells. To improve the cyclability of Li-ion cells, we added stabilized lithium metal powder to the anode. The stabilized lithium serves to replenish lithium lost to reactions within the cell. Cycle life increased when using a 1:1 molar ratio of lithium to graphite (Figure 5). This data illustrates that the NMC cathode is capable of very long cycle life.

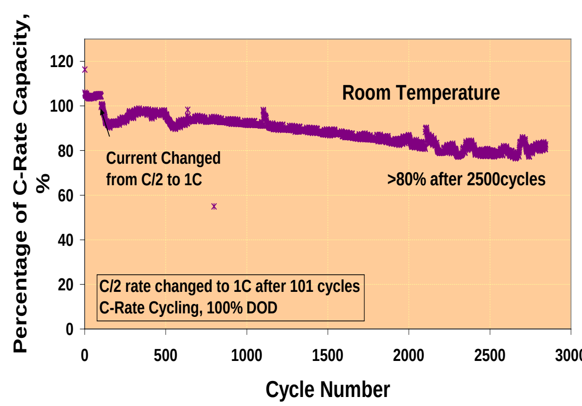

Figure 5. Cycle retention of NMC/Li rich anode

The discharge curves for the standard Li-ion cell and the Li rich cell vary slightly. The Lithium rich cell has a slightly flatter discharge voltage and a steeper end of discharge as depicted in Figure 6.

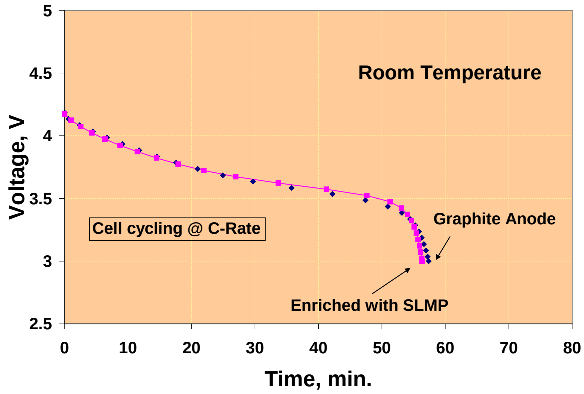

Figure 6. Discharge curves of NMC/ graphite and NMC/ SLMP+graphite cell

To lower the overall lithium in the Li rich graphite anode, we have begun to test cells with anodes having a 1:2 Li:graphite molar ratio as Figure 7 shows.

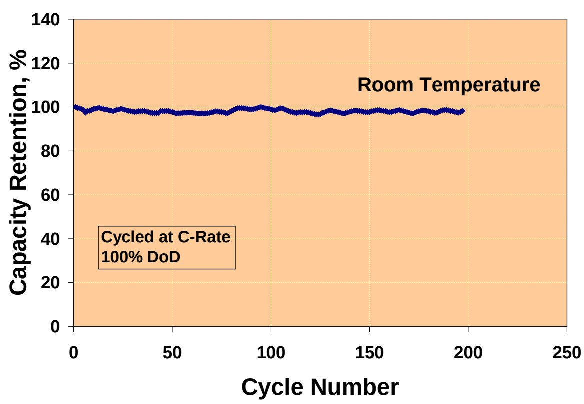

Figure 7. Capacity retention of Li/graphite cell with a Li:graphite ratio of 1:2.

Figure 8 shows the cycle life of several cells with and without a modified anode. The baseline NMC/graphite cell cycled to 1500 cycles. Using a 1:1 Li:graphite molar ratio in the anode increases cycle life to nearly 4000 cycles. Using a 1:2 molar ratio behaves similar to the 1:1 cells thus far.

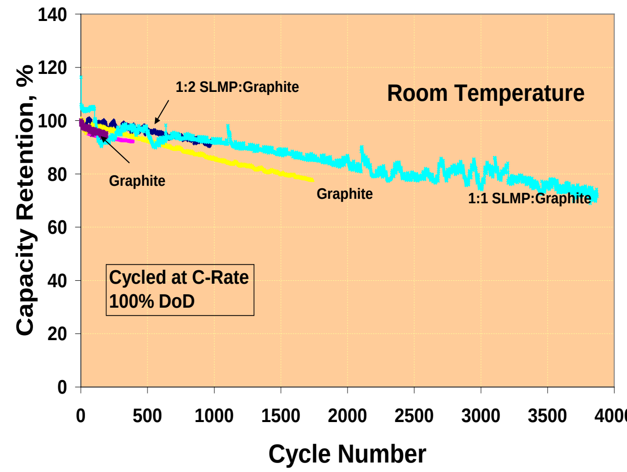

Figure 8. Comparison of capacity retention for various cells cycled with alternative anodes.

AIRCRAFT BATTERY TESTING

As a development baseline, EEI has done a preliminary battery design that would be capable of meeting and exceeding the requirements of the F-22 aircraft battery. The battery specifications for the F-22 aircraft battery are listed below in Table 1.

Table 1. Current Specifications for F-22 battery

Table 1	
Nominal Voltage, V	28
Capacity, Ah	See load profile
Energy, Wh	See load profile
Volume, liter	17.0
Weight, kg	<20.8

The wafer cell building block for this battery has a nominal voltage near 3.6 V and a capacity of 5 Ah. The cell weight is 150g. The JSF battery is built from 2 modules connected in series each having a nominal voltage of 14V and a capacity of 20 Ah. Each module has sixteen 3.6 V, 5 Ah cells in a 4s4p configuration. The specifications of the battery module are given in Table 2.

Two modules, each 14V and 20 Ah, would be connected in series to form the nominal 28 V / 20 Ah battery pack with an energy content of 576 Wh. The energy density of the proposed battery pack is 170 Wh/l and its specific energy is 110 Wh/kg. Additional details of the module and the battery pack are given in Tables 2 and 3.

Tables 2 and 3. Proposed Li-Ion Aircraft Module and Battery Pack Specifications

Table 2		Table 3	
No. of Cells	16	No. of Modules	2
Nominal Voltage, V	14	Nominal Voltage, V	28.
Capacity, Ah	20	Capacity, Ah	20
Energy, Wh	288	Energy, Wh	576
Volume, liter	1.40	Volume, liter	< 3
Weight, kg	2.4	Weight, kg	< 5
Dimensions, cm	TBD	Dimensions, cm	TBD
Specific Energy, Wh/kg	120	Specific Energy, Wh/kg	> 100
Energy Density, Wh/l	210	Energy Density, Wh/l	> 170
Specific Power, kW/kg	>2	Specific Power, kW/kg	>1

The battery pack would have a proposed power density greater than 1 kW/kg, which would allow the battery to provide continuous power of more than 5.7 kW. Our battery pack has a total energy of about 576 Wh.

EEI has built and tested 1.6 Ah wafer-cells for simulated testing in an F-22 aircraft battery. The test regime was normalized to a 28.8V/ 20 Ah battery as proposed. The test regime called for several continuous >5 C-rate draws, as well as >8 C-rate current spikes. EEI's high-rate wafer cells passed the regime easily at 23 degrees C as Figure 9 shows. The end of discharge voltage was 3.9 V, more than a volt higher than the 2.8 V lower voltage cutoff. The cell was able to handle the rates with little polarization, and gain much of the capacity back at the two allotted recharge steps.

Cells underwent the same test regime at -20 degrees C as part of the aircraft specification. Even with the severe temperature, the cells did not go below the 2.8 V cutoff voltage as illustrated in Figure 10. The end of discharge voltage was 2.94 V, 14 mV higher than the specification. In addition, the test was run on a single cell normalized to a full battery design. This design provided no allowance for higher self-heating which will occur in a full size battery. This test is therefore considered as a worst-case scenario.

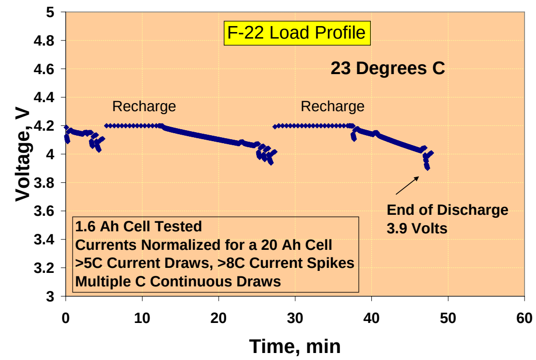

Figure 9. High rate wafer tested using F-22 test regime at room temperature. 1.6 Ah cell normalized to 20 Ah

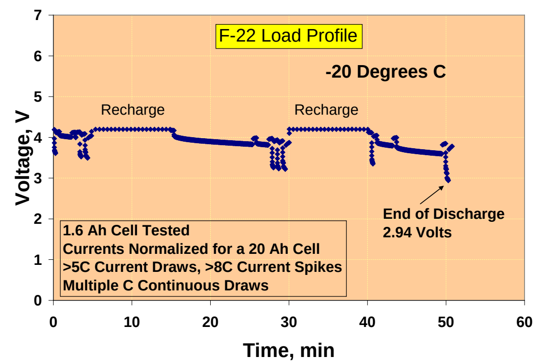

Figure 10. High rate wafer tested using F-22 test regime at -20 degrees C. 1.6 Ah cell normalized to 20 Ah

CONCLUSIONS

Electro Energy has developed a high power Li-ion battery that meets the performance requirements of the USAF F-22 aircraft battery. The battery has a number of other potential applications including power tools, HEV and PHEV.

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