High Energy Primary Technology Development

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Abstract

This paper covers EaglePicher Technologies, LLC (EPT) high energy primary technology. The lithium carbon-monofluoride (Li/CF_x) D-cell is a proven option for high-energy, low maintenance applications. EPT web-coated Li/CF_x -MnO_2 hybrid chemistry in multiple cell formats is used in applications with a focus on portable power. The primary Conformal Wearable Battery (CWB) is an advanced solution to the United States Army's request for a light-weight, flexible source of power that can be carried by an individual without significant burden.

Introduction

From an understanding of fundamental chemistries, to improvements in specific cell formats, to pioneering developments in battery assemblies, EPT has been pushing the limits of battery technology to help meet the industry's growing need for energy. The three topics reviewed represent EPT's push to further refine high-demand, mission-critical products.

Li/ CF_x D-Cell

Overview

LCF-514, also known as the pure CF_x D-cell, is a high-energy cell designed to maximize the life of far-reaching applications such as remote environmental sensors or deep-space missions. These typically feature low-rate discharges and are weight sensitive, so the LCF-514 cell was developed to specifically target these criteria.

Development

The D-Cell was specifically designed to provide a very high energy solution at lower rates. To facilitate this, laser-welded aluminum headers and cans were selected over the traditional steel used with this cell format.

Discharges between 50mA and 250mA yield a capacity of around ~20Ah with this chemistry, where discharges from 750mA to 2A and have resulted in ~17.8Ah. For 50mA discharges, the efficiency of this cell produces a specific energy of approximately 750Wh/kg. Figure 6 displays some example discharge curves at room temperature.

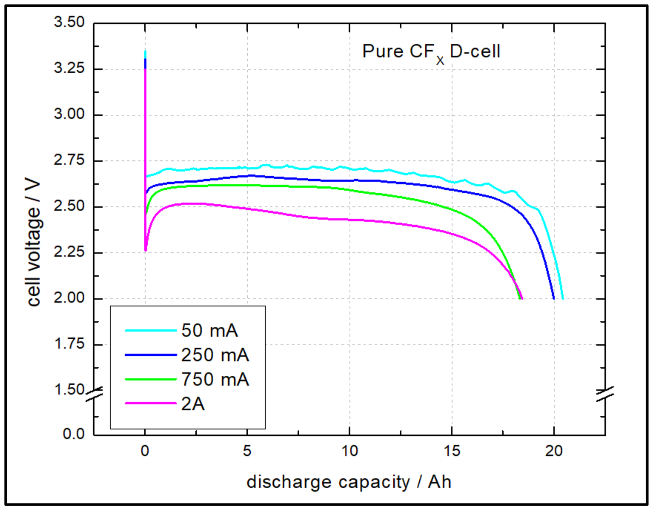

Fig. 6 LCF-514 Discharge Performance at Varying Rates

Li/ CF_x MnO_2 Chemistry

Overview

Lithium carbon-monofluoride electrolytic manganese dioxide, or Li/ CF_x-MnO_2 for short, is a primary battery chemistry with clear advantages over its industry counterparts in regards to weight efficiency, minimal self-discharge, allowable operating temperature, and abuse tolerance.

Drawbacks of the Li/CF_x root chemistry, such as low temperature voltage delay, thermal management in high-rate discharge cases, and material cost are aided with the implementation of electrolytic manganese dioxide (EMD). Performance of the high-energy hybrid chemistry has been validated at up to 1.5C rate and at temperatures ranging -50°C to 85°C.

Both the carbon monofluoride (CF_x) and EMD used in the hybrid-chemistry products discussed in this paper are commercially available resources. EMD's lower material cost enables an increased affordability in addition to performance benefits. Cathodes processed using the hybrid chemistry were generated using EPT's web-coating process, which is similar to that used to produce lithium-ion cathodes. The specific composition of material was formulated to maximize electrode density without compromising rate capability. This unique combination of cathode materials maximizes energy while enabling high-rate discharges.
To ensure the safety of these high-energy products, shut-down separator was utilized in the design to isolate the electrodes which helps to prevent thermal runaway.

Li/ CF_xMnO_2 D-Cell

Cylindrical cells utilizing the Li/ CF_x-MnO_2 hybrid chemistry see the same benefits and flaws that the pouch cells do, however inherent format differences alter the results in performance and swelling. The targets for this cell was to boast twice the capacity and specific energy of the Li/SO_2 cell. Figure 3 highlights this goal being achieved without the voltage delay intrinsic to the pure CF_x cells. The Li/ CF_x-MnO_2 hybrid cells delivered 15.5Ah, more than double the ~7.5Ah yielded by the Li-SO_2 cell.

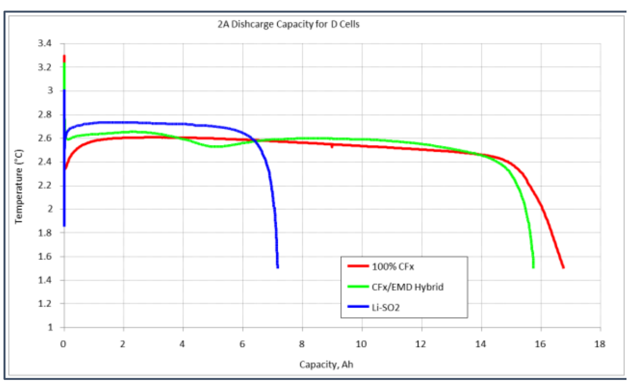

Fig. 3 D-Cell Performance at 2A Continuous, Room-Temperature Discharge

The application demanded full rate capability across a wide range of operational temperatures. This was a consideration during the refinement of the cathode, but also the optimization of electrolyte formulation. The results of that effort culminated in a cell that can deliver 13Ah while under a 2A discharge current in a -40°C environment. Performance at low temperature is displayed in figure 4.

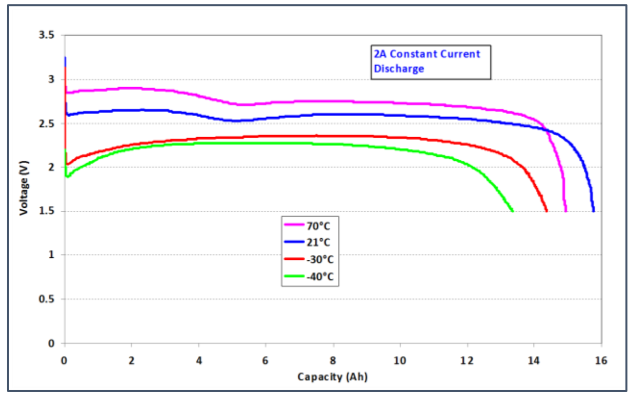

Fig. 4 D-Cell Performance at 2A, Continuous, -40°C Discharge

BA-5790 Battery Performance

The hybrid D-size cell was incorporated into the BA-5790 battery for evaluation. In addition to the advantages in capacity and specific energy, the hybrid chemistry provides significant reduction in heat generation during discharge compared to the pure CF_x chemistry. A specifically designed battery case was developed to increase heat conduction to the exterior of the battery.

Figure 5 shows the discharge performance at 2A of the Li/CF_x-MnO_2 hybrid battery. As can be seen, the hybrid cell delivered 16.0Ah above 20.0V and without voltage delay. This is twice the capacity of Li/SO_2.

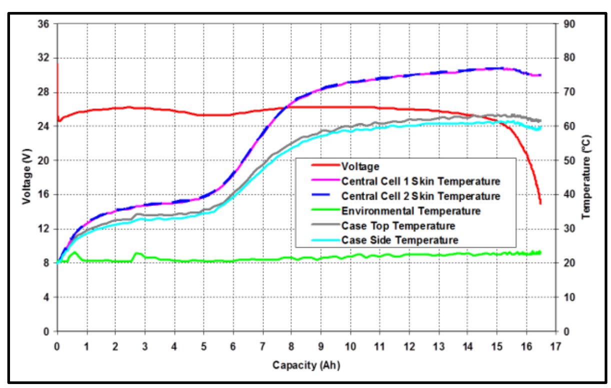

Figure 5. Discharge performance of hybrid battery at 2A

Pouch Cells

EaglePicher's pouch-cell technology benefits weight-sensitive applications by using a light packaging material and an easily packaged design. The pouch format emphasizes energy-density at the cost of physical deformation during discharge. A well-known property of CF_x is that it swells as a result of the reduction-oxidation reaction that occurs when the cell is under a load. The swelling of the CF_x negatively impacts the discharge performance of pouch cells and can deform battery cases.

To overcome the negative effects of the pouch cell and the inherent downsides to the active materials, the proper selection of the grade of the active materials needed to be investigated. Also, conductive carbon additives and carefully selected binder agent had to be chosen for use in the final product. Optimization of the material ratios was a critical effort to lower the impact of swelling, mitigate heat generation during discharge, and maximize energy density. EPT's effort on the selection of cathode loading and porosity aided in the proper balance of energy density, rate capability, and swelling. The fruit of all these efforts is evident below in figure 1 (Composition B).

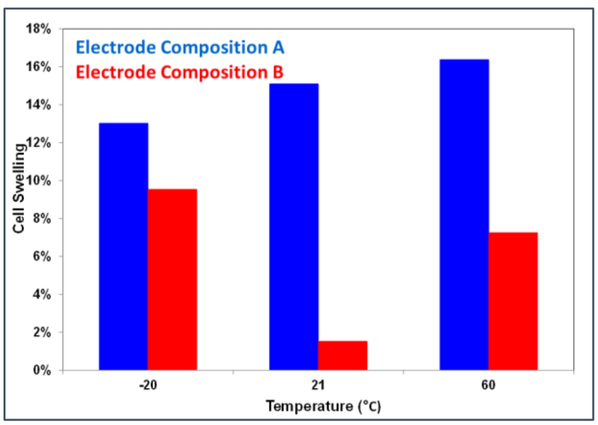

Fig. 1 Electrode Composition vs Swelling at Varied Temperatures

Performance of the hybrid pouch cell (LCF-134) was validated at up to 1.5C rate for a wide range of temperatures. As can be seen in Figure 2, the pouch cells were able to deliver high efficiency from -40°C to 60°C.

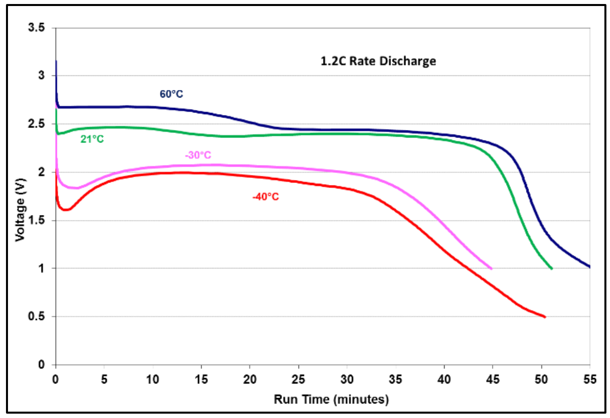

Figure 2. Discharge performance of the LCF-134

The Conformal Wearable Battery (MAP-9553)

Battery Description

The Conformal Wearable Battery (CWB) is a power-supply unit designed to provide accessible energy to soldiers on the high-tech, modern battlefield. The 24-cell, 15V CWB pack encases the Li/ CF_x-MnO_2 hybrid technology in a flexible, hermetically sealed container. With a footprint of 19.5cm x 22.1cm flat, only 2cm thick, and weighing in around 940 grams, the CWB is a designed to impose minimal burden to the wearer. External features to the battery include a state-of-charge indicator (SOCI), a complete-discharge device (CDD), and a GlenAir electrical connector. Figure 7 shows the primary conformal battery (MAP-9553).

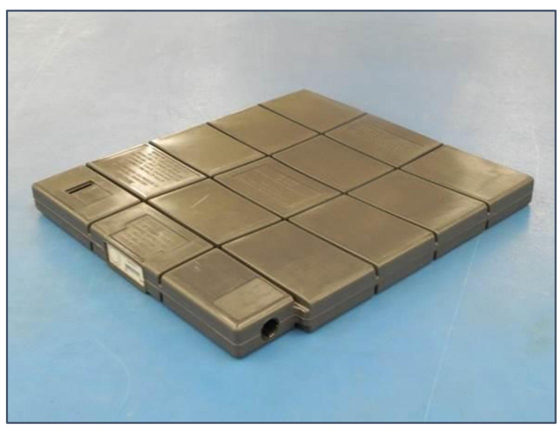

Fig. 7 Conformal Wearable Battery

Development

The CWB has been proven at temperatures as low as -20°C and as high as 55°C while still performing at a high level. For baseline, a constant power, room temperature discharge of 20W will pull about 250Wh. Soaking the battery at -20°C for 4 hours before discharging in that temperature will pull about 194Wh and incite a battery skin temperature of only 5°C. Repeating this test at the 55°C condition yields 260Wh and a skin temperature of 72°C. An example of the discharge behavior is shown in figure 8.

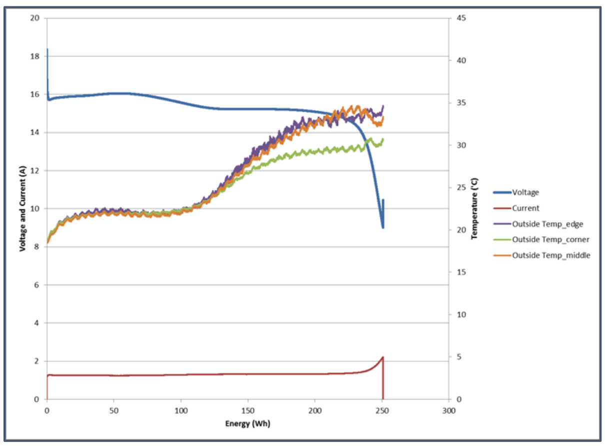

Fig. 8 CWB Discharge 20W Performance at 20°C

The battery is designed to survive the conditions of the battlefield. Subsequently, extensive abuse tests were performed on the system. Army-specified bullet penetration testing featuring 7.62mm rounds did not compromise the functionality of the battery. Visual results of the test can be seen in figure 9.

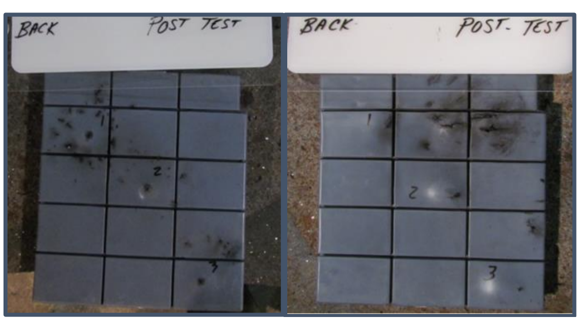

Fig. 9 CWB Bullet Penetration Test Samples

The battery survived impact testing, conformability testing, mechanical shock, random vibration, and transit drop testing. Multiple batteries were run through all of the tests mentioned in this section, with the exception of bullet penetration, and still performed. As a testament to the remarkable resiliency of this technology, one battery that went through this rigorous testing (including 5 impact cycles when only 3 were required) still delivered about 240Wh at a 20W constant power discharge without exceeding an internal temperature of 45°C. This battery also saw multiple 1-minute long, 20W discharges between tests to evaluate potential damage at each stage, which should be considered when appraising its capacitive ability.

Conclusion

EaglePicher Technologies offers an array of high-energy solutions to meet the needs of any situation.

The Li/CF_x D-Cell (EPT's LCF-514) is specially optimized towards extending the service life for single-use technology. With an extreme focus on energy, this cell offers exceptionally long life for critical applications. In pouch cells, cylindrical cells, or other formats (i.e. prismatic), the Li/CF_x-MnO_2 hybrid chemistry provides a high energy solution capable of performing safely in a wide array of temperatures. It is designed to create a long-lasting, no-maintenance solution. The BA-5790 vessel for the hybrid D-Cell displays the battery-level performance capabilities of the Li/CF_x-MnO_2 primary chemistry. The battery is currently finalizing first article testing (FAT), with plans for deliverable batteries to be built this year.

EaglePicher's primary, conformal wearable battery (CWB) is flexible, weighs less than 1.0kg, and will deliver 250Wh at room temperature and over 190Wh at -20°C. It has a very robust design with numerous safety features that has passed bullet penetration testing, impact testing, and numerous other safety tests. This was proven when U.S. Amy field-testing was performed on the MAP-9553 and only one battery was need for a 72-hour mission with energy still in reserve after the mission was completed.

The energy made available by EaglePicher products continues to serve commercial and defense customers safely and reliably, making them a must-have solution for demanding, mission-critical, applications.