Robust, Zero-Volt-Capable, High-Power Lithium-Ion Batteries for Military Platforms

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Abstract

CAMX Power has developed and is commercializing a lithium-ion battery technology, trademarked CELX-RC®, with high power and rapid charging capability, long life, exceptional performance and charge acceptance capability at extreme low temperatures (e.g., -60 ºC), excellent safety, capability for discharge and storage at 0V, and ability to be implemented in batteries without management electronics. This paper describes CELX-RC technology and its implementation in prototype batteries up to 60Ah size.

Keywords

Lithium ion; LTO; low temperature; rapid charge; 6T, 4HN.

Introduction

Rechargeable batteries needed for military applications face critical challenges including performance at extreme temperatures, compatibility with military logistical processes, phasing out of legacy battery technologies, and poor compatibility of COTS lithium-ion batteries with specialized military operational requirements and legacy platforms. To meet these challenges, CAMX Power has developed and is a commercializing lithium-ion battery technology based on our proprietary GEMX® high-performance cathode materials (licensed to L&F Co., Samsung SDI, LG Energy Solution, and EV Metals Group) implemented opposite commercial lithium titanate (LTO) anode with application-tailored electrolytes. This battery technology, trademarked as CELX-RC®, has high power and rapid charging capability, long life, exceptional performance and charge acceptance capability at extreme low temperatures, excellent safety, capability for discharge and storage at 0V, and can be implemented in batteries without management electronics. CAMX Power is developing CELX-RC for military applications that still rely on legacy chemistries such as lead-acid and nickel-cadmium, and for other applications that will benefit from its unique combination of power, life, safety, and robustness.

CELX-RC Properties

The GEMX materials used in CELX-RC cells offer the highest energy density of any Li-ion cathode material on the market today and has excellent power delivery and low-temperature performance. The LTO anode, although restricting energy density to about half that achievable with conventional graphite Li-ion anodes, nevertheless enables potentially critical performance attributes unattainable for graphite-based cells as described below.

CELX-RC Performance: Figure 1 shows performance capabilities of CELX-RC cells at extreme low temperature, demonstrating that unlike conventional Li-ion, CELX-RC cells can be charged as well as discharged at extreme low temperature.

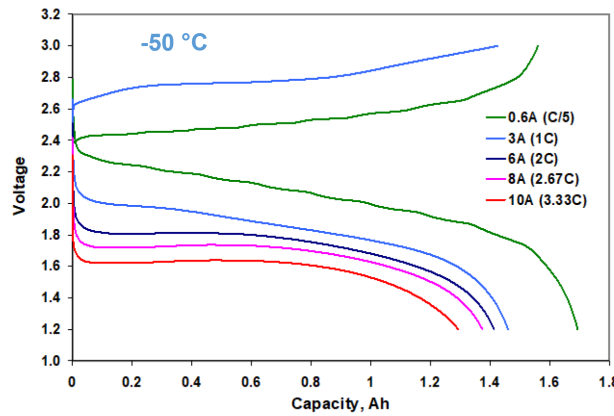

Figure 1. Charge and discharge voltage curves at indicated rates for a 3 Ah CELX-RC pouch cell cycled at -50 °C.

CELX-RC cells exhibit exceptional cycle life and 0V tolerance as demonstrated in Figure 2. Figure 3 shows the benefit of 0V tolerance for storage at elevated temperature.

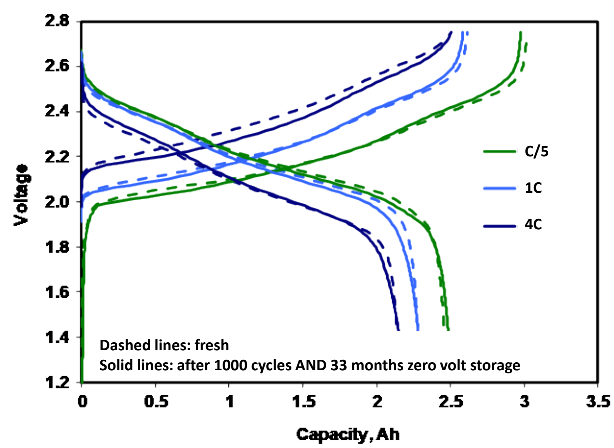

Figure 2. Charge and discharge at indicated rates for a 2.5 Ah CELX-RC pouch cell before and after 1,000 full cycles at 1C/1C rate and almost 3 years storage in the 0V condition.

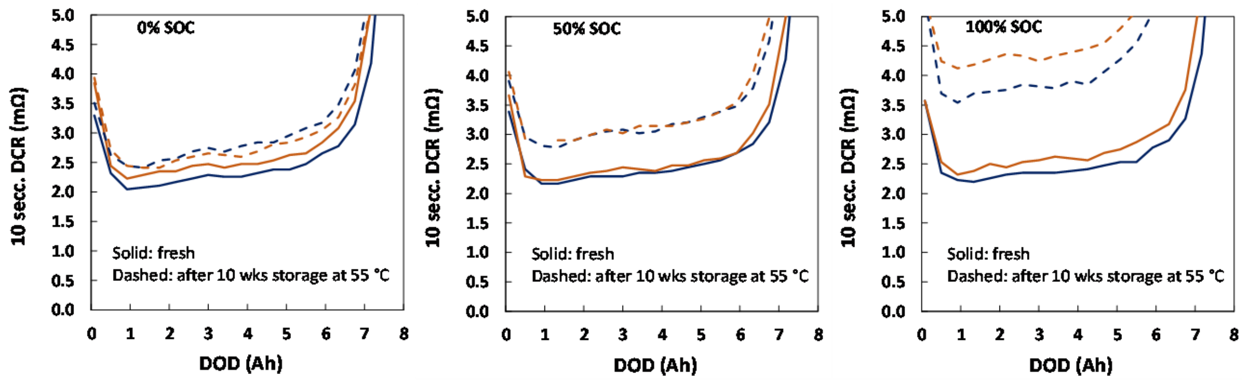

Figure 3. Direct current internal resistance (DCR) measured for 10-second, 5 A pulsing of 8 Ah pouch cells when fresh (solid lines) and after being stored at 55 °C for 10 weeks at 0% (0V), 55%, or 100% SOC (dashed lines).

The enhanced elevated-temperature storage tolerance enabled by 0V discharge capability shown in Figure 3 can greatly facilitate logistical management of batteries.

CELX-RC Safety: The CELX-RC cell technology's safety and exceptional tolerance to severe mechanical abuse have been demonstrated by tests including nail penetration, round bar crush, impact, and cutting with shears of pouch cells up to 6 Ah size and nail penetration and external short circuit testing of 18650 cells. These tests have generally resulted in only mild shorting corresponding to a low-rate discharge at worst. However, even when hard-shorted, the technology is much safer than conventional Li-ion.

Figure 4 shows an 8 Ah, 28 V 11-series pouch cell-based module after it was charged and then fully shorted by a 2 cm diameter steel nail driven through it. The cells vented electrolyte vapor smoke and limited melting of the polycarbonate case occurred (indicating ~300 °C reached), but no flames or sparks were observed, thus demonstrating SAE J2464 hazard severity level ≤ 4 (as is required for a 1-A55 Li-ion 6T battery per MIL-PRF-32565C).

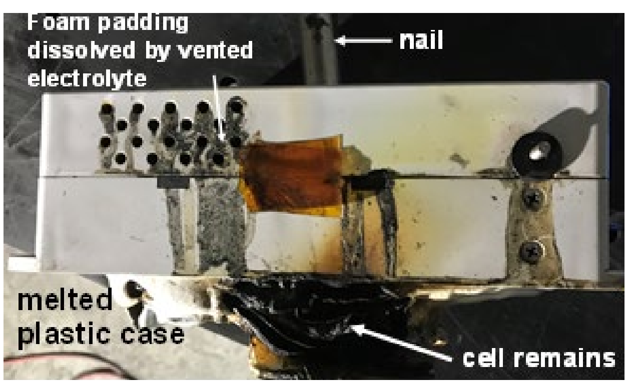

Figure 4. 200 Wh pouch cell module after charged module was penetrated by 2 cm diameter nail.

A post-mortem tear-down of the module revealed that the cells' electrodes and aluminum current collectors were intact as shown in Figure 5, thus indicating that no thermal runaway had taken place.

This level of safety under the most severe abuse conditions cannot be provided by conventional Li-ion batteries.

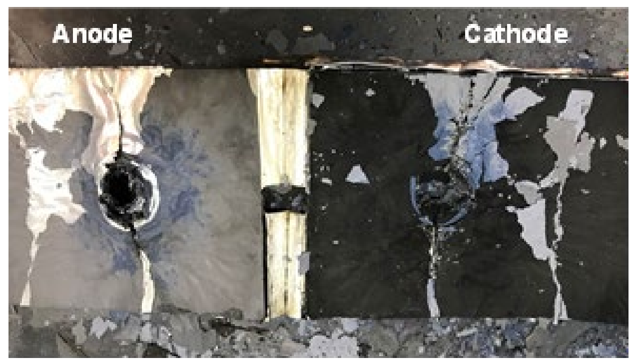

Figure 5. Torn down cell from 200 Wh module following penetration by a 2 cm diameter nail.

CELX-RC Battery Examples

Several different CELX-RC-based military battery prototypes have been or are being developed by CAMX Power in government-sponsored work. Two examples, a 0V-capable 60Ah 6T battery and a high-power buffering module are described below.

0V-Capable 6T Battery:
A CELX-RC-based, 0V-capable 6T battery prototype meeting type 1-A55 battery performance requirements of the MIL-PRF-32565C 6T Lithium-ion battery specification was made at CAMX Power from 6parallel 11-series strings of 10 Ah pouch cells. Figure 6 shows the battery's voltage characteristics. The figure shows that the battery's post-0V room temperature recharge characteristic matches its first charge curve, indicating that discharge to 0V essentially returns the battery to its as-made state. Furthermore, Figure 6 shows that the battery can be fully recharged from the 0V condition at -40 °C (-40 °F).

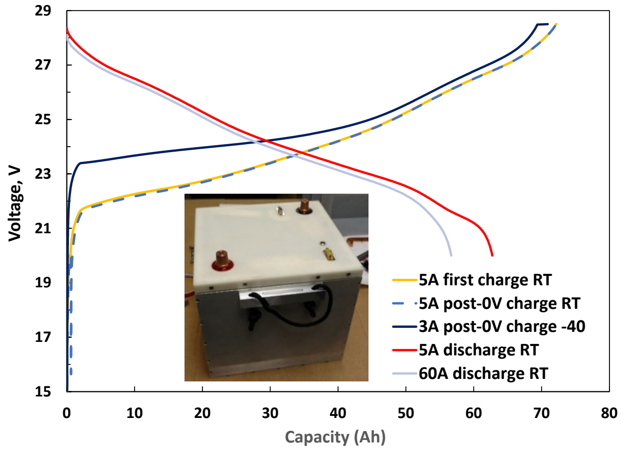

Figure 6. Charge and discharge voltage curves for CELX-RC-based 6T battery prototype (picture inset) at RT and 3A charge curve at -40 °C.

The battery's excellent low-temperature performance was further demonstrated by its cold cranking performance. While meeting the type 1-A55 battery requirement for 30-second 200 A pulse capability above 14.4 V at -40 °C, the battery also met the type 1-B55 requirement for 30-second 400 A pulse capability at -40 °C, as shown in Figure 7.

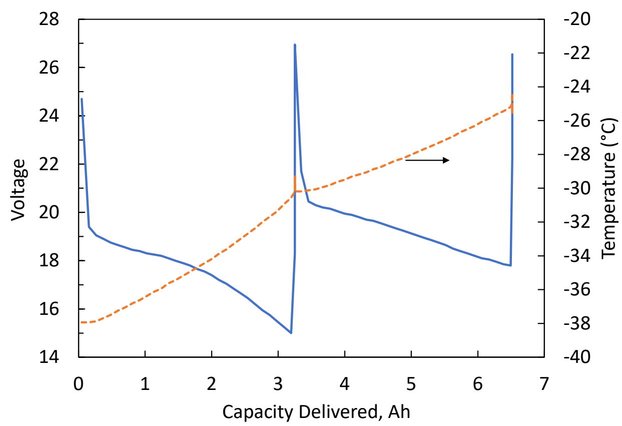

Figure 7. Voltage and internal temperature of CELX-RC-based 6T battery prototype at -40 °C as it was discharged at 400 A in two 30-second pulses with 5 minutes intervening rest.

Figure 7 shows that the battery's ohmic self-heating significantly boosted its low-temperature performance, and this was even more clearly demonstrated by results of discharge testing at -60 °C, shown in Figure 8. Results in Figure 8 show that even at such extremely low temperature, the battery delivered over half of its capacity when discharged at the 1C rate, with voltage reversal starting after about 2 Ah of charge had passed. The -60 °C discharges shown in Figure 8 were performed in sequence without removing the battery from the -60 °C temperature chamber, and with the battery being recharged to 28.5 V at 3 A rate at -60 °C, also demonstrating its exceptional low-temperature charging capabilities.

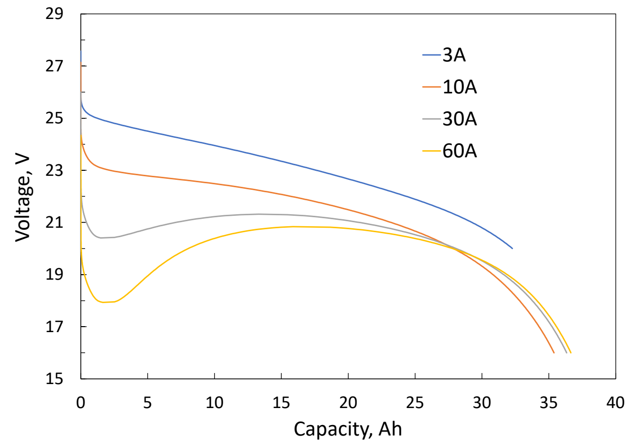

Figure 8. Constant current discharges of CELX-RC-based 6T battery prototype at -60 °C.

A 6T battery of this type could provide several unique advantages. Its 0V capability, robustness, and safety in the fully discharged condition would simplify logistical management. Its exceptional low-temperature performance can be advantageous in the emerging Arctic operational theatre. And its excellent safety in the charged condition can overcome concerns surrounding deployment of Li-ion battery-equipped vehicles by Navy vessels.

High-Power Buffering Module:
An unmanaged CELX-RC-based module built from a 12-series, 2-parallel array of 2 Ah pouch cells was developed to address replacement of the MIL-B-11188/2 4HN flooded lead-acid battery. The 4HN is used in the Bradley Fighting Vehicle to stabilize voltage when electrical load transients occur within the vehicle's turret power bus. Flooded lead-acid batteries are being replaced by AGM types, but these do not tolerate high current charge pulses as well as the older flooded batteries do, prompting interest in alternative technologies.

Figure 9 shows results for pulse charging of the 4.3Ah CELX-RC module when it was already charged to 28.5V and at >90% SOC. Results in Figure 9 show that the module accepted charge power of about 4.5 kW before reaching the 30V limit of the cycler used to run the test, and was projected to accommodate initial pulse current up to 530 A (~17.5 kW) and current up to 370 A (~12 kW) for 1 second within the 33 V operating voltage limit of the MIL-STD-1275 28V DC bus interface standard.

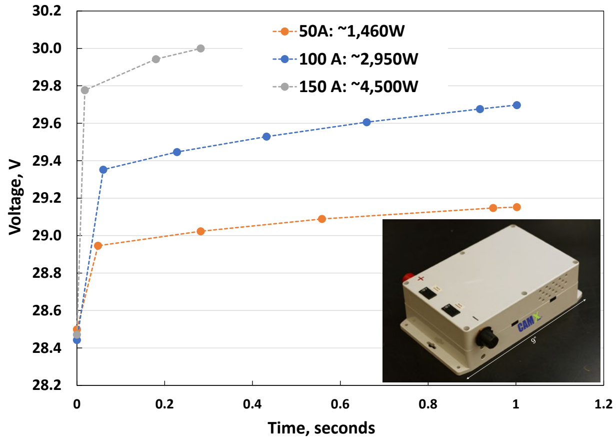

Figure 9. Voltage during constant current charging for 1 second or to 30V of CELX-RC-based 2.7 liter, 4.3 Ah, 100 Wh battery module (picture inset) at indicated currents and corresponding approximate powers, after the module had been charged to 28.5V.

The module also demonstrated exceptional high-power and low-temperature discharge performance as shown by the -18 °C pulse discharge and -40 °C continuous discharge results in Figure 10. Although the module is only one third the volume and less than one fifth the weight of a 4HN battery, it met the MIL-B-11188/2 requirement for the 4HN battery to deliver 75 A above 12V (equivalent to 1 V per cell) at -40 °C for at least 1.75 minutes. In other tests, the module readily performed discharge profiles emulating electrical loads of critical vehicle weapon systems. Other opportunities for high-power CELX-RC technology are being explored, including applications needing the power density of ultracapacitors but with up to 10 times their energy density.

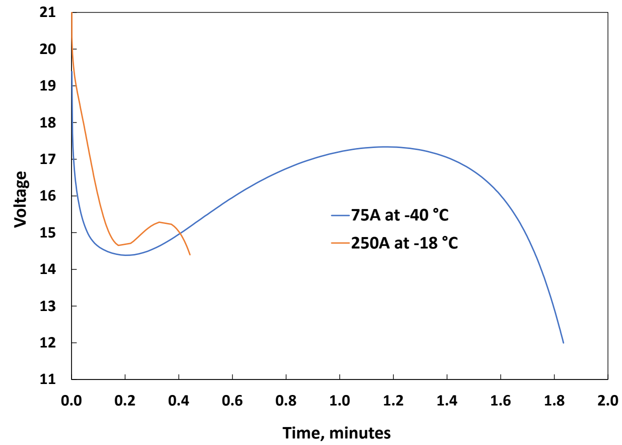

Figure 10. 30-second discharge pulsing at -18 °C and 75 A continuous discharge at -40 °C for CELX-RC-based 4.3 Ah battery module.

Conclusions

CELX-RC Li-ion cell technology offers several unique advantages that conventional Li-ion technology cannot provide for specialized military applications. Specifically, its outstanding safety, low-temperature and rapid charge capabilities, high-power capability, and tolerance for 0V discharge and unmanaged pack cycling can meet military needs that are not shared with the COTS market. CELX-RC batteries can thus provide vital benefits for critical DoD missions.

Acknowledgements

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