ALE Nail-Penetration Safe 2Ah Si Li-ion Prismatic Cell for Conformal Wearable Battery

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Abstract

ALE has developed a nail-penetration safe and UN38.3 certified 2Ah Li-ion prismatic cell (34 mm wide and 50 mm height and 6.5mm thick) using Si negative electrode for the application in U.S. Army conformal wearable battery (CWB). Compared with same sized commercial graphite cell, ALE's 2Ah Si prismatic cell shows >60% higher capacity. The cells passed not only nail penetration at 100% State of Charge (SOC) but also all UN38.3 tests including altitude simulation, thermal, vibration, shock, external short circuit, impact, overcharge, and forced discharge. The cells also showed good cycle life and demonstrated approximately ~90% capacity retention after 100 cycles at 100% Depth of Discharge (DOD). The results will be discussed with our production schedule and the future improvement road map.

Keywords

Conformal Wearable Battery; CWB; 2Ah Prismatic Si Li-ion Cell; SafeCore, Safety; Penetration; UN38.3; Soldier; Thermal Runaway.

Introduction

The conformal wearable battery, CWB, has become increasingly important for soldiers, particularly in modern warfare, where the use of technology has become more widespread. These wearable batteries provide power to a range of wearable devices used by soldiers, including communication devices, GPS systems, night vision devices, and sensors, among others.

The primary benefit of conformal wearable batteries for soldiers is their lightweight and flexible design. Conformal batteries are lightweight and can be easily integrated into wearable technology, reducing the overall weight burden on the soldiers. Additionally, the flexibility of the battery allows it to conform to the shape of the wearable technology, making it more comfortable to wear and reducing the risk of damage to the battery.

One of the challenges of using conformal wearable batteries in the military is the limited capacity. Conformal batteries have a smaller capacity compared to traditional batteries, which can limit their usefulness in military operations. Soldiers rely heavily on their wearable technology to carry out their duties effectively, and the limited capacity of conformal batteries can lead to devices running out of power quickly, compromising the success of a mission. The current available conformal wearable batteries have energies of 150Wh (8S4P) with nominal capacity 10Ah and nominal voltage 14.8V (reference 1). The single graphite cell capacity is 1.25Ah. Therefore, larger capacity Li-ion cells for CWB are highly demanded.

Safety is another challenge of using conformal wearable batteries in the military. Li-ion cells contain a flammable electrolyte and a highly reactive lithium-based cathode material. If the cell is damaged or exposed to extreme or abuse conditions, such as overcharging, impact, or bullet penetration , nail, puncture, it can result in a thermal runaway reaction, leading to a fire or explosion.

Thermal runaway in single cell level would cause chain reactions and whole battery pack failure, resulting in catastrophic effect in electric vehicles or energy storage devices. It's widely accepted that most cases are caused by mechanical, electrical, or thermal abuses, and all these abuses would cause short circuit in cell, which finally lead to thermal runaway. Figure 1a depicts the temperature change during the three stages from initiate minor internal short circuit to SEI decomposition, separator melting, cathode decomposition, electrolyte oxidation, and finally thermal runaway. The solution of thermal runaway needs to interrupt the internal short and limit the accumulation of Joule heating, and subsequent positive feedback loop reactions.

ALE has developed SafeCore® technology in the assembly of electrodes (figure 1b and 1c), i.e., insert a resistive layer between either two layers of separator and cathode layer, separator and anode layer, cathode layer and cathode current collector, anode layer and anode current collector. In the case of abuse conditions, the short circuit will be interrupted by the decomposition of the resistive layer triggered by the set voltage, current, or temperature. Furthermore, The resistive layer doesn't change the normal cell performance.

ALE has developed a 2Ah Li-ion Si prismatic cell, >60% higher capacity than the current 1.25Ah graphite cell. The cell is nail-penetration safe and passed all UN38.3 tests based on SafeCore® technology for conformal wearable batteries. The width, height, and thickness of the cell is 34mm, 50mm, and 6.5mm, respectively. The active compositions are high nickel NMC for positive electrodes and nano Si for negative electrodes. The specific energy of ALE's 2Ah Si prismatic cell is ~260 Wh/kg.

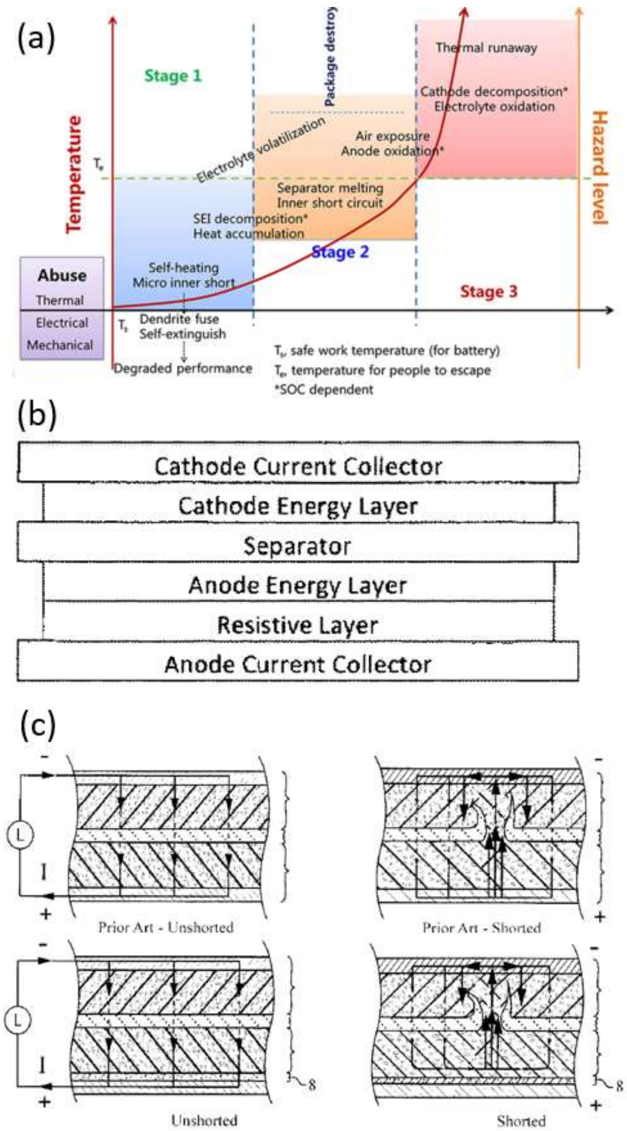


Figure 1. (a) Three stages in battery TR, Ts, safe work temperature (for battery); Te, temperature for people to escape; *SOC dependent, reproduced from reference 2;(b) the cross view of electrode of Li-ion batteries with a resistive layer (c) Four scenario of current flow of film-type Li-ion batteries between unshorted and shorted, and without and with a resistive layer between, reproduced from reference 3.

ALE 2Ah CWB Cell Performance

As shown in Figure 2, ALE 2Ah CWB cells have been evaluated for their cycle life at C/5 rate (0.4A, clamped) and at C/2 rate (1A, no clamp). The capacity of the 1st cycle is 2Ah, and of the 300th cycle is 1.74Ah, thus the capacity retention is 87% at C/5 rate (Figure 3a, 3b). The capacity of the 1st cycle is 1.84Ah, and of the 100th cycle is 1.68Ah, thus the capacity retention is 91.3% at C/2 rate. Therefore, the energy in an 8S4P CWB is 224Wh with nominal capacity 16Ah and nominal voltage 14V.

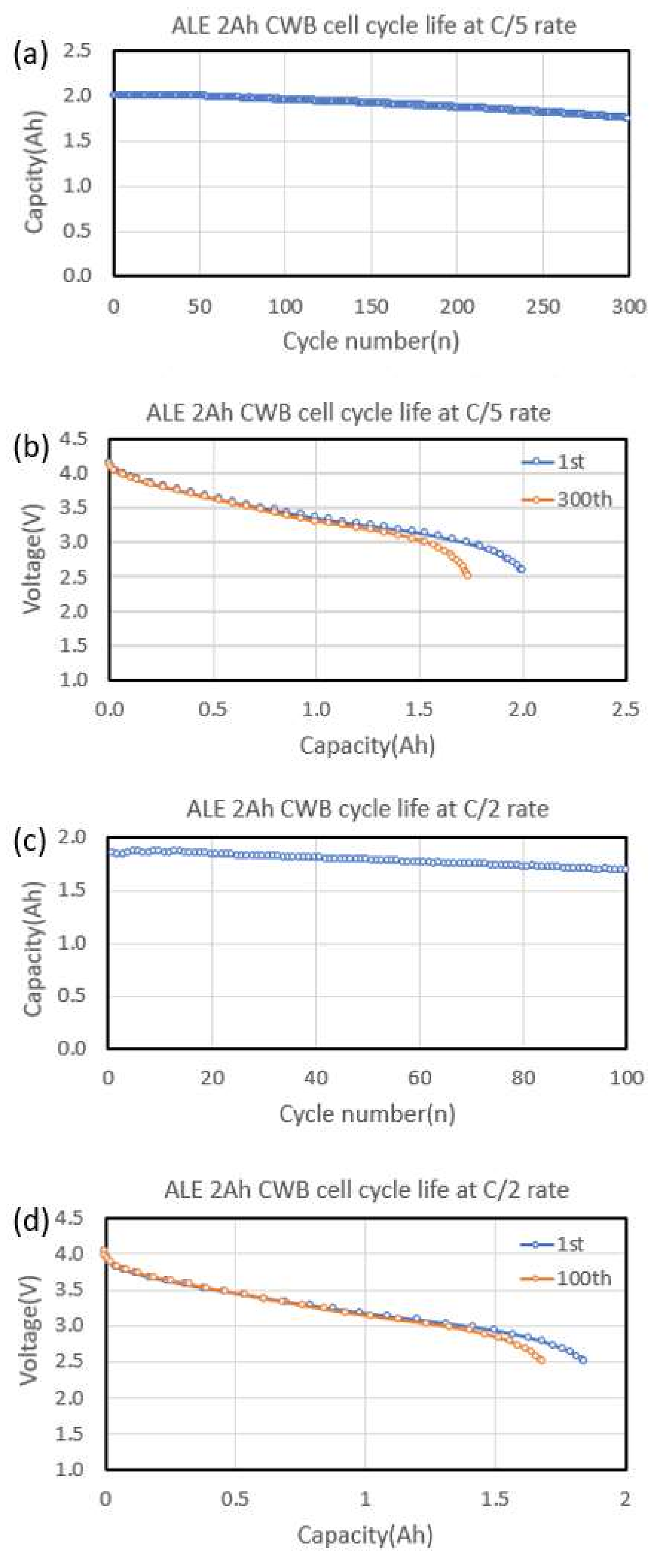


Figure 2. ALE 2Ah CWB cell cycle life (a) discharge capacity at 0.4A vs cycle number profile (b) voltage-capacity at 0.4A profile at different cycle numbers (c) discharge capacity at 1A vs cycle number profile (d) voltage-capacity at 1A profile at different cycle numbers

Nail Penetration

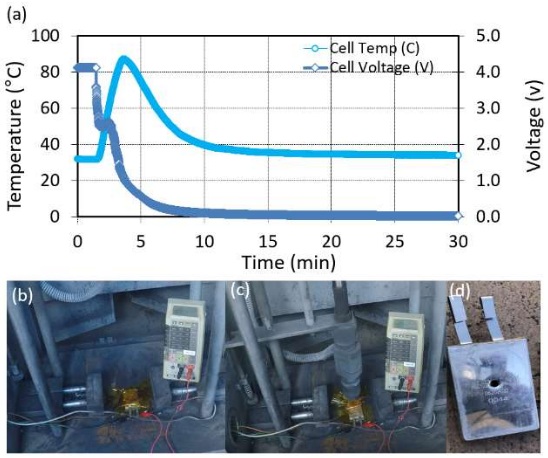
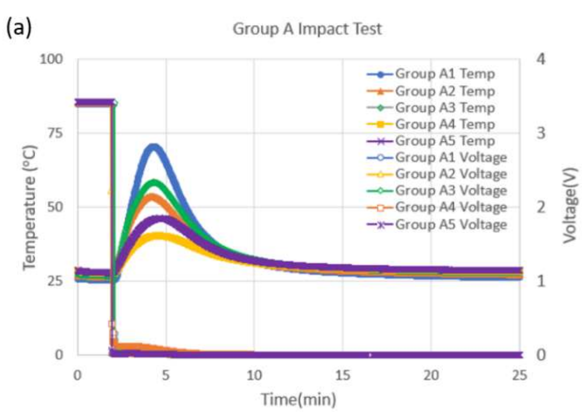


Figure 3. (a) Temperature and voltage observed on 2Ah Li-ion CWB cell during nail test (b) voltage before nail (c) voltage during nail (d) cell image after nail.

Figure 3 shows a typical nail test of 2Ah Li-ion CWB cell. The cell was first put in a chamber, positive and negative tabs were connected to a voltage meter to monitor voltage change, and a thermocouple was attached on the surface of the cell. The cell OCV reading was 4.13V for two-minute rest time before being penetrated by a 3 mm diameter nail for 30 minutes. Figure 3a shows the voltage and temperature change during the test. The voltage drops from 4.13V to 2.5V in the first 3 minutes, and slightly back a while and slowly drops to 0V in the remaining test time. No fire, smoke or explosion was observed.

Mechanical Abuse Test

Figure 4 shows the two different groups that underwent impact tests (T6 in UN38.3), Group A cycled 1 time and group B cycled 25 times. The voltage immediately drops to 0V from 3.4V after impact, with the temperature increasing from room temperature to 50~70 ºC. The cells were severely distorted, but no leaks, fire, or explosion was observed. Table 1 summarizes the detailed values for weight and voltage before and after the test.



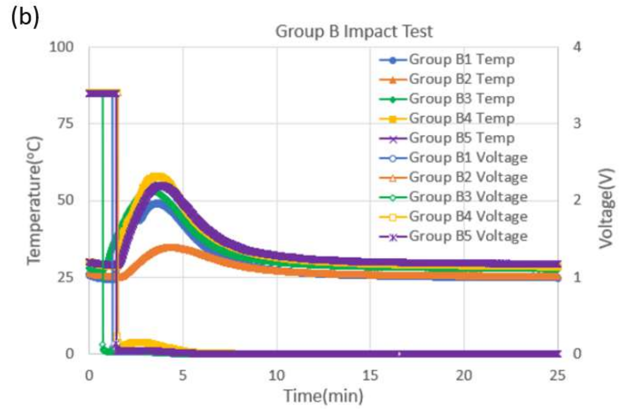


Figure 4. (a) Group A impact test with temperature and voltage recorded (b) group B impact test with temperature and voltage recorded (c) Cell images after impact test

Table 1 Impact test for 10 cells for before test (B.T.) and after test (A.T.)

S/N	A1	A2	A3	A4	A5
Weight B.T.(g)	26.82	26.68	26.92	27.20	26.70
Voltage B.T.(V)	3.406	3.418	3.416	3.410	3.419
Weight A.T.(g)	26.82	26.68	26.92	27.20	26.70
Voltage A.T.(V)	0.006	0.003	0.005	0.002	0.001
Max. Temp. (ºC)	70.5	53.6	58.4	40.4	46.2
S/N	B1	B2	B3	B4	B5
Weight B.T.(g)	26.86	26.95	26.92	26.80	26.89
Voltage B.T.(V)	3.415	3.410	3.426	3.423	3.418
Weight A.T.(g)	26.86	26.96	26.92	26.80	26.89
Voltage A. T.(V)	0.003	0.002	0.008	0.007	0.003
Max. Temp. (ºC)	49.1	34.8	53.3	58.1	54.9

Electrical Abuse Tests

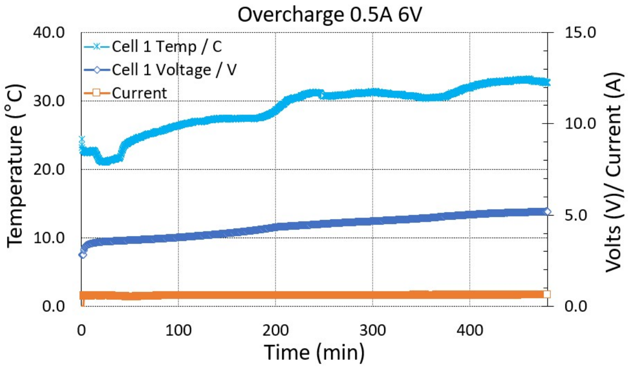


Figure 5. A typical overcharge test at 0.5A 6V for 8 hours

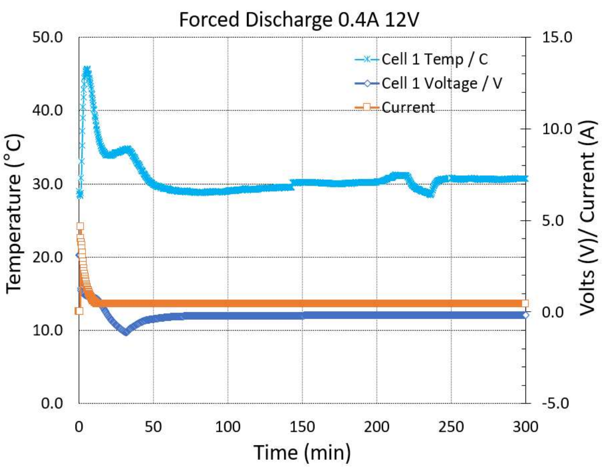


Figure 6. A typical force discharge at 0.4A 12V

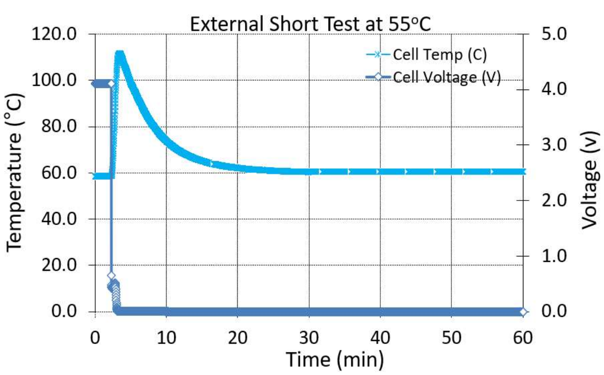


Figure 7. A typical external short test at 55°C

Figure 5 shows a typical overcharge test (T7 in UN 38.3) for 2Ah prismatic CWB cell for 8 hours. The initial voltage was ~3V, and final voltage was 5.2V, the total charge capacity is 4Ah. No fire or explosion was observed after the test.

Figure 6 shows a typical force discharge test (T8 in UN 38.3) for a 2Ah prismatic CWB cell for 6 hours. The initial voltage was ~3V, the lowest voltage was -1V, and the final voltage was -0.2V. The total discharge capacity is 2Ah. No fire or explosion was observed after the test.

Figure 7 shows a typical external short test at 55°C. The voltage fast drops to 0V after external short with the immediate temperature increase up to 110 °C. No fire or explosion was observed after the test.

Other abuse tests T1-T5, altitude simulation, thermal, vibration, shock, external short circuit, have been tested in different cells and packs by Bren-Tronics, Inc. They all passed UN 38.3 tests.

In summary, 2Ah prismatic Si Li-ion cells have been developed for CWB, with high safety passing nail penetration, and certified with all UN 38.3 tests for safe transport. Although the energy density has been increased to ~260Wh/kg, it still needs to be improved at least 25%, ~325Wh/kg, i.e., 2.5Ah in the same cell size. This will require extremely stable positive electrodes or materials, or the non-flammable electrolyte which might suppress the decomposition of high nickel compounds at fully charged state and subsequent thermal runaway.

Acknowledgements

The authors gratefully acknowledge lab tests from Bren-Tronics, Inc. and thank Steven Chew, David Shoemaker, Julianne Douglas for research guidance and helpful discussion.

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