Y9.ET5.2: Safety Testing of Li-ion Batteries

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1. Project Goals

Lithium-ion batteries (LIBs) have been chosen by FREEDM as energy storage cells in DESD system to be integrated with GEH Testbed. The LIBs are widely used as a power source in portable electrical and electric vehicle products. While the rate of failures associated with their use is small, several well-publicized incidents related to lithium-ion batteries in actual use (including fires and explosions) have raised concerns about their overall safety. 2015 SVT has raise consideration that "The ongoing work related to DESD subsystems needs to emphasize the integration of battery systems and safety issues." In this task, we propose to conduct safety tests of Li-ion battery cells.

2. Role in Support of Strategic Plan

To address some of the safety risks associated with the use of LICs, a number of standards and testing protocols have been developed to provide Enabling Technology level (Distributed Energy Storage Device Development, Dr. Srdjan Lukic) and then to the Demonstration Testbed level (Green Energy Hub, Dr. David Lubkeman) with guidance on how to more safely construct and use LIBs.

3. Fundamental Research, Technological Barriers and Methodologies

The large amount of test and analysis on LIB cell safety issues have been done by LIB manufactures; however, it is important to provide independent safety testing support for FREEDM needs since the LIB performance depends on the chemistries of LIB and operational conditions.

4. Achievements

Lithium-ion Capacitor (LIC) is a recent innovation in the area of electrochemical energy storage that hybridized lithium-ion battery (LIB) anode material and electric double layer capacitor cathode material as its electrode. The LIC can reach 23 Wh/kg in energy density compared with the maximum theoretical value of 5-7 Wh/kg of conventional supercapacitors. The LIC is capable of a rapid rate of charge/discharge pulse power and a lifetime of over 100,000 cycles with a projected lifespan of 20 years. However, the swelling and gassing of the LIC, when subjected to abuse conditions, is still a critical issue concerning the safe application. LIC is relatively safer than Li-ion batteries due to the absence of little or no oxygen and oxides in the cell, limited lithium deposition, and quick energy release. This features has made LICs less prone to thermal runaway when abused. There have been very few studies on the LICs safety but they have been very brief and do not investigate the entire range of safety issues. However, it is imperative to carry out thorough investigation that characterizes the safe operation of LICs. To further investigate the safety of LIC for commercial applications, comprehensive abuse tests were conducted on LIC 200 F pouch cell type with voltage ranging from 3.8 V to 2.2 V developed by General Capacitors LLC and their responses were studied. The investigated cell has a specific energy and specific power to be 14 Wh/kg and 6 kW/kg respectively. In this study, different types of abuse testing were performed on LIC 200 F specification and their result showed differences in response due to different types of abuse conditions. The overcharge, over discharge, external short circuit, crush (flat plate and blunt), and nail penetration test were performed on the cell. The thermal characterization of the cell heat generation, thermal stability and ability to withstand high temperature (150 ºC) limit without resulting to thermal runaway was also studied.

<u>Experimental/Methods:</u> The LICs were tested under external short circuit, overcharge, over discharge and nail penetration abuse conditions. A 200 F LIC pouch cell 58 mm height, 48 mm width, 4.5 mm thickness and 16 g typically used in the consumer electronics and potential use for electric vehicles was tested. The operational voltage range of the cell is 2.2 V to 3.8 V with maximum voltage of 4.2 V. All cells were fully charged (i.e. 100% State of Charge) following the manufacturer's specification before conducting the safety tests. All measurement such as voltage variation, current and temperature rise and fall were data log. All abuse tests were performed in a transparent glass box placed inside a fume hood. Electrochemical impedance spectroscopy (EIS) were performed on the LICs.

<u>External short circuit:</u> Fig. 1 shows the result of the LIC external short circuit test. The sudden drop in the voltage is as result of separator damage thus releasing energy in form of heat. The current source shuts down when the voltage dropped to zero volt. The cell swell as shown in Fig. 2 with an increase in temperature as well as the thickness of the cell. The cell thickness before the test was 3.7 mm and after the test was 10.3 mm. Maximum temperature of 68 ºC due to exothermic reaction was reached without thermal runaway as shown in Fig. 2.

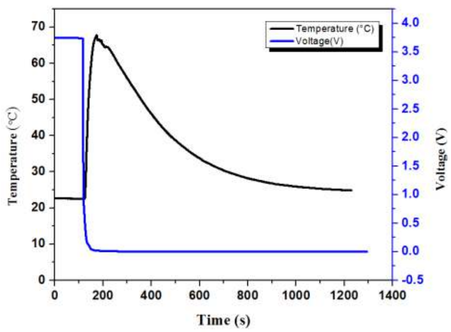

Fig. 1. External short circuit test results of LIC

Fig. 2. LIC before (left), during (middle) and after (right) external short circuit test

<u>Overcharge:</u> Fig. 3 shows the overcharge test result. The overcharge test resulted in the LIC resulted into swelling, gassing and temperature rise due to exothermic reaction between the electrodes and the electrolyte. The voltage increase with increasing delithiation of the cathode. The overcharge current suddenly drops when the internal temperature of the cell reaches the shutdown temperature of the separator and the temperature falls without thermal runaway. The maximum temperature reached was 37 ºC. Figure 8 and 9 show the overcharge result and LIC before and after overcharge. Fig. 3 shows the LIC over discharge test with a gradual decrease in the cell voltage and there was loss

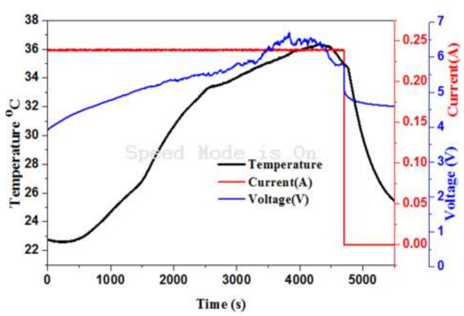

Fig. 3. Overcharge test results.

in the capacity. The cell temperature remains at room temperature throughout the over discharge period.

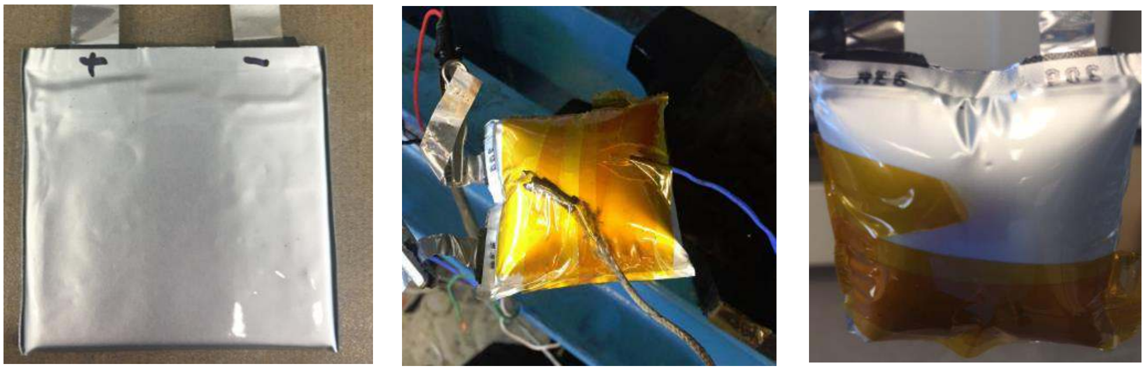

Fig. 4. LIC before (left) and after (middle and right) overcharge test

Nail Penetration test: There was a sudden drop in the LIC voltage with a corresponding rapid increase in the cell surface temperature measured by Arbin BT 2000 and Omega Type K thermocouple respectively. The voltage drop was as a result of an internal shorting of the electrodes by the nail which is a stainless-steel material and it is highly conductive. The cell temperature peaked at 90 ºC with excessive gassing, smoke and swelling of about 18.74 mm thick. It was observed from Fig. 5 that, temperature increases exponentially because of high rate of exothermic reaction and decrease partly linear without fire. The result above show that LIC demonstrated safe, good thermal and chemical stability.

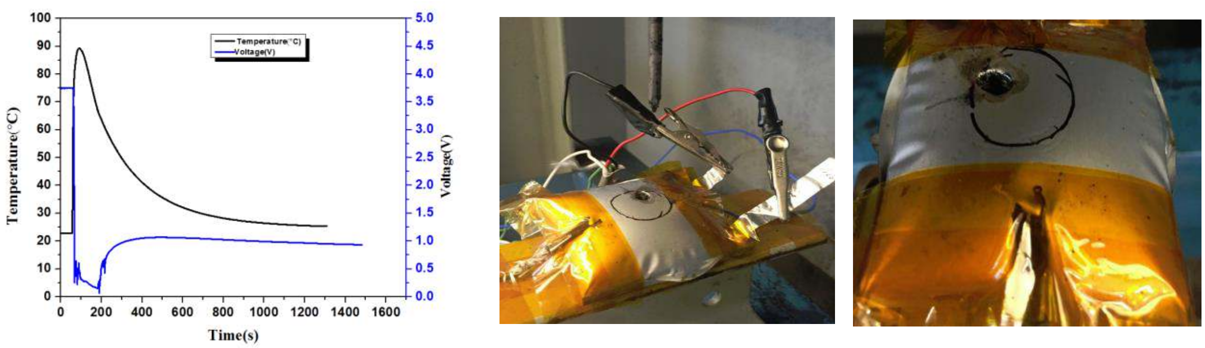

Fig. 5. LIC nail penetration test results

Blunt and Flat Plate Crush Test: Fig. 6 and 7 show the results for blunt indent crush tests and flat plate crush tests, respectively. As the battery is indented, due to the mechanical impact, the indenter compresses the cathode, separator and the anode thereby creating an internal short that yielded a high temperature increase to

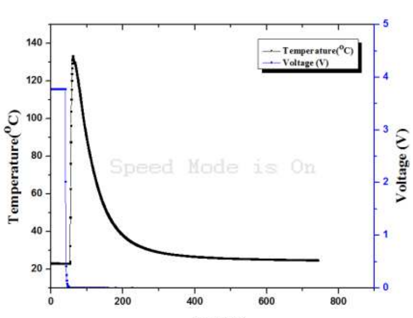

Fig. 6 Blunt crush test results

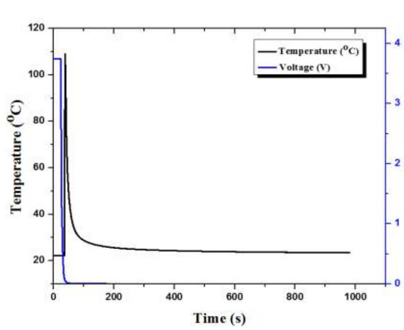

Fig. 7 Flat plate crush test results

about $120^{o}C$ within few seconds of crushing. This was due to the exothermic chain reaction occurrence within the cell that led to the decomposition of electrolyte and separator damage. The cell was physically damage due to the mechanical impact of about 1.75 psi. The cell busted with emission of smoke, gases without any fire.

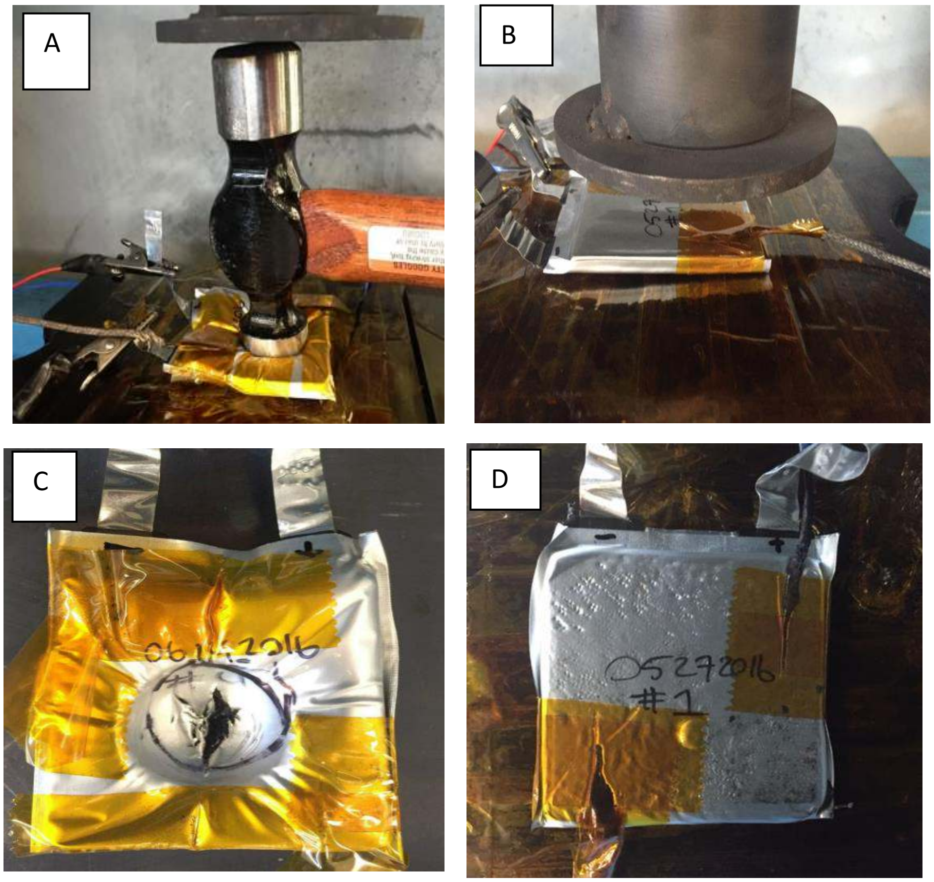

Fig. 8: Crush test (A-before & C-after) and flat plate test (B-before & D-after)

5. Other Relevant Work Being Conducted Within and Outside of the ERC

General Capacitor engineers has closely worked with faculty and students to provide independent safety testing support for their own products.

6. Milestones and Deliverables

Q3 (9/30/2016) – Complete the design of test method and setup for overheating test
Q4 (12/31/2016) – Complete the overheating tests for lithium-ion capacitors
Q1 (3/31/2017) – Complete electrical, mechanical, and environmental safety tests for lithium titanate (anode) battery
Q2 (6/30/2017) – Complete electrical, mechanical, and environmental safety tests for NMC (cathode) battery

7. Plans for Next Five Years

7.1 Develop test methods suitable for safety standards;
7.2 Assess Li-ion battery cells' ability to withstand certain types of abuse. We intended to assess specific risk from electrical, mechanical, and environmental conditions which can be occurred in

reality, including external short circuit test (a direct connection between the anode and cathode terminals), Over charge test (an over-charging current rate and charging time), crush test (a specified crushing force applied by two flat plates, e.g. 12 kN), needle penetration test (a steel needle placed across the cell), and heating test (a specified application of an elevated temperature for a period of time, e.g. 150^{o}C).

8. Member Company Benefits

General Capacitor LLC, a FREEDM spin-off Li-ion capacitor (LIC) company is also interested to develop LIC safety testing methods, which should be similar to that for testing of LIBs.

9. References