TEST METHOD FOR SIMULATING INTERNAL SHORT CIRCUITS IN LITHIUM ION CELLS

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A review of the publicly available lithium-ion battery research shows a strong focus on understanding and mitigating cell failure modes, specifically those due to internal short circuits. Though only brief accounts of field failures are available, in some cases, the presence of manufacturing defects has been noted to lead to internal short circuits within the cell. A particle, depending upon its size and morphology, may pierce the separator allowing for direct contact between electrodes (internal short circuit). There is also the possibility that the over-charge or over-voltage subjection of lithium-ion cells causes the formation of lithium dendrites, small thin crystal needle-like structures, which may eventually puncture the separator leading to an internal short circuit (ISC). However, once an ISC is established, a localized heat source is generated within the cell. This is termed joule heating and the extent of the heat produced locally depends upon the internal resistance of the cell and state of charge (current flow) along with other factors.

When portions of the cell affected by joule heating reach certain temperatures (generally above 120°C), exothermic reactions between the active electrode materials and the electrolyte are initiated. Depending upon the ability of the cell to dissipate the heat, the heat generated may continue to sustain these exothermic reactions with a rapid increase in the temperature of and pressure within the cell (thermal runaway) . In cases, where the pressure build-up is relieved via the safety vent, then expulsion of the contents is still a chemical hazard.

The combined high pressure and lower modulus of the casing due to high temperatures can compromise the integrity of the casing leading to explosive release of volatile gases, which may further ignite. The high temperature of the cells could certainly lead to ignition of nearby flammable objects. In the case of battery packs (or bundles of lithium-ion cells), the highly dense configuration of the cells creates a condition where one cell failure could spread to adjacent cells without proper external battery thermal management.

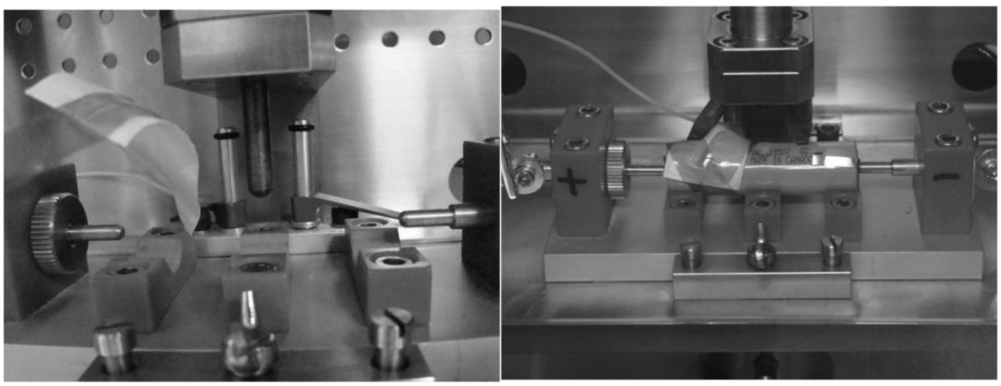
Indentation Induced Internal Short Circuit Test

Currently, there are only two new simulated internal short circuits (ISC) tests, which are either under consideration or part of some consensus-based standards. One is the Forced Internal Short Circuit (FISC) test and the other, being refined by NASA and UL is based on an indentation type approach. The FISC requires the disassembly of the cell with testing being conducted on the jelly-roll (cell internals without the casing) making it useful mainly for research studies. Generally, the disassembly of a cell is not considered a best practice for tests in safety standards, especially, as this operation for a lithium-ion cell involves a hazardous condition. Instead, we have chosen an approach that will be called an Indentation Induced ISC test. This co-developed test is based on a history of indentation type testing by NASA and UL with the intention of bringing the best features of both together into a single ISC test.

Indentation testing evolved from previous methods that depended upon an object either penetrating (nail penetration test) or crushing (rod circumference crush test) the cell. In the penetration approach, there is little deformation of the cell, however, the nail acts as a bridge generating an ISC that is not localized. The breach of the casing also dissipates any hazardous pressure buildup. For the rod circumference crush test, the deformations of the cell are large and generally the safety mechanisms relieve the pressure. Of course, both these may be necessary if they match abuse conditions that the cell can be subjected to in the field. However, neither generates the localized ISC within a closed cell that is considered to simulate the field failures noted previously.

The current Indentation Induced ISC test setup for cylindrical lithium-ion cells is shown in Figure 1. The cell is placed in a holder that prevents rotation or translation of the cell. An indenter with a smooth profile presses from above against the cell casing at a constant speed (0.01 – 0.1 mm/s). Test measurements include temperature of the casing surface at a point near the indentation site, distance traveled by indenter (amount of cell casing deflection), applied force through indenter, and open circuit voltage. The cells can be at different states of charge (SOC) or stages of aging. This entire setup is placed within a chamber that allows for control of ambient temperature.

Figure 1 Pictures of Indentation Induced ISC test for cylindrical lithium-ion cells



As the indenter presses against the casing, layers of separator, anode and cathode immediately below the indentation region are deformed due to localized high curvature (Figure 2). The resulting high stress/strain will lead to a mechanical failure of the separator allowing for direct contact between electrodes at a distance only a few layers below the casing surface (Figure 3). Though this mechanical event cannot be observed and documented in real-time, the effect of the separator failure is a sudden drop in the open circuit voltage (Figure 4). For some cells, seconds after a measured drop in the open circuit voltage (100-500 mV), there is a rapid increase in cell surface temperature (as high as 700°C) with an outcome involving explosive release of gases and flames (Figure 5).

Figure 2 CT scan images of cylindrical lithium-ion cell prior to testing (left) and single CT scan image of cell after indentation (right)

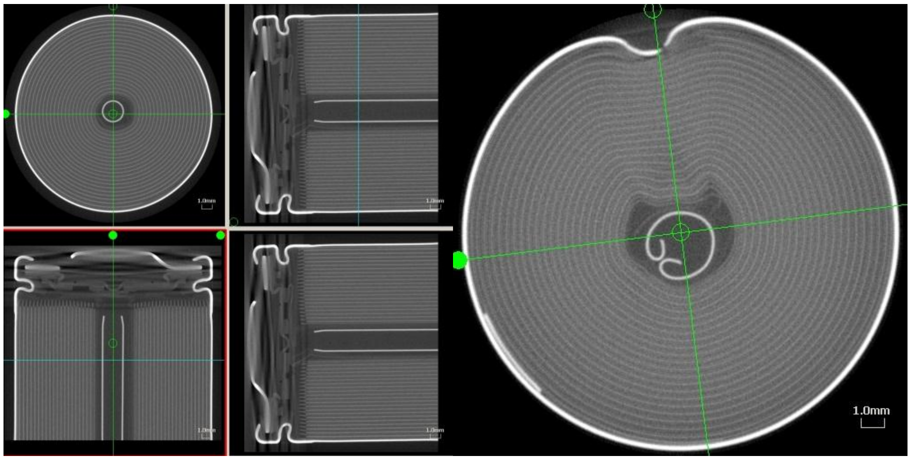
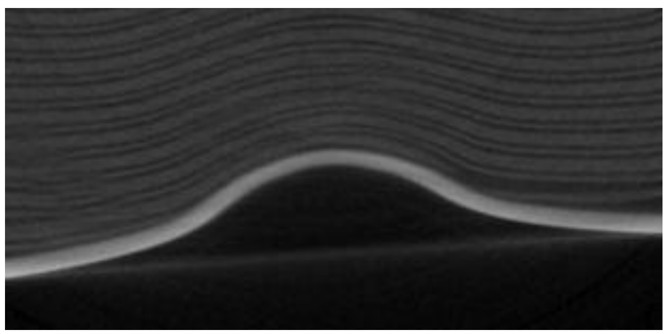


Figure 3 CT scan image of cell showing breakdown of layers directly below indentation region



Now the typical risk measure consists of severity of failure multiplied by probability of failure. In forcing a failure, the Indentation Type ISC test is basically measuring the severity of cell failure. This approach is one that has been adopted by NASA in screening of COTS rechargeable batteries for space applications. Cells that do not perform well under this type of test would then be subjected to more stringent secondary testing schedule that might help establish the probability of ISC cell failure.

Figure 4 Measurements taken during the indentation test for a cell that undergoing thermal runaway

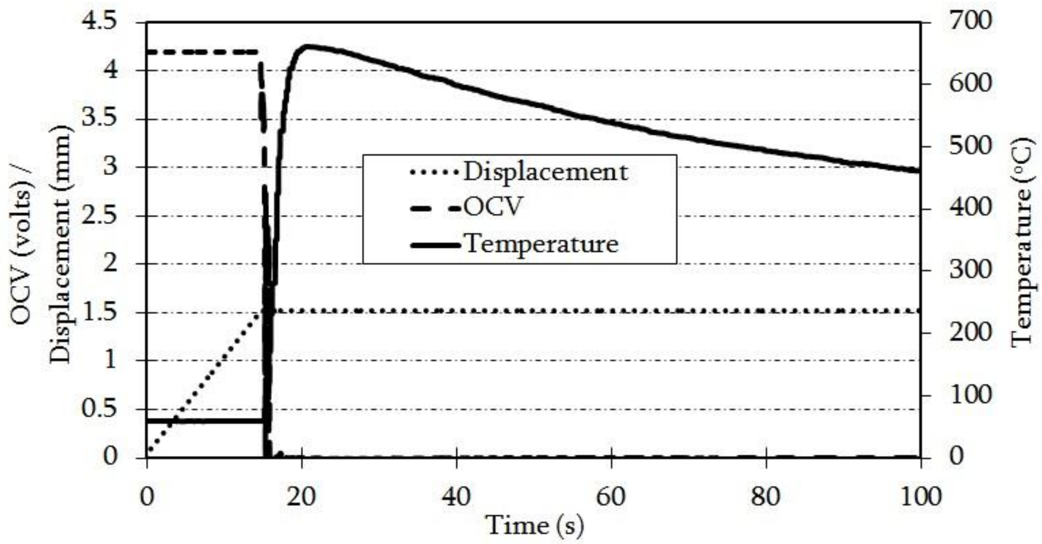
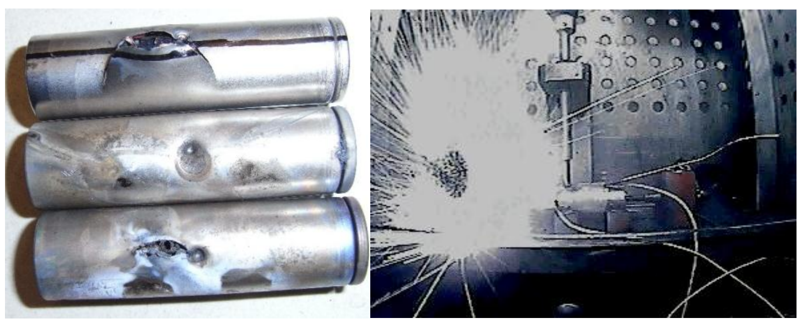


Figure 5 Picture of cells experiencing thermal runaway (left) and one example of explosive failure of a lithium-ion cell during indentation test (right)



So far, analysis of results from cells subjected to this indentation type ISC test shows a correlation between test performance (observed severity of failure) to energy density, thermal stability of active materials, and chemistry of cell.