Decreasing Risk of Electrical Shorts in Lithium Ion Battery Cells

AN ELECTRICAL SAFETY TEST WHITE PAPER

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On rare occasions, an electrical short can develop inside the cell after passing production tests due to burrs or particles on the positive electrode reaching the negative electrode after inflation occurs. If these cells that are susceptible to failure pass through to the end user, the results could be catastrophic. This paper describes how to mitigate these occurences in the dry cell stage.

Introduction

Lithium ion battery technology has played a big role in the advancement and user experience of electric vehicles and other consumer electronic products. As market competition increases, manufacturers are striving to reach higher power densities and throughput in production. While lithium ion technology has matured, risk of failure, fire and even explosion while in use is an ongoing concern for battery makers. In order to decrease the risk of failure in the field – and these failures can be catastrophic - the root cause must be identified and any defective cells must be filtered out before they reach the end user. So how do you identify the root cause which makes a cell susceptible to a greater risk of failure?

First, let's look at the basic design of the lithium ion battery jelly roll cell, also known as a dry cell

In the jelly roll design, shown in *Figure 1*, an insulating sheet is laid down, then a layer of an anode (-) material is laid down, a separator layer is applied over the anode to avoid a circuit to the final cathode (+) material placed over the top. This layering of material is then rolled up, like a Swiss Jelly Roll, and inserted into a hollow tube casing. The casing is then sealed and metal contacts are attached per the cells application.

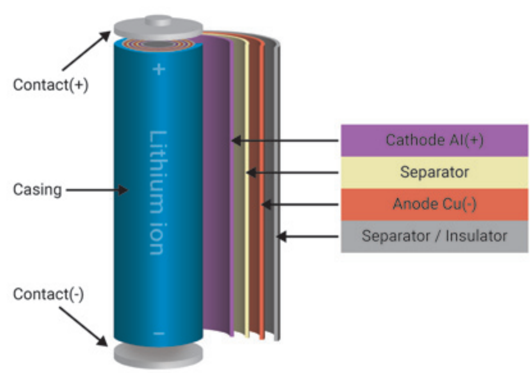


Figure 1. *Basic jelly roll design*

What increases the risk of cells failing?

Lithium ion battery manufacturers are improving testing methods to ensure safety and increase their product's life cycle. However, on rare occasions an electrical short can develop inside the cell after passing production tests. Research indicates that the root cause of ignition is due to an internal short circuit between the positive electrode (cathode) and the material coated on the negative electrode (anode) inside the cell. As the length of time contact increases, the temperature rises and escalates the risk of failure.

Many conditions will cause temperature to rise, but when the aluminum (Al) shorts with the anode material, the rise is significant *[Figure 2]*. This combination of high energy and rapidly rising temperature on a concentrated location could easily ignite the electrolyte. The risk of a fire is more dependent on the heat generated in the localized spot rather than the current magnitude of the short circuit.

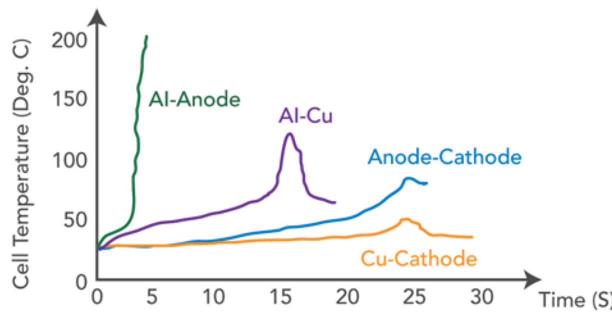


Figure 2. Temperature rising of differrent short circuit scenarios

What causes the short circuit?

While many conditions can exist for causing short circuits within a cell, our research found four primary internal short circuit patterns that lead to battery failure; burrs on the aluminum plate, impurity particles in the coating of the positive electrode, burrs on the welding point of the positive tab, and irregularity of the insulation tape pasted on the tab [Figure 3]. Additionally, any excessive external pressure to the edge of the cell could cause a short circuit. This article will focus on the testing for burrs and particles inside the materials of lithium ion batteries.

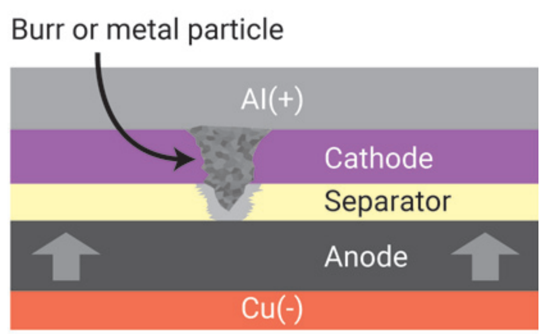


Figure 3. A burr extruded from the positive electrode coming in contact with the material coated on the negative electrode will cause an internal short circuit

When do short circuits occur?

When burrs or particles exist, internal short circuits can occur at different times in the life cycle of the battery. Lab experiments indicate that at about 10 charging/discharging cycles the graphite material on the negative electrode could inflate up to 24% of its original thickness and the silicon materials on the same negative electrode could increase by even 110% of original thickness *[Figure 4]*. As the charge/ discharge cycle repeats, it is likely that it could continue to expand until any burrs or particles on the positive electrode eventually reach the negative electrode resulting in a short circuit and possibly fire.

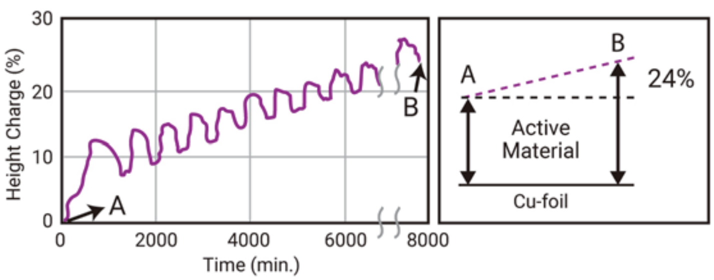


Figure 4. Lab experiments show that the graphite material on the negative electrode can inflate 24% after only 10 charge/discharge cycles

Typically, several charge/discharge cycles are conducted on battery cells in the factory before shipping. However, some potential hazards can go undetected. See *Figure 5* for example. In this scenario, two cases of defective cells are present in the production line. Each has a single burr at different lengths on its aluminum plate; Case 1 and Case 2. Case 1 is a longer burr and will be detected at the second charging cycle by the factory since the burr touches the anode. However, as in most cases, the second shorter burr (Case 2) will go undetected in factory testing until after more charge/discharge cycles inflate the negative electrode materials to the point of failure, most likely after it reaches the consumer.

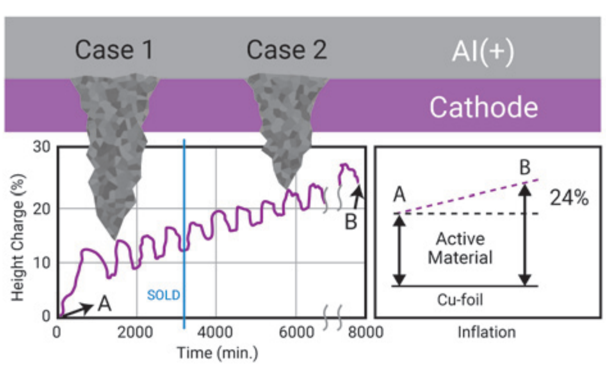
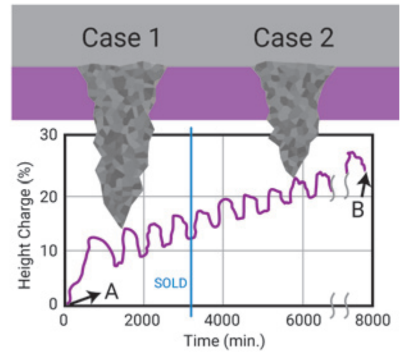


Figure 5. Two burrs (Case 1 & Case 2) at different heights extruded from the aluminum positive electrode may casue short circuits at different times

Traditional testing will not detect potential hazards

Traditionally, battery makers conduct hipot and insulation resistance (IR) tests to detect burrs in the jelly roll. If a short circuit exists it will be detected. However, basic hipot/IR tests will not detect potential hazards in the cell due to inflation of the negative electrode and the burr or particles. For example, as in Case 2 from *Figure 5*, a burr is extruded from the aluminum only slightly. A basic hipot test will indicate the leakage current is lower than your limit. An IR meter will show a high IR value resulting in a PASS since the burr is away from the anode. This does not provide a safe test result due to the inflation issue we learned previously.



Correct testing should determine if the distance between the electrodes is enough to be safe throughout the charge/discharge cycles of the battery. The equation to determine distance is shown and explained later. If burrs or particles go undetected, the distance between is not enough. Additionally, if impurities are not detected in the dry cell state, it will not be detected by the general "Rest" method since the distance between electrodes will not change while resting.

Another concern is melted holes

During regular insulation resistance and hipot testing on the dry cell, an electrical discharge known as Partial Discharge (PD), may happen to the burrs or particles on the positive aluminum plate. This partial discharge can cause a hole to melt in the separator layer resulting in failure down the road if the burrs or particles come in contact with the anode.

Chroma's university joint-research program recently conducted a study on dry cells and discovered a partial "fast-charge" phenomenon when observing melted holes. They discovered that lithium metal accumulated on the anode material near the melted hole. This phenomenon poses a threat to safety and reduces the quality and life expectancy of the lithium ion cells.

New solution detects the insulation distance left between the positive electrode and anode

Detecting burrs and particle impurities on the positive aluminum layer requires going beyond the traditional testing methodology. Using Hipot/IR testers to measure leakage current only provides the final leakage current value. *Figure 6* shows some overshoots during the Constant Current (CC) and Constant Voltage (CV) process and these would not have been detected using common Hipot/IR instrumentation. For this, partial discharge (PD) or flashover detection *plus* leakage current measurement is a more comprehensive test methodology. This method detects the insulation distance left between the positive electrode and the anode.

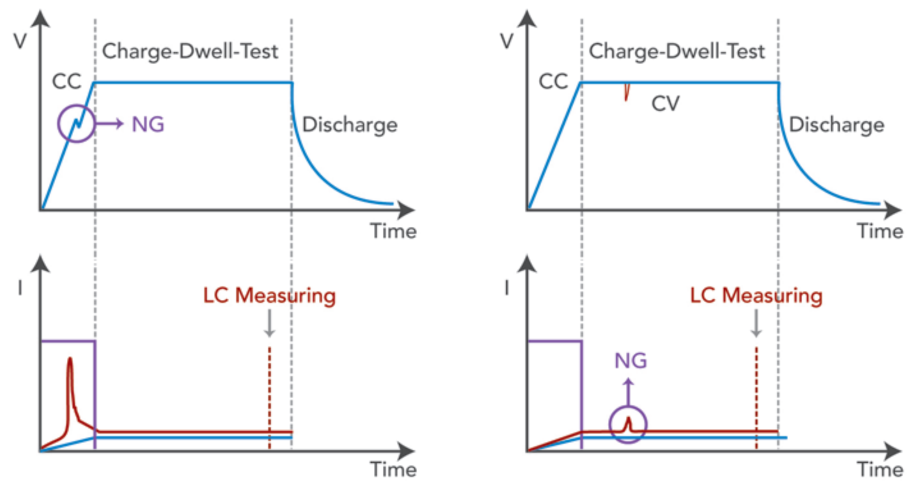


Figure 6. PD/flashover detection in both CC (charging) and CV (measurement) phases

Chroma introduced a dry cell insulation tester specifically developed for lithium ion batteries and capacitors that is able to perform manually or in automated systems. The 11210 battery cell insulation tester measures leakage current (LC) and insulation resistance (IR) of the dry cell as well as other insulation materials. In addition to standard LC/IR measurement, the 11210 has a unique function that detects partial discharge or flashover that may have occurred inside the insulation material during the high voltage insulation testing process. With PD detection of the battery's internal status before electrolyte filling, defective products can be filtered out before entering the next stage of production and, most importantly, before it reaches the market. Read further for more detailed information on partial discharge detection.

The 11210 has a wide range of voltage output from 1V for mobile phone battery cell testing (pouch cells) up to 1000V or 50mA to test high voltage and high charging current applications. Leakage current measurement ranges from 10pA ~ 20mA. It's also incredibly fast. Each cell test can be completed in 20ms which is a positive impact to production throughput.

Key Features

- Test voltage: up to 1KV(DC)
- Charge current: 50mA max.
- Wide range of Leakage Current (LC) measurement (10pA ~ 20mA)
- Partial discharge/flashover detection (A112100)
  - PD level and number of occurrence display
  - PD events and V/I waveform monitor
  - Programmable PD level limit setting
  - PD and V/I waveform logging (A112101)
- Built-in reliable contact check
- Automated test sequence: charge-dwell-measure-discharge
- High speed testing (20ms/device)
- 480×272 pixel full-color display and touch panel
- Standard Handler, USB, RS-232, Ethernet interfaces

Chroma11210 battery Cell Insulation Tester
A112100 - PD Detection Card
A112101 - PD Analyzer Card
A112102 - PD Tester Checking Kit
A112103 - Handler Interface Converter Box

Detecting Partial Discharge before failures occur

The optional partial discharge (PD) detection function of Chroma 11210 has the ability to detect those defects inside the battery cells in the dry cell stage prior to electrolyte filling. When burrs on the electrode or particles inside the insulation layer exist in the cell, the insulation distance left between them is shortened but not shorted. As stated previously, they cannot be detected by traditional insulation tests since there is no short at the time of executing the tests. The 11210 is the only instrument that can detect possible shorts before any failures occur. With the appropriate test voltage applied and PD threshold level set, the 11210 measures the effective distance left between the negative electrode and the graphite material *(see equation and explanation to the right)*.

$$E = V/d$$
$$E_{max} = V_{max}/d$$

The maximum insulation capability of a certain material is the maximum electrical field it can withstand, which is the quotient of the voltage divided by the distance. Thus, with the known characteristic (Emax) of a certain insulation material and the voltage applied, the distance left inside the material can be calculated.

The 11210 provides two phases of detection with different circuitries used. The first phase is in CC mode when the 11210 charges the cell with a user defined constant current. During this mode, the slope of the voltage level is monitored. Any glitches on the voltage slope or any unexpected changes of the slope will be detected and reported as a PD occurrence. The second phase is in CV mode where only a stable leakage current should exist. Any unusual or protruding pulses on the current waveform are typically the result of an abnormal discharge (PD or flashover) and will be detected and reported by the 11210 as a PD occurrence. The 11210 not only detects up to 99 occurrences, but also measures the magnitude of the PD pulses during these modes (Figure 7). The magnitude can then be set as a threshold for pass/fail measures.

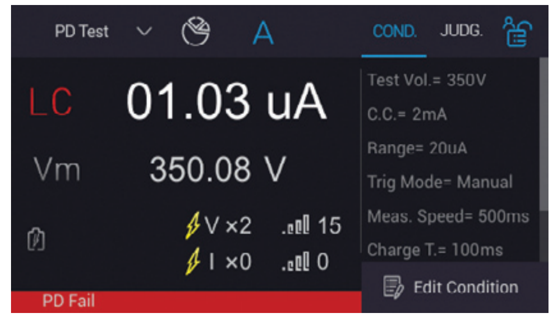


Figure 7. PD detected in CC & CV mode and reported by the 11210

Engineering review

For detailed review, Chroma provides an optional PD analyzer built into the PD waveform monitor that records waveforms for QA or R&D analysis. In the event engineering needs to review actual voltage and current waveforms on a failed cell due to PD, Chroma 11210 offers an advanced option that can record and store both voltage and current waveforms from each individual cell after tests are completed. Ultra-stable test voltages with ripple and noise down to the millivolt enables the 11210 to spot very small glitches on the voltage or current waveform. Built-in zooming functions allows the engineer to clearly view waveform details of each PD occurrence. Figure 8 below illustrates that without looking into the details of the voltage waveform, minor PD or flashover inside the cell could not be detected. Since PD can't always be duplicated, the waveform recording function is an important tool for the engineer.

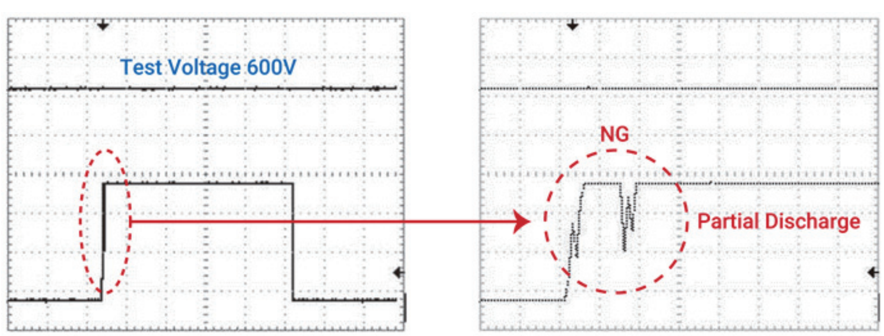


Figure 8. PD Without looking into the details of the voltage waveform (left), you see nothing abnormal. With the Chroma 11210 zooming into the details, we can see two PD events have occured; one in CC mode, the other in CV mode (right)

Conclusion

On rare occasions, an electrical short can develop inside the cell after passing production tests due to burrs or particles on the positive electrode reaching the negative electrode after inflation occurs. If these cells that are susceptible to failure pass through to the end user, the results could be catastrophic. Testing with basic hipot or insulation resistance test instrumentation does not provide any indication to whether the space between the electrodes is safe enough to undergo the charge/discharge cycles of the battery. Partial Discharge (PD) detection in addition to insulation resistance testing, like what's found in the Chroma 11210, could detect those defects in the dry cell stage prior to electrolyte filling. Detecting burrs or particles early in the production phase allow for these cells to be filtered out before shipment. This can greatly increase product quality, reduce failures, and mitigate any danger that may come from an internal electrical short.

Learn more with Chroma

Chroma has the knowledge and technologies to assist battery manufacturers in setting up reliable inline tests or provide complete turnkey test solutions.
For more information, please visit chromausa.com