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UNDERSTANDING AND PREDICTING THE RISKS IN Li-Ion BATTERIES

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ABSTRACT

Battery-related fire and explosion incidents are increasing because lithium-ion batteries have become the first choice for various electronic devices. This work analyzes the battery internal structure and built-in risk mitigation mechanisms through battery disassembly and nondestructive X-ray computed tomography. Combined with voltage/temperature monitoring, battery behavior during thermal runaway incidents is analyzed and classified into three stages.

Keywords: Lithium-ion battery, safety mechanism, risk mitigation, thermal runaway, rupture.

INTRODUCTION

Lithium-ion batteries are more advanced than the previous rechargeable lead-acid and nickel-cadmium batteries due to their higher capacity and voltage. As a result, lithium-ion batteries are becoming popular for many energy storage systems - from smartphones that contain a single cell to electric vehicles that contains thousands of batteries. Combined with the expanding applications, the number of battery-related fire and explosion incidents is increasing every year. The safety risks of lithium-ion batteries cannot be ignored. The lithium-ion batteries related incidents are threatening the consumer's life and property. Meanwhile, these incidents hinder the further development of lithium-ion batteries. The direct cause of these incidents is thermal runaway, which is a self-sustained temperature increasing process accompanied by gas generation and increased pressure (Lecocq *et al.*, 2016 and Feng *et al.*, 2018). In order to prevent or mitigate the potential risk of thermal runaway, lithium-ion batteries are equipped with multiple fail-safe mechanisms (Finegan *et al.*, 2015). Understanding the battery's internal structure and these built-in risk prevention/mitigation mechanisms is necessary for analyzing and predicting battery behavior during the incidents.

RESULTS AND CONCLUSIONS

In this work, we disassembled cylindrical batteries to reveal the built-in battery risk prevention/mitigation mechanisms. For the cylindrical batteries, the fail-safe functions for abnormal operation are implemented by several components in the battery cap area near the positive terminal. Based on the working mechanism, these components can be classified into three categories: the positive temperature coefficient (PTC) resistor, the current interrupt device (CID), and the vent system. The PTC is a ring-shaped component located under the battery positive terminal. Its resistance will sharply increase once the temperature is higher than a critical value. The PTC is an effective method to suppress abnormal current surges. The CID is comprised of the vent disk and the bottom disk as shown in Figure 1. These two parts are made of metal and are part of the circuit. During normal operation, the vent disk and bottom disk are electrically connected. Once the generated gases accumulate inside the battery, the increased battery internal pressure can push the vent disk away from the bottom disk and cut the electrical circuit. The vent system is the last fail-safe mechanism for preventing the entire rupture of the battery. As seen in Figure 1, the vent system contains the positive terminal, which has a premade through-hole for gas release; the vent disk, which is the actual boundary for a battery; and the bottom disk, which also has a premade through-hole. The white arrows in Figure 1(a) show the designed pathway for the gas release, but this pathway is blocked during normal operation due to the existence of the vent disk, which hermetically seals the battery. However, when the battery internal pressure is large enough to breach the weak spot on the vent disk, the vent disk will open and allow the gas to release. The weak spot of the vent disk is marked by a notch that is applied on purpose.

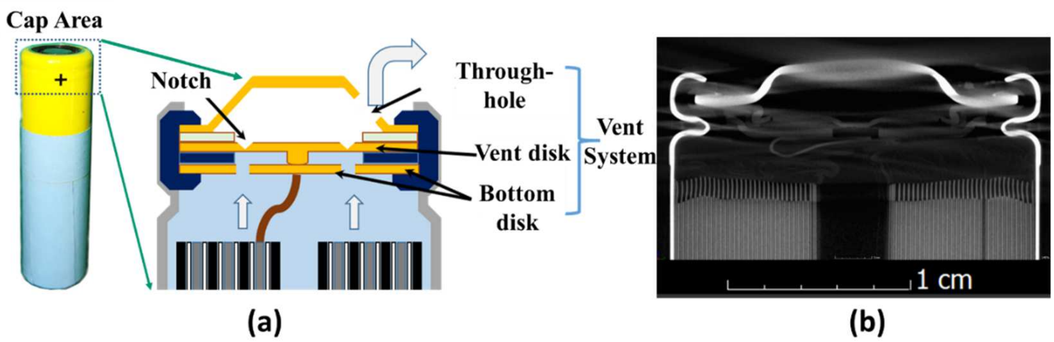

Fig. 1 - The schematic (a) shows the cylindrical battery cap structure with the components for the vent system, and the structure was validated with (b) the X-ray CT image

Based on the activation of these fail-safe mechanisms, the thermal runaway process can be classified into three stages. The battery's abnormal current increase can be suppressed by the activation of the PTC. Later, gas accumulation can lead to CID activation and open circuit status. If the thermal runaway was not stopped in the earlier stage, the vent system will work and allow the gas to be released before fire ignition or explosion. Combined with X-ray computed tomography (CT), the battery internal structure was compared before and after fire or explosion caused by thermal runaway. Through the X-ray CT analysis, it was found that the current design of the fail-safe mechanisms does not always work well. If the vent system is blocked, it is possible to rupture the battery case. The results of this study can be used to evaluate and improve battery safety.

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