Exploratory Investigation of Early Detection for High-C Discharge-Induced Failure in 18650 Lithium-ion Batteries

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ABSTRACT

The surge in demand for high-energy-density lithium-ion batteries has led to the exploration of high-C (high current draw) discharges in various applications. However, these high-C discharges introduce significant challenges related to battery performance and safety. This exploratory study aims to investigate early current interrupt device failure detection mechanisms in 18650 lithium-ion batteries subjected to discharges up to 16C. Our controlled experimental setup induces a 40 amp discharge to a single lithium nickel cobalt aluminum oxide 18650 cell. Employing Digital Image Correlation techniques, the structural changes in the battery are monitored during discharge, pinpointing subtle deformations and strain patterns as potential precursors to failure. This data, coupled with voltage and temperature measurements, offer a more comprehensive understanding of the battery performance under extreme conditions, allowing for future methods to further enhance safety protocols for high-C discharge.

Keywords: lithium-ion battery, high-C discharge, Current interrupt device, Digital Image Correlation, battery safety, non-destructive evaluation.

1. INTRODUCTION

Reliance on batteries is expanding beyond portable electronics[1] to encompass electric vehicles, aviation, naval, and energy storage applications. Lithium-ion batteries stand out for their high energy density and longevity.[2] Specific applications, particularly those used as backup power for safety critical systems, will occasionally demand high or pulse currents[3] that exert considerable stress on batteries, potentially initiating a premature failure. This research aims to advance our understanding of how to preemptively recognize and mitigate the risk of current interrupt device (CID) failure due to gas expansion within the battery. By identifying pressure build-up early as seen in Fig. 1 it is predicted that further gas generation can be prevented before failure, ensuring reliability and safety across various applications.

Due to the high energy capacity of batteries, several safety measures are put in place to open the internal circuit of the battery before it fails catastrophically by entering thermal runaway. In this experiment, the limit of the CID in a Samsung 25R nickel cobalt aluminum (NCA) 18650 was observed. In commercial 18650 cells, such as the one used in this experiment, the CID consists of the top disk a second plastic insert, and a bottom disk.[4] In the event of abnormal operation such as high-C discharge, gas will be generated inside the cell.[5] This gas will pressurize the inside of the cell until the top disk is pushed away from the bottom disk irreversibly breaking the internal connection of the battery which in turn opens the circuit and prevents further current flow through the battery.

The safety features inside 18650 cells are crucial to ensure the safe operation of these cells. However, these solutions rely on irreversible changes to the structure of the cell which stops future use of the battery.[6] This paper aims to identify if another method of pressure sensing can be added to the other safety features in order to predict imminent failure in advance before the cell is permanently damaged.

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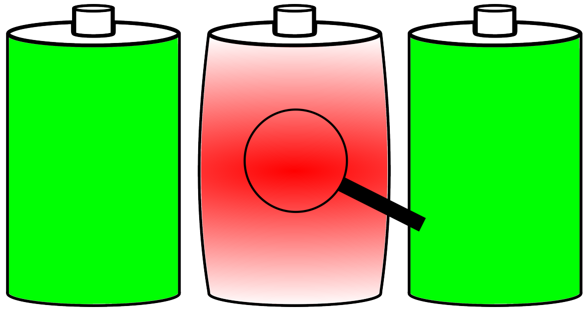

Figure 1. The battery that experiences excessive strain should be identified to reduce the likelihood of failure.

2. METHODOLOGY

To subject the 18650 lithium-ion battery to extreme stress, a load of 40 amps was imposed on the battery to induce rapid expansion and potential CID failure. To capture the progression of internal pressure buildup leading up to failure, the battery was speckle painted on its surface allowing the use of Digital Image Correlation

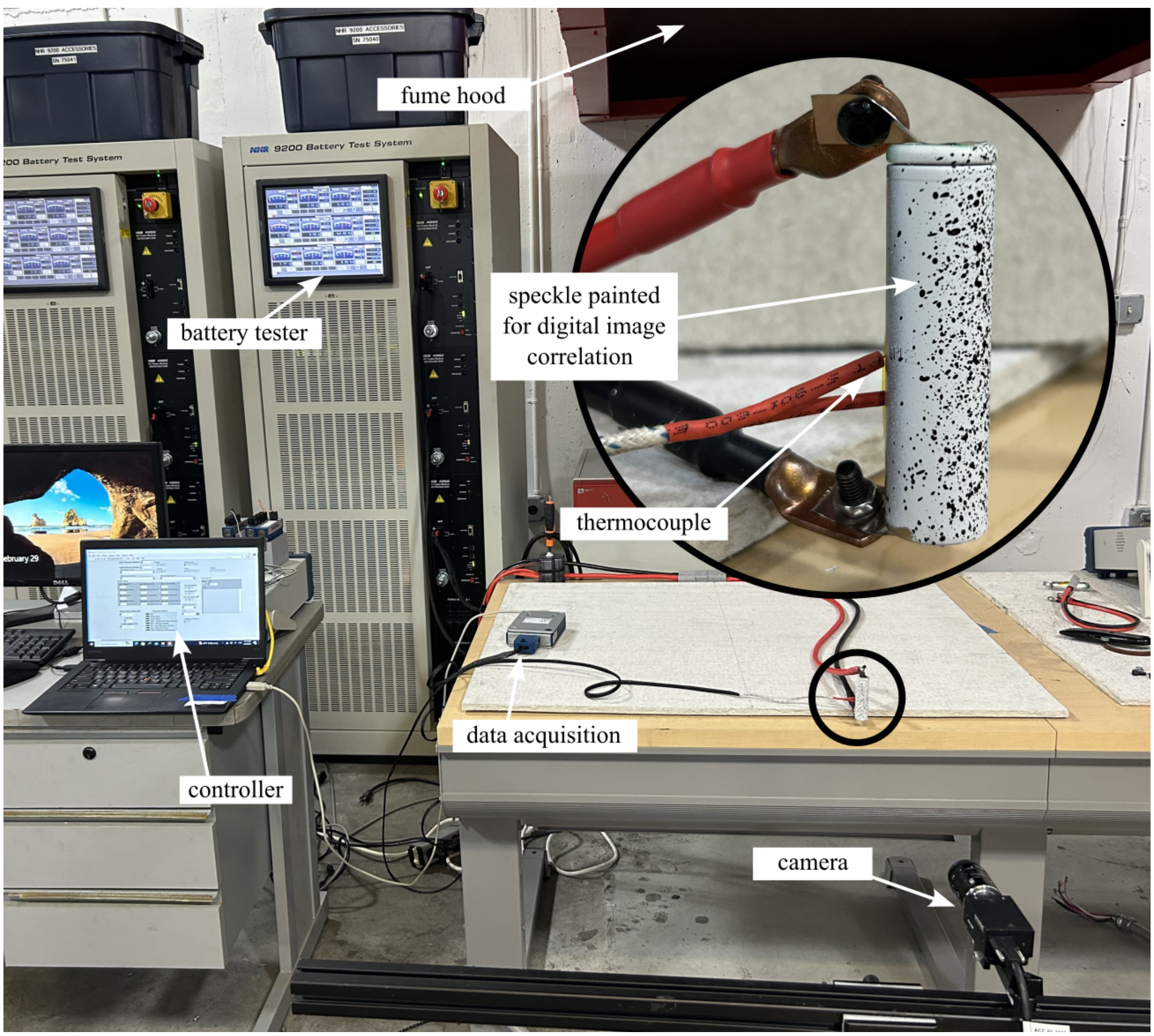

Figure 2. Battery testing setup showing the battery testers connected to a single 18650 cell under a high-C (40-A) discharge.

(DIC) for precise deformation tracking. A Samsung 25R at 100% state of health and state of charge was placed under a fume hood, equipped with a NI-9210 thermocouple signal conditioner for temperature monitoring, and observed with two high-resolution cameras set up to perform 3D DIC analysis. This configuration allowed the recording of deformation patterns on the battery casing, while at the same time tracking cell voltage and current measurements from the NHR-9200 battery tester. This multi-angled approach provides invaluable insights into the internal pressure dynamics and structural integrity up until the point of CID activation and subsequent test termination. The test current was set to 40 amps because it proved to consistently cause battery failure, offering a reliable basis for evaluating the effectiveness of our testing methodology.

Figure 2 presents the DIC setup employed to monitor strain on the battery's surface during the discharge process. Strain analysis is specifically focused on an area of 18 mm by 65 mm of the battery for both image clarity and simplicity. This approach facilitates a direct comparison between the strain experienced by the battery and discharge parameters. In this study, two 5 MP cameras, managed with VIC-snap software from Correlated Solutions, were utilized for image capture, while the VIC-3D software handled data processing. Strain readings from the DIC were simultaneously collected alongside current, voltage, and temperature using the outlined acquisition systems for each device. The findings from the DIC analysis were further processed to understand the strain distribution across the battery during the discharge. For DIC analysis, both the hoop and axial strain components were taken into account during the data processing phase.

3. RESULTS

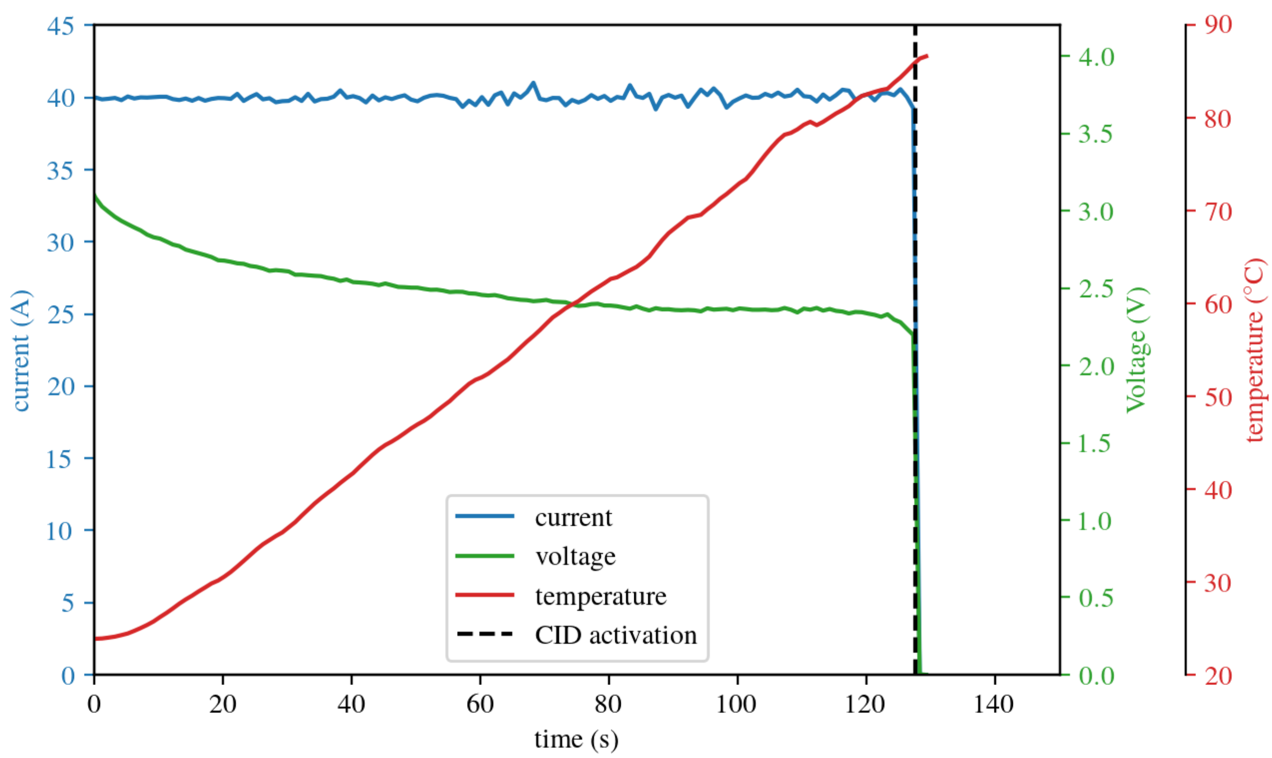

Figure 3. Experimental Electrical and Temperature response of 40-amp discharge.

Figure 3 presents the voltage and temperature response to the 40 amp current discharge of a cylindrical battery. These characteristics are observed against the hoop and axial strain measured in $\mu\epsilon$ seen in figure 4. The figure displays the constant increase of stress and provides insights into the pairing the mechanical and electrical performance. This behavior gives additional insight into how tracking strain on the surface of the battery could be correlated to gas generation and, in turn, potential failure of the battery CID.

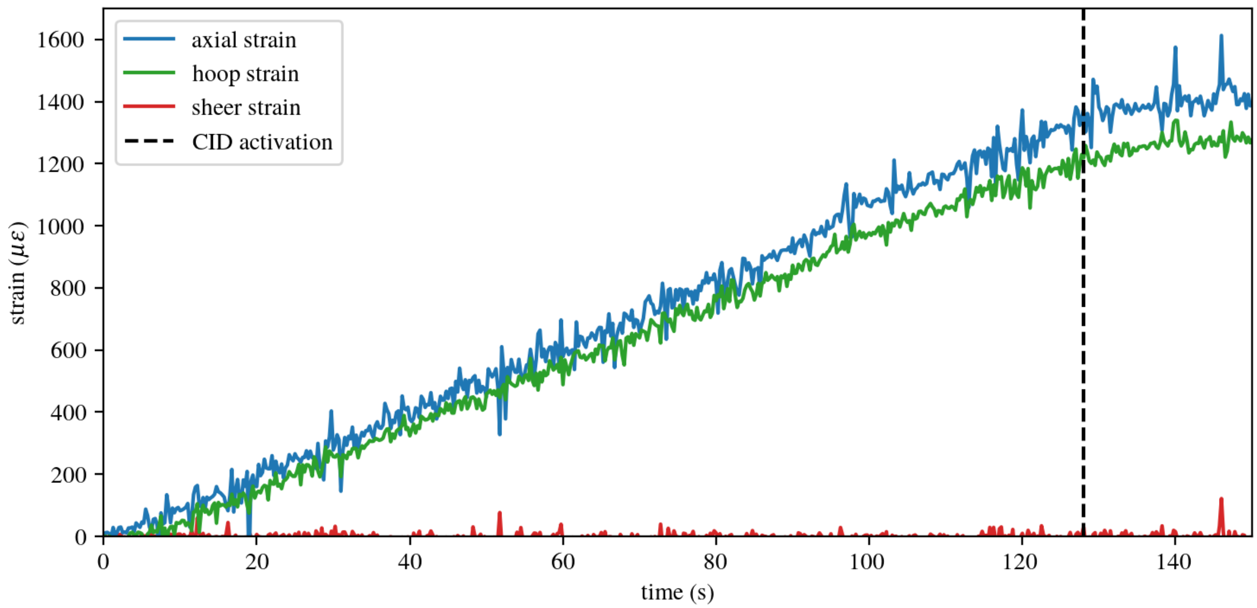

Figure 4. Strain response to 40 amp discharge.

Looking at the increase of strain in Figure 4, initially, the axial and hoop strains rise steadily as temperature increases. The strain increase from temperature should be isotropic and we see that for the first minute of the test. As the test progresses further we start to see the divergence of axial and hoop strain. This shows evidence of another force besides the temperature expansion that could be the gas generation leading to CID failure.

4. CONCLUSION

This exploratory study illuminates the potential for using battery deformation as a method of early detection of imminent CID failure in lithium-ion batteries under high-C discharge conditions. The findings show potential for the integration of non-destructive evaluation methods into battery monitoring systems, offering a proactive approach to ensuring safety and reliability during dangerous operations. Future research will focus on refining this early detection technique and explore ways to reduce the interference of temperature on the strain measurements. The implementations of strain gauges alongside DIC will be explored as alternate ways to detect the strain of battery expansion. These preliminary results show potential for future research.

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