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Thermal characterizations of a large-format lithium ion cell focused on high current discharges

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HIGHLIGHTS

- Thermal imaging of a large-format lithium ion cell up to 300 A discharge current.
- Long-time stable contact resistance to investigate inner cell characteristics.
- Study on absolute temperature and 3D distribution for cell and battery tests.
- Reveals interdependence between distribution of temperature and local SOC, I, SOH.
- Study of temperature characteristics for miscellaneously aged cells.

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ABSTRACT

The thermal behavior of a large-format lithium ion cell has been investigated during measurements on cell and battery level. High current discharges up to 300 A are the main topic of this study. This paper demonstrates that the temperature response to high current loads provides the possibility to investigate internal cell parameters and their inhomogeneity. In order to identify thermal response caused by internal cell processes, the heat input due to contact resistances has been minimized. The differences between the thermal footprint of a cell during cell and battery measurements are being addressed. The study presented here focuses on the investigation of thermal hot and cold spots as well as temperature gradients in a 50 Ah pouch cell. Furthermore, it is demonstrated that the difference between charge and discharge can have significant influence on the thermal behavior of lithium ion cells. Moreover, the miscellaneous thermal characteristics of differently aged lithium ion cells highlight the possibility of an ex-situ non-destructive post-mortem-analysis, providing the possibility of a qualitative and quantitative characterization of inhomogeneous cell-aging. These investigations also generate excellent data for the validation and parameterization of electro-thermal cell models, predicting the distribution of temperature, current, potential, SOC and SOH inside large-format cells.

1. Introduction

Thermal management of lithium ion batteries is a key issue in order to meet performance, range and lifetime requirements of automotive application. Especially for large-format lithium ion cells and high constant discharge current, which is requested for full electric vehicles, a proper thermal management can extend lifetime and range significantly. Key research tasks concerning lithium ion technology are directly influence by temperature distribution inside the cell. A case in point is the problem of low temperature performance and lithium-plating due to the strong temperature dependence of internal kinetics [1]. Furthermore, the operation limit of 55 °C and calendaric as well as cycle life, following Arrhenius law [2,3], are strongly affected by temperature. Thermal gradients, which are expected to negatively affect cell aging, are another temperature related issue.

In order to develop a sufficient thermal management strategy, it is essential to know internal and external cell parameters during high current discharges. Therefore, this study presents a comprehensive experimental investigation of these parameters up to 300 A discharge current. Former studies [4,5] are limited to currents smaller than 100 A. Even for these smaller currents, it can observe a significant heat flux from the cell conductors into the cell stack due to electrical contact resistances. In that case, this heat flux is the

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dominant heat source on the cell surface, masking the heat generation inside the cell originating from internal electrochemical processes. Hence, a solution minimizing the external contact resistance is demonstrated in this paper.

Furthermore, it is important to know the cold and hot spots inside the cell during all operating states for online diagnostic analysis during battery operation. Consequently, this work is also dedicated to the identification of hot and cold spots during different operating states by analyzing measurements on cell and battery level, pointing out the difference between these two test environments as well as their transferability.

The underlying study exhibits results for one lithium ion cell type, providing an experimental standard in order to compare the thermal as well as electrical behavior of lithium ion cells also with different chemistry.

For a thermal management strategy it is not sufficient to know the current cell parameters. In addition to that, models and algorithms are needed to predict the thermal behavior. This kind of models are also necessary in order to support diagnostics, because in common battery designs possibilities and locations for measuring are strongly restricted by limited construction space, cost and cell specifications. The measurements shown here provide excellent data for parametrization and validation of such models. Moreover, electro-thermal models reduce development time and costs significantly during the engineering process by providing the possibility to reduce testing cases and time between iteration steps of potential thermal management strategies.

2. Design of experiment

In order to identify internal cell processes during high current tests, it is necessary to consider special issues in the design of experiment. Furthermore, measuring cell behavior and temperature distribution over the cell in a closed battery system yields to challenges on measurement techniques and systems. These difficulties and the comparability of measurements on cell and battery level will be addressed by presenting the developed design of experiment in the following section.

2.1. Experimental setup on cell level

The investigated lithium ion cell is a 50 Ah pouch cell with graphite anode coated on a copper foil and NMC chemistry on an alumina cathode. The cell contains a highly porous ceramic separator. The dimensions of the cell are around 31 cm in length, 17 cm in height and 1.3 cm in width. The cell exhibits two about 10 cm long tabs on the longitudinal edge.

An overview of the experimental setup on cell level is shown in Fig. 1. The cell is located in a climate chamber on an isolating plastic mat. Thermal imaging measurements are performed to investigate the temperature distribution on the pouch foil of the cell. In order to avoid reflection in the infrared spectra and to ensure a constant emission coefficient on surface the cell was painted in black with a camera lacquer. In addition, all metal surfaces are covered by paper towel. PT-100 electrical sensors are located on the backside of the cell in order to compare the front and backside of the cell faced different boundary conditions. Due to that fact, the temperature profile in the direction perpendicular to the cell stack can be evaluated. Both measurement systems exhibit an accuracy of ±0.01 K. The camera records with a resolution of 640 times 480 pixels.

The principal task is to develop a long time-stable contact resistance for the connection of the load cables. A comparable small electrical contact resistance is inevitable to study internal cell processes during high current discharges, suppressing the dominant heat flow from the contact area inside the cell. To solve this problem it has to be avoided the growth of the oxide layer on the alumina cathode, leading to a high electrical transient resistance. The tests, this study is based on, last for more than one week. In order to ensure comparable and reproducible conditions a bolted connection can not be used. Fig. 2 presents an investigation on the electrical contact resistance for different load cable connections.

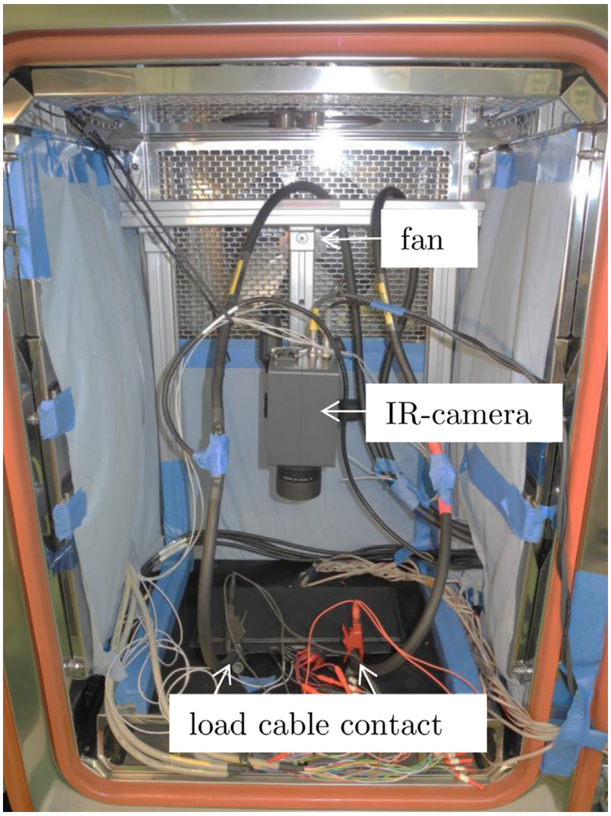

Fig. 1. Experimental setup to perform thermal imaging measurements on cell level; showing lithium ion cell in climate chamber prepared with Tetanal camera lacquer in order to avoid reflections.

The objective is to achieve a long-time stable connection with a contact resistance around 30 μΩ, which is comparable to a welding used in common batteries. This kind of contact resistance avoids significant heat input into the cell. For instance, a contact resistance of 100 μΩ results in a power loss of 9 W during a 300 A discharge, which is almost 10% of the power loss of the full cell. This power dissipates at the small-sized contact area and, therefore, generates a significant heat flow inwards the cell.

Fig. 2 indicates that the untreated bolted connection at the cathode shows a significant increase in contact resistance within a few days in comparison to the untreated anode. Preventing the growth of the oxide layer on the aluminum contact, the cathode contacts isolated from air exhibit also a substantially lower increase for the contact resistance. The best results are obtained with the direct contact of the load cables to the cell conductor preparing the contact surfaces at the cathode with a conductive epoxy containing silver. The nickel coated copper conductor on the anode side exhibits no changes in the contact resistance.

Concerning the comparability between measurements on cell and battery level it has to be mentioned that the connection of the load cables causes non negligible heat extraction from the cell. This can not be prevented without greater effort. Additionally, environmental boundary conditions are different in a battery setup