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Two Accelerating Rate Calorimeters (ARC) from Thermal Hazard Technology have been installed, one ES-ARC for coin and small cylindrical cells and one EV-ARC for pouch cells and different measurement routines have been elaborated. These include cycling under isoperibolic and adiabatic conditions and heat capacity measurements.

The isoperibolic investigations were performed at specific temperatures in the range from 23 to 60 °C. In this range the applied environmental temperature did not largely influence the battery thermal behavior both for cylindrical and pouch cells. Generally, an overall exothermic behavior for discharging half cycles and an overall endothermic behavior for charging half cycles was observed. This can be seen in Fig. 1 which shows that e.g. the temperature difference on a cylindrical 18650 cell with $LiMn_2O_4$ cathode (LMO cell) during isoperibolic cycling and 1 C rate is 4 °C almost independent of the environmental temperature.

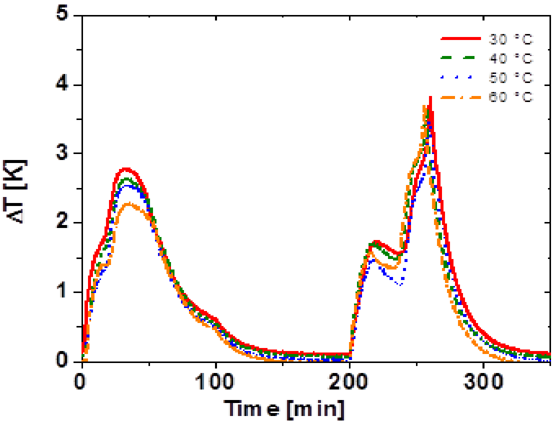

Fig. 1 Temperature difference on a cylindrical 18650 LMO cell during isoperibolic cycling at different temperatures and 1 C rate.

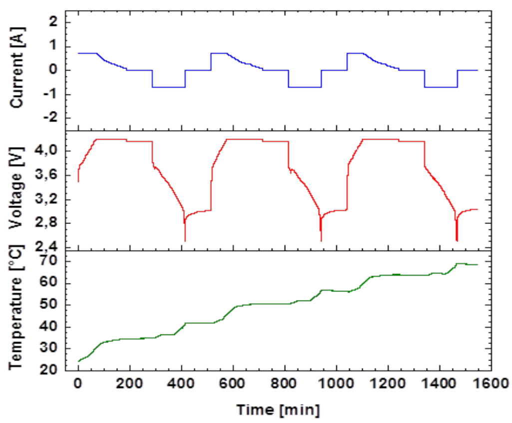

Fig. 2 Current, voltage and temperature curves on a cylindrical 18650 LMO cell during adiabatic cycling at 0.5 C rate starting at 23 °C.

Tests under adiabatic conditions more accurately simulate the actual operating environment if several cells are put in a battery pack and the neighboring cells hinder or prevent the heat transfer. Cells were studied at starting temperatures between 20 °C and 40 °C at 0.5 C rate. In this case the temperature of LMO cells was largely increasing over 3 cycles by more than 40 °C before reaching the safety limit temperature of 70 °C as shown in Fig. 2.

The next step was to measure the heat capacity by using a heater mat between two identical cells. In order to determine the heat dissipation rate the calorimeter constant had to be determined, which is the effective heat transfer coefficient times the cell surface area, by using dummy cells made of the aluminum alloy $AlMgSi_{0.5}$ EN AW-6060 F22 with the same dimensions as the cells. As an example Fig. 3 compares the heat dissipation rates at different discharging rates measured on a cylindrical 18650 LMO cell during isoperibolic cycling at 60 °C. By integrating over the heat dissipation rate and the enthalpy accumulation rate the total generated heat was determined. Using potentiometric measurements and current interruption technique the separation of reversible and irreversible parts of the heat was achieved. Moreover for larger pouch cells with a $Li(Ni_{0.33}Mn_{0.33}Co_{0.33})O_2$ cathode (NMC cell) it was possible to measure the surface temperature distribution during either isoperibolic or adiabatic cycling as shown in Fig. 4 for isoperibolic cycling at C/8 rate and 25 °C using 8 thermocouples (TC1-TC8) placed on the cell surface [1].

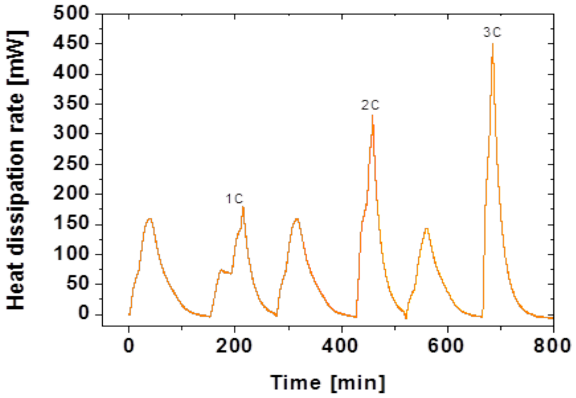

Fig. 3 Comparison of heat dissipation rates at different discharging rates measured on a cylindrical 18650 LMO cell during isoperibolic cycling at 60 °C.

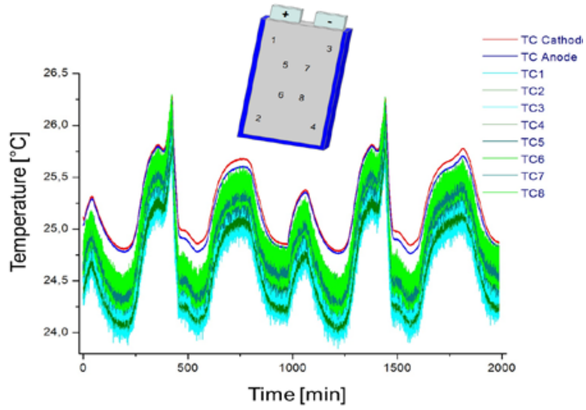

Fig. 4 Surface temperature distribution on a NMC pouch cell during isoperibolic cycling at C/8 rate and 25 °C.

All these data can be used as input data for thermal modeling and for the adaption of a thermal management system.

[1] D.M Cupid, E. Schuster, C. Ziebert, H.J. Seifert, Thermodynamics and phase diagrams for lithium ion batteries, in: Phase Equilibria - Materials for the future, Extended Abstracts of APDIC World Round-Robin Seminar, London, UK, June 25, 2012, Institute of Materials, Minerals and Mining, 1 Carlton House Terrace, London, UK, ISBN 978-1-86125-174-9, (2012) 29-32.