Development of Thermal Models of Lithium-ion Batteries for Electric Vehicles

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The development of battery electric vehicles (BEVs) has been intensively studied owing to an increase in the environmental concerns. Above all, the advancement of lithium-ion batteries (LIBs) are quite important as energy storage devices in BEVs. As the temperature environment affects the performance, life, and safety of LIBs, predicting the thermal behavior of LIBs is required for development of BEVs. The prediction of thermal behavior is also important for the development of LIBs and next-generation LIBs to clarify the required performance for BEV applications. In this study, we built electrochemical heat generation model and heat transfer models using an LIB cell of 60 Ah class LIB and a 24-cell module from a commercially available BEV. Thereafter, we used experimental data to examine the validity of the thermal model.

The electrochemical and thermal properties of the cell were studied to build the thermal model. The heat generation model caused by cell overpotential was built using an equivalent circuit model (Fig. 1). Fitting the charge/discharge characteristics of the cell and a small cell reconstructed using the cell electrodes yielded the equivalent circuit parameters. The calculated parameters accurately reproduced the charge/discharge characteristics of the cell during driving-simulated charging and discharging. In addition, the reversible entropic heat of the cell was calculated by measuring the temperature dependence of the open circuit voltage. With the thermal properties of the measure cell, we built a cell model using the electrochemical heat generation and heat transfer models. We confirmed that the cell thermal model could reproduce the thermal behavior of the experimental data with an error of up to 1.0°C. Thereafter, we built a module model by incorporating the cell model into the computer aided design (CAD) model of the module. The temperature distribution calculation after 1C-constant current/constant voltage charging is shown in Fig. 2. The temperature change of the experimental measurement point was compared to that of the calculated data in Fig. 3. The simulation accurately reproduced the thermal behavior, with an error of up to 3.0°C. The thermal behavior of LIB cells and modules could be predicted using cell electrochemical properties and a conventional heat transfer model with component thermal properties. Furthermore, the cell electrochemical parameters can be obtained using a reconstructed small cell, implying that the BEV pack level performance and thermal behavior can be predicted using the small sized next-generation LIBs that are currently under development.

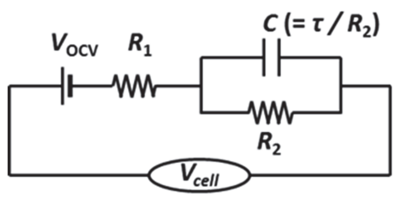

Fig.1 Equivalent circuit model for modeling cell characteristics.

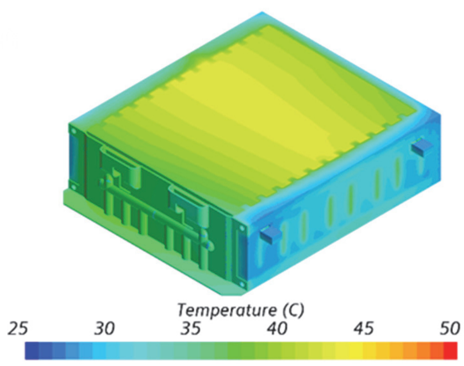

Fig.2 Result of temperature distribution calculation after 1C-CCCV charging of a model of an LIB module.

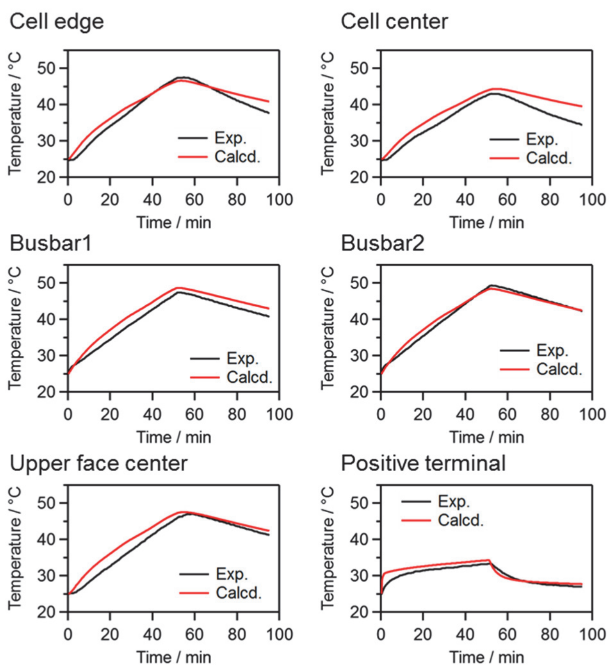

Fig.3 Validation results of a model of an LIB module.