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Development of accelerated degradation test method for lithium-ion batteries for EV and PHEV applications

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Abstract

In FY2007, the national project “Lithium and Excellent Advanced battery Development (Li-EAD)” was launched in Japan. Central Research Institute of Electric Power Industry (CRIEPI) has started to research and develop the basic technologies required to evaluate the safety and performance of advanced Li-ion batteries in conjunction with Japan Automobile Research Institute (JARI) and the National Institute of Advanced Industrial Science and Technology (AIST). In particular, CRIEPI aims to develop an advanced method for evaluating the life of Li-ion batteries. In the Li-EAD project, we have been examining an accelerated life evaluation test for high-energy and high-power Li-ion batteries developed as power sources for electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs). We have developed methods for accelerating the degradation of Li-ion batteries to evaluate the long-life durability in order to promote the R&D of Li-ion batteries for commercializing EVs and PHEVs. Assuming that PHEVs have an all-electric mode, we separated the driving schedule into three modes: charge-depleting (CD) mode, charge-sustaining (CS) mode, and recharge mode. Additionally, we considered the PHEV parking time (battery rest time), and we examined the acceleration factors by performing storage tests at various temperatures, state of charge (SOC), and storage modes.

Keywords: PHEV, lithium battery, battery calendar life, battery SoH, state of charge

1 Introduction

The reduction of greenhouse gas (GHG) emissions is of great importance for our future. Transport is responsible for more than 20% of world energy-related GHG emissions, three-quarters of which is emitted by road vehicles. Pressing problems related to transport include air pollution and fossil fuel dependence. Vehicles with low or no emissions should be introduced as soon as possible. The Ministry of Economy, Trade and Industry (METI) of Japan has studied strategies for reducing fossil fuel consumption in order to decrease GHG emissions and has proposed a policy titled “A New Strategies of Energy in Japan,” and an initiative of fuel for next-generation vehicles. In 2007, METI and the New Energy and Industrial Technology Development Organization (NEDO) launched a new project, “Lithium and Excellent Advanced Battery Development (Li-EAD),” to research and develop high-energy-density and high-power lithium batteries for low-GHG-emission vehicles, electric vehicles (EVs) and plug-in or hybrid vehicles (PHEVs). Central Research Institute of Electric Power Industry (CRIEPI) has started to research and develop the basic technologies necessary to evaluate the safety and performance of advanced lithium batteries and has started to collect data to establish codes and standards in conjunction with Japan Automobile Research Institute (JARI) and the National Institute of Advanced Industrial Science and Technology (AIST). In particular, CRIEPI aims to develop an advanced method for evaluating the life of Li-ion batteries.

In a previous national project, “Development of Lithium Battery Technology for Use in Fuel Cell Vehicles and Hybrid Electric Vehicles,” CRIEPI attempted to develop technology for evaluating Li-ion batteries. We evaluated prototype cells and battery modules developed by battery manufacturers by a consistent test procedure. We developed a method for evaluating the calendar life of Li-ion batteries for fuel cell vehicles (FCVs) and proposed evaluation test procedures. The proposed method of estimating calendar life for Li-ion batteries involved a combination of an accelerated life test and extrapolation. It was clarified that a high state of charge (SOC), a high environment temperature, and discharge/charge power stress have the effect of accelerating the cycle life and lifetime evaluation of Li-ion batteries [1].

The conditions of use required for secondary batteries for EVs and PHEVs are different from those for hybrid electric vehicles (HEVs). In the case of HEVs, the battery is usually around 50% SOC, and pulse discharge/charge is repeated if necessary. In this case, several percent of the capacity will be used for the FCV or HEV battery used an auxiliary power source. Therefore, we can diagnose the battery state of health (SoH) by examining the battery characteristics at 50% SOC. On the other hand, in the case of EVs and PHEVs, 70 - 80% of the capacity will be used, and the battery will be almost fully charged each day. Therefore, in comparison with the battery for HEVs, the voltage range in which the battery for PHEVs can be used is wide, and it is necessary to diagnose the battery SoH after having grasped the battery characteristics over a wide range of SOC.

In this work, as the first step toward the proposal of an accelerated life evaluation test method for Li-ion batteries for PHEVs, we extracted the valid acceleration factors that can shorten the life evaluation test period.

2 Experimental

2.1 Test cells

Our test is intended to evaluate Li-ion batteries for PHEVs under development. However, in the early stage of development, it was difficult for us to obtain test cells designed for PHEVs. Therefore, battery manufacturers provided us with prototype Li-ion batteries designed for FCVs and HEVs for this test that were developed in the previous national project. The main specifications of the provided batteries are shown in Table 1.

Table1: Main specifications of test cells.

	1 Wh	20 Wh
Cell Type	Cylindrical	Prismatic
Nominal Capacity	260 mAh	7.2 Ah
Cathode Material	Mn-oxide based	Ni-oxide based
Anode Material	Carbon	Carbon

2.2 Test conditions and procedure

2.2.1 Acceleration factors considered in the driving schedule of PHEVs

We assumed the daily driving schedule of PHEVs to consist of the following (shown in Figure 1): vehicle driving in charge-depleting (CD) mode and charge-sustaining (CS) mode, parking (battery rest time) at a low SOC (30%), recharging, and parking at a high SOC (90%). In this paper, we carried out a storage test that simulated the parking time, which was assumed to comprise the largest part of the daily driving schedule, and attempted to clarify the tendency of battery degradation under different storage conditions and to extract valid acceleration factors for battery life evaluation. As acceleration factors, we adopted the test temperature, SOC, and storage mode.

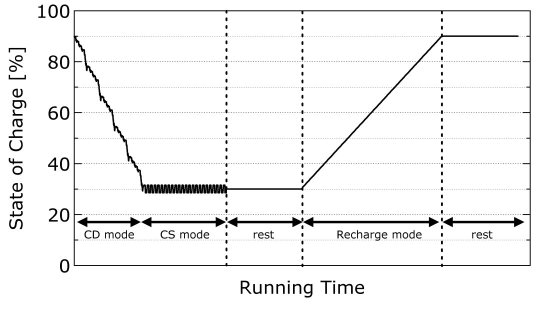

Figure1: Conceptual graph of PHEV cycle pattern.

2.2.2 Measurement of the standard capacity

The nominal capacity of the test cells mentioned in 2.1 was measured by the battery manufacturers. In this work, we adopted the $C_1/1$ rate (the rate corresponding to completely discharging a fully charged device in exactly one hour [2]) as the discharge current for the capacity test to shorten the test time. Therefore, we measured the standard capacity (Q_{STD}) at $C_1/1$ rate at 25 ^oC.

2.2.3 Definition of the standard current

We used the C-rate to express charge/discharge current in 2.2.2. However, there is the case that Q_{STD} is quite different from nominal capacity. Therefore, we define I_t as the current corresponding to Q_{STD} for a one-hour discharge.

2.2.4 Definition of SOC

In *Battery Technology Life Verification Test Manual* [2], SOC is defined as "the available capacity in a battery expressed as a percentage of actual capacity. " However, the standard for SOC changes during a battery life evaluation test as the battery capacity decreases. In this work, we define SOC with the initial open-circuit voltage, which is measured on the basis of the quantity of electricity calculated from Q_{STD}, to simplify the test procedures.

2.2.5 Storage test

Three types of storage test were carried out as follows:

Mode 1: Test cells are charged to a target SOC and stored in an open circuit at various temperatures. (This is known as the conventional storage test or "shelf-life test.")

Mode 2: Test cells are charged to a target SOCand maintained at the same voltage as the SOC defined in 2.2.4.

Mode 3: 1 I_t charge/discharge cycle with 5% of SOC swing and 4 h rest at the target SOC are combined in this mode. For example, for a target SOC of 90 %, a charge/discharge cycle at 85 – 90% SOC and 4 h rest at 90% SOC are performed.

2.2.6 Periodic performance test

Each storage test includes periodic performance tests such as a capacity test (1I_t rate), and AC impedance and DC-IR measurements (1, 3, 5, 10 I_t rate for 10 s) at 30% SOC and 25 ^oC. The power density is calculated from DC-IR data and used to confirm cell performance.

3 Results and Discussion

3.1 Effects of temperature and SOC on battery degradation

The behaviours of capacity retention and power retention for 1 Wh cells were measured by storage tests (Mode 1) at 25, 40, 50, and 60 ^oC. Figure 2 shows the capacity retention (a) and power retention (b) against the number of storage weeks. All cells were stored at 90% SOC. The figure indicates that the rates of degradation of capacity and power increase with the test temperature. The same tendency was also observed in the test results of our previous work [3]. In future, we plan to obtain the maximum temperature that is valid as an acceleration factor from data analysis and postanalysis studies [4].

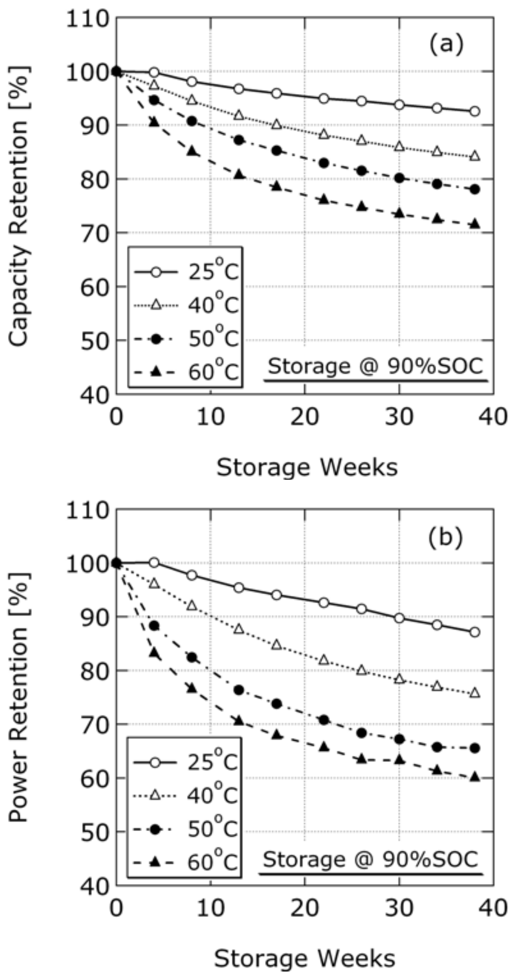

Figure2: Capacity retention* (a) and power retention (b) against the number of storage weeks in storage tests (Mode-1) at 90% SOC for 1 Wh cells at 25, 40, 50, and 60 ^oC.

The behaviours of capacity retention and power retention for 1 Wh cells were also measured by storage tests (Mode 1) at 30 and 90% SOC. Figure 3 shows the capacity retention (a) and power retention (b) against the number of storage weeks. All cells were stored at 40 ^oC. There is no capacity fade and little power fade (only 5% in 9 months) at 30% SOC. These results indicate that we can disregard most of the degradation occurring during parking at a low SOC and that we should only carry out storage tests at a high SOC. By carrying out tests under these conditions, a shortening of the test period is expected.

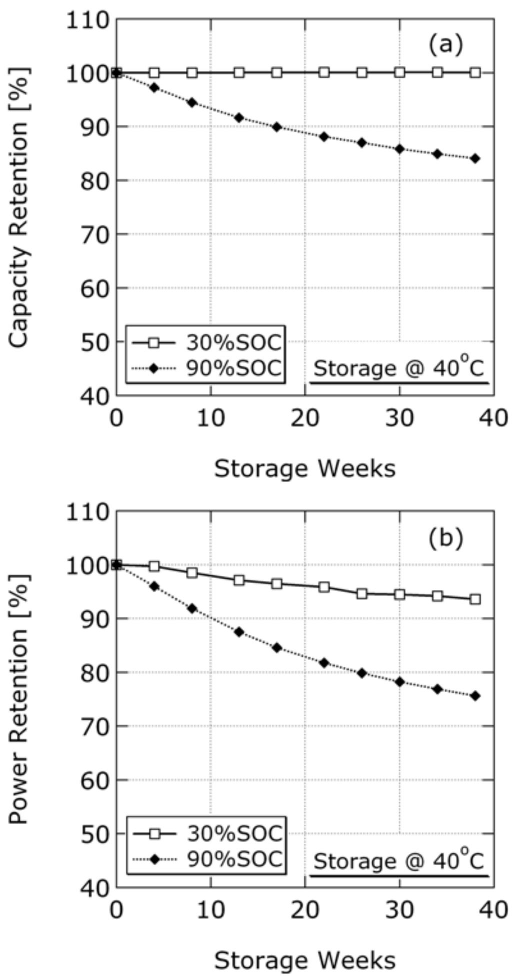

Figure3: Capacity retention* (a) and power retention (b) against the number of storage weeks in storage test (Mode-1) at 40 ^oC for 1 Wh cells at 30 and 90 % SOC.

*In capacity test for 1 Wh cells, constant capacity (260 mAh) charging was carried out.

3.2 Effects of storage mode on battery degradation

The behaviours of capacity retention and power retention for 20 Wh cells were measured by various storage tests at 50 ^oC. Figure 4 shows the capacity retention (a) and power retention (b) against the number of storage weeks. All cells were stored at 90% SOC. In all storage modes, capacity fade and power fade are 5% in 4 months. These results indicate that the storage mode does not have a significant effect on the rate of degradation at 90% SOC. Therefore, valid to carry storage tests can be carried out in the simple and conventional mode (Mode 1).

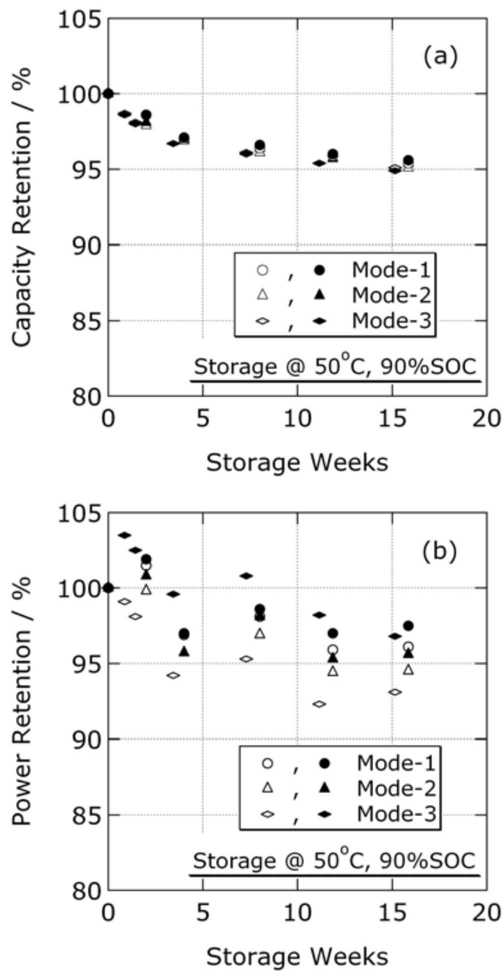

Figure4: Capacity retention (a) and power retention (b) against the number of storage weeks in storage test at 90% SOC for 20 Wh cells in various storage modes.

4 Summary

1. A high temperature and high SOC are promising acceleration factors for the accelerated evaluation of the life of Li-ion batteries for PHEVs.
2. The battery performance degradation at 30% SOC is sufficiently small in comparison with that at 90% SOC for us to disregard most of the degradation occurring during parking at a low SOC, and we should only carry out storage tests at a high SOC.
3. The storage mode does not have a significant effect on the rate of degradation during the storage test.

Acknowledgments

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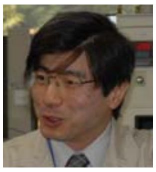

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