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Evaluation of the influence of JC08-based cycle stress on batteries in plug-in hybrid electric vehicle

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Abstract

Although plug-in hybrid electric vehicles (PHEV) are expected to reduce both consumption of petroleum and emission of CO_2 in comparison with ordinary hybrid electric vehicles (HEV), these advantages strongly depend on the reliability of batteries in PHEVs. For instance, their capacity reduction by degradation shortens the range of the travelling distance with electrical energy. However, there are no concrete test methods to evaluate the degradation of the batteries. In order to construct a test method for the evaluation of battery degradation, load conditions that reflect the situation of an actual vehicle in use has been investigated. In this study, the degrees of influence of two load terms, both a specific charge/discharge load (corresponding to the cycle life) and a thermal load (corresponding to the calendar life), in the capacity reduction were compared and a condition for an accelerated test was also discussed.

Keywords: PHEV (plug in hybrid electric vehicle), lithium battery, state of charge, regulation

1 Introduction

Plug-in hybrid-electric vehicles (PHEV) are expected to reduce both petroleum consumption and CO_2 emission more than usual hybrid electric vehicles (HEV). A PHEV has two different energy sources, which are petroleum and electricity that is charged from house outlets. During a short trip, for example 10 to 20 km, this vehicle could be mainly driven by electricity and save petroleum. Also, in areas where electricity is generated by low CO_2 emission systems, such as nuclear power generation, the use of this vehicle contributes to reduce CO_2 emission.

However, these advantages strongly depend on the reliability of a battery in a PHEV. For example, the range of the travelling distance with electrical energy is approximately proportional to the capacity of the battery. Therefore, if the capacity of the battery decreased from the initial capacity, the range would be shortened from its initial range. Consequently, the PHEV would be driven with an engine, and both petroleum consumption and CO_2 emission would increase even in a short trip.

Nevertheless, the influence of battery degradation on the environmental performance, such as the fuel economy, of PHEV is not yet accounted for in the Japanese approval test for PHEV [1].

For the evaluation of battery degradation, the construction of appropriate load conditions that reflect the actual usage of batteries in a PHEV is required. The degree of battery degradation, such as reduction in capacity and increase in internal resistance, varies from load conditions that basically consist of both thermal and electrical load factors. Thus, load conditions, especially to evaluate battery degradation in a short period (such as 3 to 6 months), have been studied with the conditions that were constructed by thermal and electrical load factors [2].

In our previous report, the capacity reduction of a test battery that had experienced a specific charge/discharge load that simulated JC08 drive mode at 25 deg. C (ambient temperature) was measured and reported [3]. The results illustrated that the capacity reduction of the test battery appeared much earlier than that of the calendar lifetime of the test battery. It suggested that the capacity reduction was strongly affected by the influence of the specific pattern that based on JC08 drive mode. However, the degree of influence both thermal and electrical load in the reduction has not been investigated.

In this paper, the influence of thermal load on the capacity reduction is firstly detailed. Then, the degree of influence of two load terms, both a specific charge/discharge pattern load (corresponding to the cycle life) and a thermal only load (corresponding to the calendar life) on the capacity reduction are compared. In addition, an example of an accelerated test by raising the ambient temperature is also discussed.

2 Test method

The measurement system is drawn in figure 1. 12 test battery cells assembled in the same lot management condition were prepared for this experiment. A group of 3 test battery cells was preserved in a test chamber that was controlled to keep the chamber interior at a constant temperature. The temperatures of the chambers were 25, 40, 55 and 70 deg. C, respectively. All test battery cells were float charged at 4.0V.

The capacity Ah of each of the test battery cells in discharge at 1C (15A) was measured once every week. The voltage of test battery cells was set at 4.0V before they were soaked in each of temperature conditions.

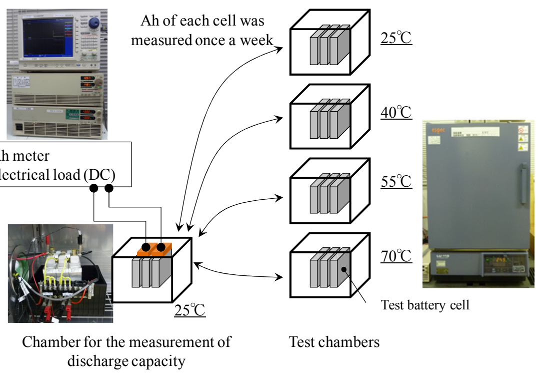

Figure 1: The measurement system

The specification of the test battery cell is displayed in Table1. The type of the test battery cell was the same as the batteries were used in the previous experiment [3].

Table1: the specification of the test Battery

capacity	15Ah
volume	0.36L
weight	0.91kg
Energy density	73Wh/kg
Power density	470W/kg
Maximum current	200A

This test battery cell consisted of LiC_6 negative electrode, $LiMn_2O_4$ positive electrode and organic electrolyte that included $LiPF_6$. The test battery does not include any specific chemicals to improve its durability against both thermal and charge/discharge load.

3 Results

The discharge capacities of the test battery cells were obtained from the integration of measured discharge current. The current of each of the test battery cells was measured until the voltage of each of the cells reached the lowest limit, during the discharge. An example of the voltage variation in the discharge is shown in figure 2. The blue curve in figure 2 is the voltage of the test battery cell that had not experienced thermal load. The red curve in figure 2 shows the voltage variation of the cell that was stored at 40 deg. C for 1190 hours. The voltage of the test battery cell that had experienced thermal load dropped early in comparison with the voltage variation of the test battery cell with no thermal load. The period from 0sec to the time that the red curve in figure 2 fell to the same value with the lowest value of the blue curve became short and the integration period to calculate Ah for the red curve was shortened to approximately 3200s.

The average calendar lifetime of the test battery cells was shorter than that of ordinary lithium ion batteries that were modified to meet the demand for car usage. The capacity of the test battery cell (@55deg. C) decreased by 20% within 1000 hours. In comparison to this, the capacity reduction of a cell that was modified for commercial use was less than 1% for the same period. (For example [4])

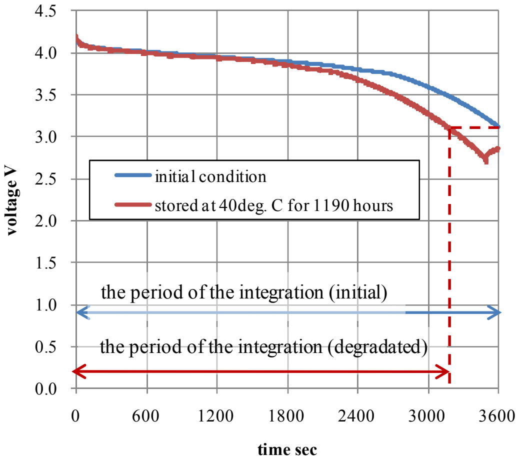

Figure 2: a comparison of the voltage curves of a test battery cell both not-stored and stored at 40 deg. C

Figure 3 shows the curves of average discharge capacity of the test battery cells. The curve of the average capacity in 70 deg. C fell down to the level of 60% of the initial capacity within 1000 hours. In contrast, the curve of the average capacity of the test battery cells in 25 deg. C sloped down moderately.

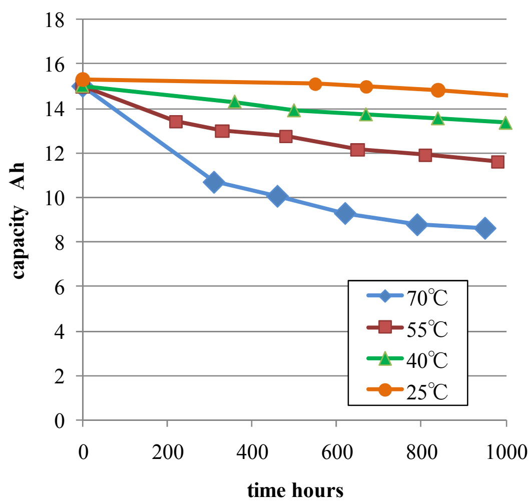

Figure 3 decrease of Ah capacity in each temperature conditions

4 Discussion

4.1 Calendar life of the test battery cell

In this section, the characteristics of the capacity reduction of the test battery cells were analyzed. The capacity reduction by only thermal load was compared to that of the specific charge/discharge pattern that simulated JC08 drive mode in the later section.

By referring other reports regarding the reduction process of capacity of lithium ion battery the measured results were analyzed. The reduction process of capacity has been investigated with the increase of the thickness of SEI (Solid Electrolyte Interface) in a lithium ion battery. Broussely et al. proposed a model that the increase in the thickness of SEI changed the electrical conductance and represented a function to relate the increased thickness of SEI to the conductance [5]. Ploehn et al. followed with a further analysis on the growth of SEI with a solvent diffusion model and showed that both capacity loss and SEI thickness are proportional to the square root of time [6]. By referring these studies, the measured capacity loss against the square root of days was plotted (figure 4).

From the result, in the condition that the ambient temperature was below 55 deg. C, the capacity loss of test battery cells was proportional to the square root of days. Although the test battery cells had relatively short lifetime, the characteristic of the capacity loss against thermal load was same as that of other typical lithium ion batteries.

Only the variation of the capacity loss under the condition of 70 deg. C was not proportional against the square root of days and it suggested that other degradation processes, for example the degradation in the electrolyte, might be influenced.

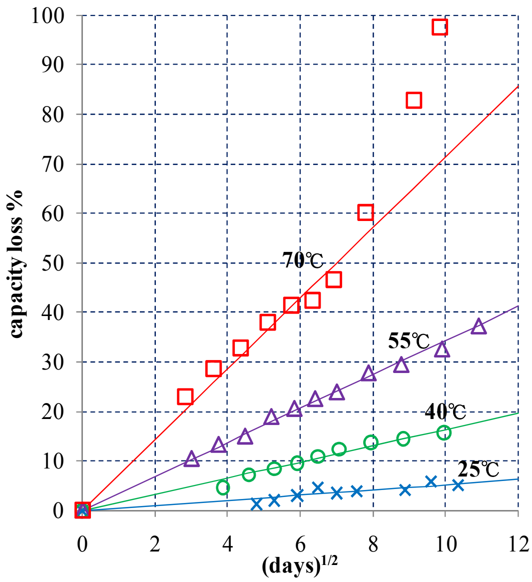

Figure 4 decrease of Ah capacity in each temperature conditions

The correlation between the capacity loss and the ambient temperature in the results of figure 4 will allow the setting of conditions for an accelerated test. For instance, under the condition of 25 deg. C, 7% of capacity was lost in 144 days. In contrast, under the condition of 55 deg. C, the same amount of capacity was lost in 4 days. The capacity reduction will be accelerated by raising the ambient temperature and the acceleration ratio becomes 36 in this case.

4.2 Influence of JC08 charge/discharge load pattern on the capacity reduction

As the second step, the influence of charge/discharge load on the capacity reduction was investigated.

In the previous study, the capacity reduction by the JC08 charge/discharge load pattern was observed [3]. Figure 5 represents the voltage variation of the test battery module. The test battery module was operated to trace a power variation pattern. The power variation pattern was calculated from the function of kinetic energy of a vehicle when the vehicle was driven in the JC08 driving mode. The calculation of the power variation pattern was detailed in [3]. The SOC (State Of Charge) of the test battery module varied from 80% to 50% in one JC08 drive operation.

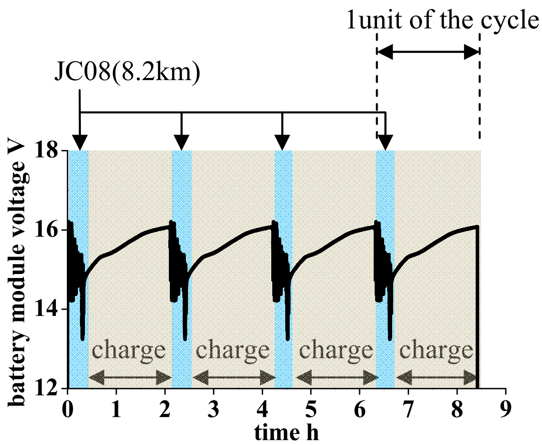

Figure 5 voltage variation of the test battery module with the JC08 charge/discharge patterns

Figure 6 illustrates the degree of influence of two terms, both the specific charge/discharge pattern that simulated JC08 drive mode and a thermal only load (without any electric load), on the capacity reduction. In figure 6, the capacity reduction with the JC08 charge/discharge pattern is the red curve and the capacity reduction with the thermal only load is the black curve.

In figure 6, it can be seen that 7% reduction in discharge capacity was influenced by the specific pattern that simulated JC08 drive mode. The total ratio of discharge capacity reduction of the test battery module was 17% in 300 days (600 units of JC08 charge/discharge pattern). 17% reduction in the discharge capacity included 10% reduction by thermal only load. Therefore, 7% reduction in discharge capacity was expected to be caused by the load of the JC08 charge/discharge pattern.

7% reduction in discharge capacity will be caused in a short period, in comparison with 300 days. In the experimental condition, the test battery module had experienced 600 units of JC08 charge/discharge pattern over 300 days. The period of 300 days included intervals without charge/discharge periods, for the maintenance of the experiment system. One unit of the pattern cycle in figure 5 took about 2 hours, thus, 7% reduction in the discharge capacity will be caused in the period of about 50 days.

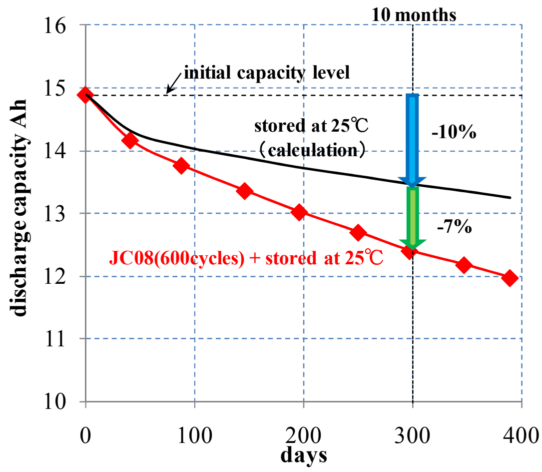

Figure 6 variation of the discharge capacity against days

4.3 Example of an accelerated test condition

In this section, a condition for an accelerated test is discussed. As a case study, an accelerated test for reducing the period of 17% decrease in the discharge capacity is projected. The period is shortened from 300 days to 50 days.

As the explanation in the above part of this chapter, the test battery module could experience 600 units of JC08 charge/discharge pattern in the period of about 50 days. Thus, the modification of condition of JC08 charge/discharge pattern to accelerate the capacity reduction is not necessary. The continuous application of the pattern cycle of figure 5 on the test battery module, without intervals, will provide 7% reduction in discharge capacity in the period of 50 days.

In comparison with the electrical load, the acceleration of discharge capacity reduction by thermal load is required to cause 10% reduction in discharge capacity in the period of 50 days. From the result in figure 4, 39 deg. C was estimated for the 10% capacity reduction. The prediction of variation of the discharge capacity by only thermal load at 39 deg. C is shown as the black curve in figure 7.

In figure 7, the prediction of variation of the discharge capacity with the condition that consists of the JC08 charge/discharge pattern cycle and the thermal load (at 39 deg. C) was shown as the orange curve.

For the construction of accelerated test conditions, further discussion is required. In this case study, the influence of heat which the continuous of JC08 charge/discharge generated on capacity reduction was not estimated. The heat will also accelerate the capacity reduction and the discharge capacity will drop early in comparison with the estimation of the orange curve in figure 7.

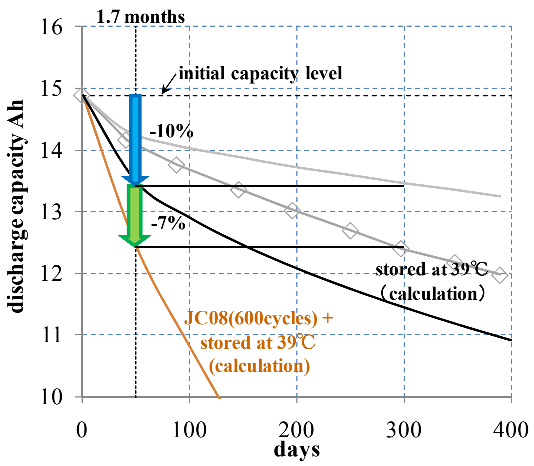

Figure 7 calculated curves of discharge capacity under the condition for an accelerated test (example)

5 Conclusion

The degree of influence of two load terms both the JC08 pattern cycle (corresponding to the cycle life) and the thermal load (corresponding to the calendar life) on the capacity reduction was compared. From the results, it was observed that the 7% difference in the capacity reduction between the specific pattern and the thermal only load.

In addition, the potential of a thermally accelerated test under the condition that consists of both the JC08 charge/discharge load and thermal load was shown. This methodology will contribute to evaluate battery degradation in a short period.

Acknowledgments

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References

[1] Road transport bureau of Ministry of land infrastructure transport and tourism Japan, Legal codes for automotive, pp.1171-1172, Daiichihoki, Japan (2008)

[2] H. Haskins, V. Battaglia, J. Christophersen, I. Bloom, G. Hunt and E. Thomas, Advanced Technology Development Program For Lithium-Ion Batteries Battery Technology Life Verification Test Manual (2005)

[3] T. Niikuni, T. Kawai and Y. Goto, An evaluation of the degree of battery degradation in plug-in hybrid-electric vehicles, EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, 13 To 16.May 2009, Stavanger, Norway

[4] V. Manev, Large Format Li Ion Batteries for Stationary Power Application, proceedings of the 5th Large Lithium Ion Battery Technology and Application (2009), p.11

[5] M. Broussely, S. Herreyre, P. Biensan, P. Kasztejna, K. Nechev and R.J. Staniewicz, Aging mechanism in Li ion cells and calendar life predictions, Journal of Power Sources, vol. 97-98 (2001), p. 13-21

[6] H. J. Ploehn, P. Ramadass and R. E. White, Solvent Diffusion Model for Aging of Lithium-Ion Battery Cells, Journal of the Electrochemical Society, vol. 151(3) (2004), p. A456-A462

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