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Development of the High Performance $LiFePO_4$ Cell for BEV/PHEV Application

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Abstract

Lithium iron phosphate ($LiFePO_4$) is a very attractive material because of its features such as high thermal stability and environmentally-friendliness. The large size prototype cells with capacity of 50 Ah were fabricated using $LiFePO_4$/graphite chemistry to evaluate durability performance. From the results of long-term tests over 2 years, it has turned out that the $LiFePO_4$/graphite chemistry meets the requirements of life performance of BEV/PHEV applications. 20 Ah prismatic Al-housing cells with $LiFePO_4$/graphite chemistry have been developed based on these experiences. The developed cells are able to supply the stable output-power more than 1100 W / kg over wide range of 10 to 90% SOC. In addition, the cells exhibit the higher acceptability to be charged over 90% SOC within 30 minutes at 25 ^oC. Furthermore, it was found that the cells showed the superior safety of EUCAR hazard level 3 on the crush and overcharge tests. From these results, the 20 Ah cells are promising for BEV/PHEV applications.

Keywords: BEV, PHEV, battery calendar life, cycle life, safety

1 Introduction

Electrification of automotive is one of the most important technologies to reduce the greenhouse gas emission. We have already carried out mass production of 50 Ah lithium-ion cells for BEV application since 2009 [1]. After that, we have produced various lithium-ion cells with large capacity for several electric vehicles and industrial applications.

Lithium-ion cells installed in the electric vehicles have to promise the higher safety and longer life similar to the gas vehicle. $LiFePO_4$ has superior thermal stability [2] compared with conventional positive active materials such as $LiMn_2O_4$ and $LiNi_xCo_yMn_zO_2$. In addition, $LiFePO_4$ is expected as the availability and the cost saving because of its environmentally-friendliness. Therefore we have researched the characteristics of $LiFePO_4$ since the early 2000s, and the large-sized-prototype cells have been evaluated for the application of electric vehicles [3]. Furthermore, we have confirmed by results based on long-term endurance tests over 2 years that our $LiFePO_4$/graphite cells satisfy the requirements of life performance of the battery for BEV/PHEV applications.

This paper describes the electrical performance and the reliability of the newly developed 20 Ah prismatic Al-housing cells with $LiFePO_4$/graphite chemistry.

2 Durability of $LiFePO_4$/graphite cell

Long-term durability tests were carried out using prototype cells with large capacity of 50 Ah. The specification and appearance of the cells are shown in table 1 and Fig. 1. The cells apply the carbon-loaded $LiFePO_4$ as positive active material, the graphite as negative active material, and the structure parts used by commercialised cell for BEV application, respectively.

The results of long-term calendar life tests at various temperatures and SOCs are shown in Fig. 2. It was found that the capacity fading was affected by the change of temperature and SOC level.

Fig.3 shows the cycle life performances at 25 and 45 ^{o}C. The capacity retention after 6000th cycle at 25 ^{o}C is a remarkably high value of 80%. The lifetime estimation in various driving conditions can be carried out using the degradation factor calculated by these long-term durability test results. For example, the prototype cells show the stable performance over 10 years without serious degradation under the typical usage condition such as 1 cycle per day and 300 days driving per year at warm climate.

Table 1 Specifications of 50 Ah prototype cell for durability tests.

Rated capacity	/ Ah		50
Nominal voltage	/ V		3.3
Dimensions	/ mm	H	100*
		W	44
		T	171
Volume	/ l		0.75
Mass	/ kg		1.70

*Without terminal height

Fig. 1 Appearance of 50 Ah prototype cell.

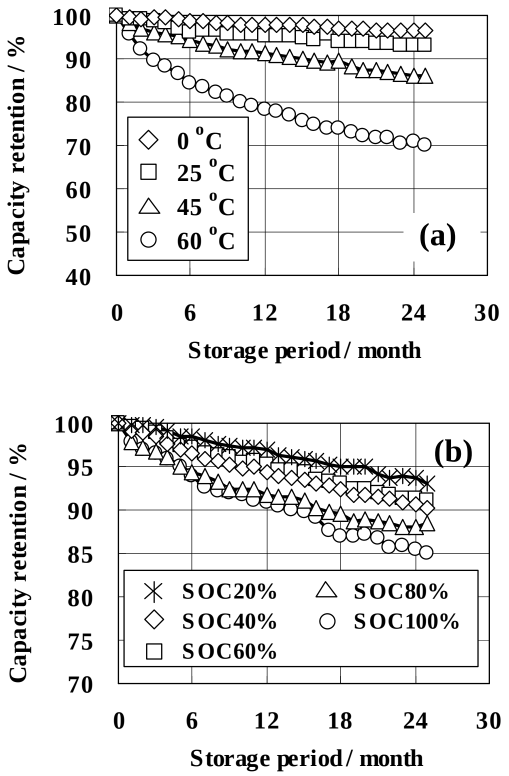

Fig. 2 Calendar life performance for 50 Ah prototype cells; (a) various temperatures at 100% SOC and (b) various SOCs at 45 ^{o}C. Monthly capacity check conditions: 1 CA to 3.5 V followed by its voltage until cutoff current of 0.1 CA and 1 CA to 2.0 V at 25 ^{o}C.

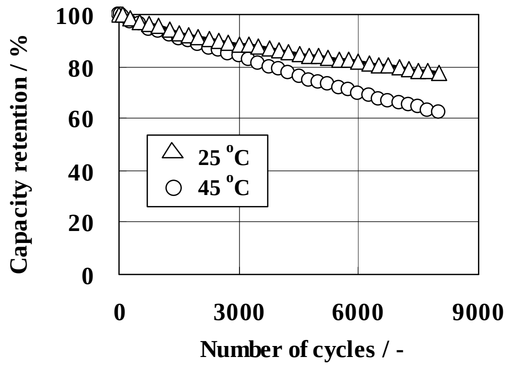

Fig. 3 Cycle life performance for 50 Ah prototype cells. Charge and discharge conditions: 1 CA to 3.5 V followed by its voltage until cutoff current of 0.1 CA and 1 CA to 2.0 V at 25 or 45 ^{o}C.

3 Cell performances

The 20 Ah cells were prepared by applying the same chemistry as 50 Ah prototype cells. The specifications and appearance of its cells are shown in table 2 and Fig. 4.

Table 2 Specifications of 20 Ah $LiFePO_4$/graphite lithium-ion cell.

Rated capacity	/ Ah		20
Nominal voltage	/ V		3.3
Dimensions	/ mm	H	85*
		W	21
		T	173
Volume	/ l		0.31
Mass	/ kg		0.63

*Without terminal height

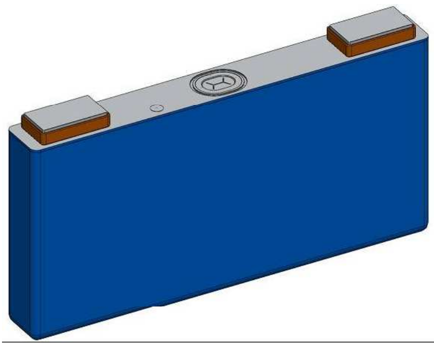

Fig. 4 Appearance of the 20Ah cell.

The cells are equipping the prismatic aluminium metal housing and the terminals available for welding. The specific energy density exceeds 100 Wh / kg by the use of high-density electrode.

4 Cell performances

4.1 Output power

The specific output power was investigated by changing the ambient temperature and SOC. The dependency on temperature and SOC are shown in Fig. 5. The developed cells are able to supply the stable output-power more than 1100 W / kg over wide range of 10 to 90% SOC. In addition, the cell had enough power even at extremely low temperature of -20 °C.

4.2 Charge acceptability

Fig. 6 shows the required time for full charge under the two different conditions. The cells were acceptable to be charged over 90% of full capacity within 60 minutes by 1 CA charge condition. In addition, the cells exhibit the superior charge acceptability under the rapid charge condition. The cells can be charged up to 90% SOC within 30 minutes using rapid charge mode with 50 A of maximum charge current.

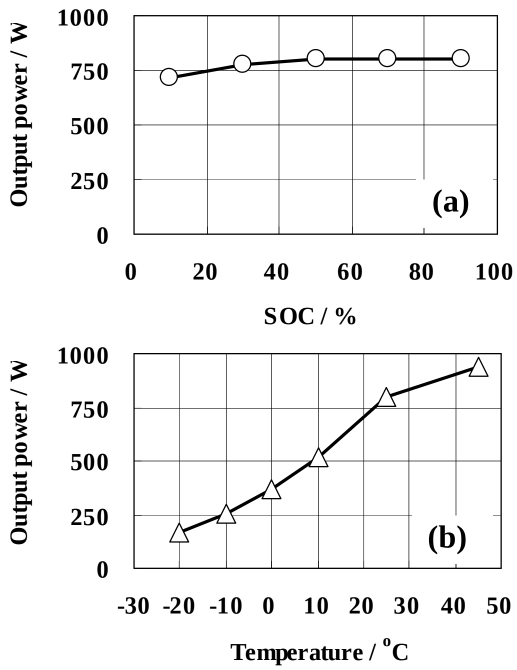

Fig. 5 Output power performance of the 20 Ah cell; (a) various SOCs at 25 °C and (b) various temperatures at 50% SOC. Power calculated limitations: 350 A of max current and 2.0V of lower voltage. Discharge duration: 10 sec.

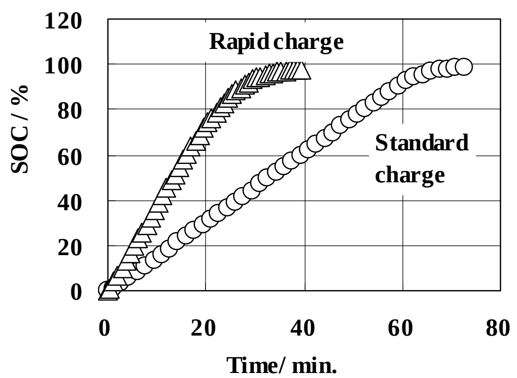

Fig. 6 Charge profiles of newly developed cell. Charge: 1 or 2.5 CA to 3.5 V followed by constant voltage until cutoff current of 0.1 CA at 25 °C.

4.3 Safety reliability

The crush test was carried out on the assumption of the collision accident of vehicles. The fully charged cells were crushed by 150 mm diameter bar in three different directions. These tests were performed in two stages. In the first stage, the cell was crushed to 85 % of initial dimensions for a few minutes. In the second stage, the crushing was subsequently continued until a 50% deformation of initial dimensions or a force limitation of 1500 kgf. The change in voltage and temperature during the tests and the appearance after its tests are shown in Figs. 7, 8 and 9.

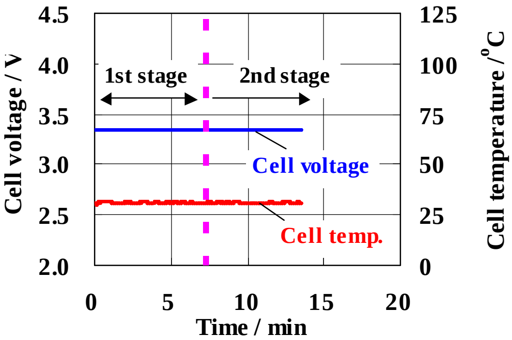

Fig. 7 Appearance of 20 Ah cell after the crush test in X-axis.

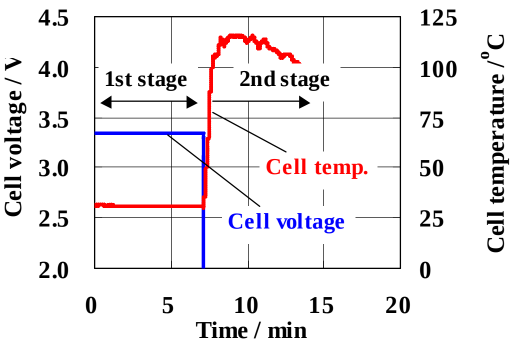

Fig. 8 Appearance of 20 Ah cell after the crush test in Y-axis.

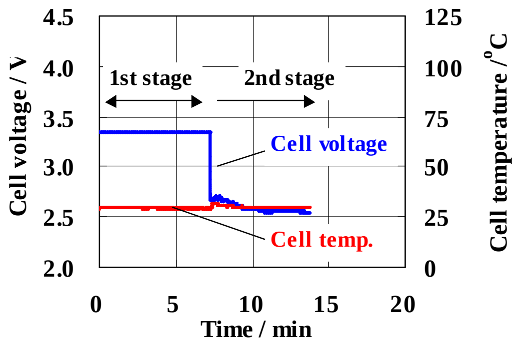

Fig. 9 Appearance of 20 Ah cell after the crush test in Z-axis.

In the first stage, there were no voltage drop and temperature rise in all directions of crushing. It is supposed that the internal short circuit was not occurred by 15% deformations. In the second stage, voltage drop and temperature rise were observed in each Y- and Z-axis crush, but maximum cell temperature didn't exceed 120 °C. The results of crush tests are EUCAR hazard level 3.

The overcharge test was carried out on the assumption of the system failure of the battery management unit and the battery charger.

Overcharge voltage was set up in 7.2 V corresponds to two times of the maximum charge voltage of the cells. The test result is shown in Fig.10. The internal short circuit didn't occurred during this test, but slowly heat generation and a few electrolyte mists from the rapture valve were observed. This result is EUCAR hazard level 3.

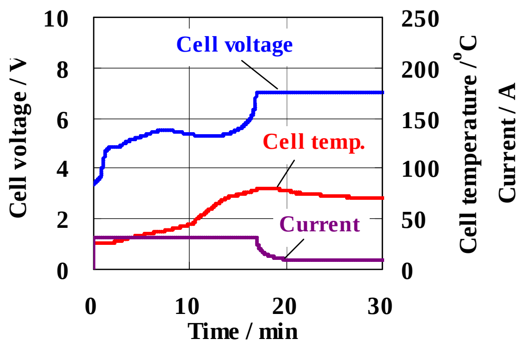

Fig. 10 Change in cell voltage, current and temperature during overcharge test. The fully charged cell was overcharged at 1.6 CA to 7.2 V followed by its voltage.

From these results, it is found that the developed 20 Ah cells show the high safety reliability.

4.4 Life performances

Fig. 11 shows the comparison of cycle life performance for the 20 Ah cell and 50 Ah prototype cell at 45 °C. These two type cells show almost the same capacity retention. The change in the output power during cycling of the 20 Ah cell is shown in Fig. 12. It turned out that the degradation of output power was only 11 % at 2000th cycles.

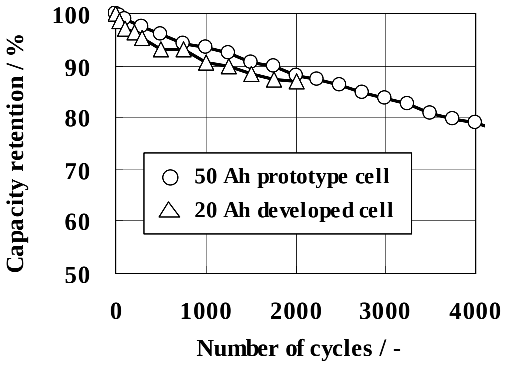

Fig. 11 Comparison of the capacity retentions between 50 Ah and 20 Ah cells during cycling at 45 °C. Charge and discharge conditions: 1 CA to 3.5 V followed by its voltage until cutoff current of 0.1 CA and 1 CA to 2.0 V at 45 °C

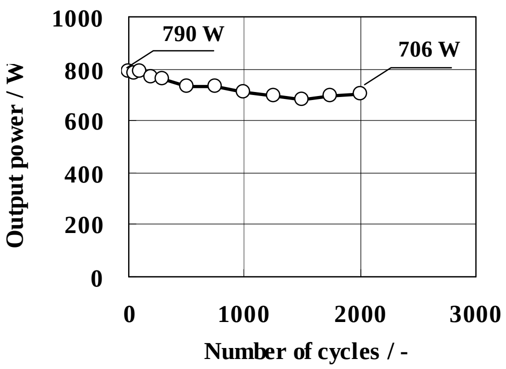

Fig. 12 Change in the output power during cycling of the 20 Ah cell at 45 °C. Charge and discharge conditions: 1 CA to 3.5 V followed by its voltage until cutoff current of 0.1 CA and 1 CA to 2.0 V at 45 °C Power calculated limitations: 350 A of max current and 2.0V of lower voltage. Discharge duration: 10 sec.

5 Conclusions

Newly developed 20 Ah prismatic cells using $LiFePO_4$/graphite chemistry are promising for BEV/PHEV applications because of the superior performances such as stable output power, rapid charge acceptability, outstandingly longer life, and high safety reliability even at large capacity of 20 Ah.

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