# Characterization of Large Lithium Ion Battery and Its Application to Railcar

**Hiroshi Matsuo [1], Takashi Ogihara [2], Hitoshi Aikiyo [3], and Shigenobu Yamanaka [4]**

[1] *Graduate School of Material Science & Engineering, University of Fukui, matsuo@kkf.biglobe.ne.jp*
[2] *Graduate School of Material Science & Engineering, University of Fukui, ogihara@matse.u-fukui.ac.jp*
[3] *Daiken Chemical Co.,Ltd., aikiyo@daiken-chem.co.jp*
[4] *Daiken Chemical Co.,Ltd., yamanaka@daiken-chem.co.jp*

## Abstract

*The running test of railcar was examined using large lithium ion battery in the local line in Japan. 90 kWh of Mn type lithium ion battery was used. The relation between running time and voltage, current and integrating watt was investigated in detail. The railcar was run when the lithium ion battery module was discharged between 660 V and 480 V. The use of lithium ion battery had little voltage changes and enabled the smooth running compared with contact-wire type railcar. On one charge, it was also found from the running test that the railcar could run for about 40 km and the mileage improved 9 %. The running performance of lithium ion battery type railcar was equivalent to the contact-wire type railcar. It was found that the railcar powered by lithium ion battery was effective for the replace of diesel type railcar in the local line.*

## Keywords

*railcar, lithium ion battery, energy saving, contact-wireless*

## 1. INTRODUCTION

Recently, the rechargeable battery and fuel cell have been applied on the running of contact-wireless type of railcar. [Sameshima et al., 2003, 2004] Lithium ion battery is expected as the driving source of it because of highest energy density and power density among the rechargeable battery. Some following advantages of contact-wireless type railcar with lithium ion batteries are expected. (1) The townscape is improved and the maintenance cost of overhead contact wire is reduced. (2) It is possible to utilize as an emergency power source in the overhead contact wire supply failure by disaster and accident. (3) The discharge of carbon dioxide, nitrogen oxides and sulphurous oxides can be drastically reduced compared with diesel car. (4) The energy-saving effect for running of railcar is improved by charging regenerative energy with rechargeable batteries. The use of large lithium ion battery is effective as alternative method of driving of the local diesel car.

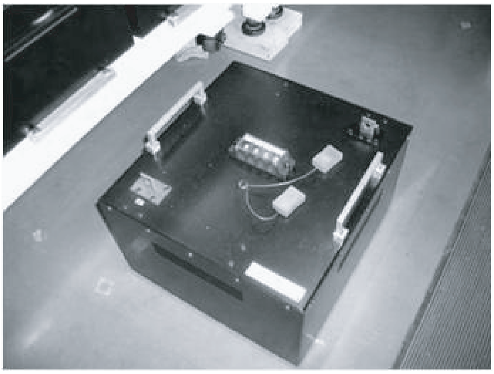
We have been tried the running test of DC 600 V type railcar by using 45 kWh of Mn type lithium ion battery in the business line of Echizen railway and Fukui railway. [Ozawa et al., 2008] The running performance and energy-saving effect of railcar were discussed. It was found that the running performance of railcar with lithium ion battery was equal to that of contact-wire type railcar and the mileage was improved. However, it was difficult for the conventional lithium ion battery of 60 kWh to run coming and going in Echizen line. [Ozawa et al., 2008] In this work, the running characterization of railcar was investigated using by DC 600 V type railcar with large lithium ion battery of 90 kWh.

## 2. EXPERIMENT

### *2.1 Lithium ion battery*

Lithium manganate powders ($Li_{1.08}Al_{0.05}Mn_{1.95}O_4$, LMP) were used as cathode materials. LMP was offered from Daiken chemical. The cathode was prepared using 88 wt% LMP, 6 wt% acetylene black and 6 wt% fluorine resin. LMP powders were mixed with acetylene black and N-methy1-2-pyrrolidinone binder of polyvinylidene fluoride to obtain slurry and then coated on an aluminum sheet using a doctor blade. A mixture of hard carbon and graphite (1:1 volume ratio) was used as the anode. A porous polypropylene sheet was used as the separator. As the electrolyte, 1 mol/$dm^3$ $LiPF_6$ in ethylene carbonate/1,2-dimethoxyethane (EC:DME = 1:1 in volume ratio) was used. A laminate sheet type of lithium ion cell (323 mm × 130 mm × 7 mm, 570 g, 16.8 Ah, 3.8 V) was assembled in a glove box under an argon atmosphere.

Figure 1 shows Mn type of lithium ion battery submodule and module consisted of 54 submodules. This submodule (323 mm × 240 mm × 323 mm, 22 kg, 168 Ah, 11.4 V) was consisted of 30 laminate sheet type of lithium ion cells. 3 lithium ion cells connected in series were connected in parallel. The number of parallel was 10.



(a) Submodule

(b) Module

**Fig. 1** Mn type of lithium ion battery submodule and module

The aluminium case was used to release a heat from the sheet cell during the charge and discharge. The protection circuits were installed in all submodules to avoid the overcharge and overdischarge because of safety. 54 submodules were connected in series to obtain 90 kWh (168 Ah, 615.6 V) lithium ion battery module with a weight of 1188 kg.

### *2.2 Railcar*

Figure 2 shows DC 600 V type of railcar used in the running examination. Lithium ion battery module was installed in the centre of the railcar (moha 6001 type, 40 t) and fixed in the exclusive rack in order to stand the vibration in the running. Lithium ion battery module was directly connected with the motor of the railcar.

**Fig. 2** DC 600 V type railcar used in this work

### *2.3 Evaluation of railcar*

The running characterization of railcar was evaluated at Katsuyama business line (25 km) in Echizen railway which was 150 m altitude and slope way course with gradient of 4 %. Each change of voltage, current and temperature in the running was incorporated in personal computer through the data logger set in the centre of submodule.

## 3. RESULTS AND DISCUSSIONS

Figure 3 shows the initial discharge curve of laminate sheet type of lithium ion cell from 1C to 7C. The initial discharge capacity of it was 16.5 Ah at 1C. It decreased to 13.8 Ah at 7C. The voltage of about 0.5 V decreased with increasing to 7C. The initial discharge capacity decreased to 14.9 Ah after 1000 cycles at 1C and 90 % of it was maintained. On the other hand, the discharge capacity was 11Ah after 1000 cycles at 7C and the retention of it was 80 %. It was found that lithium ion cell had higher cycle stability at high discharge rate.

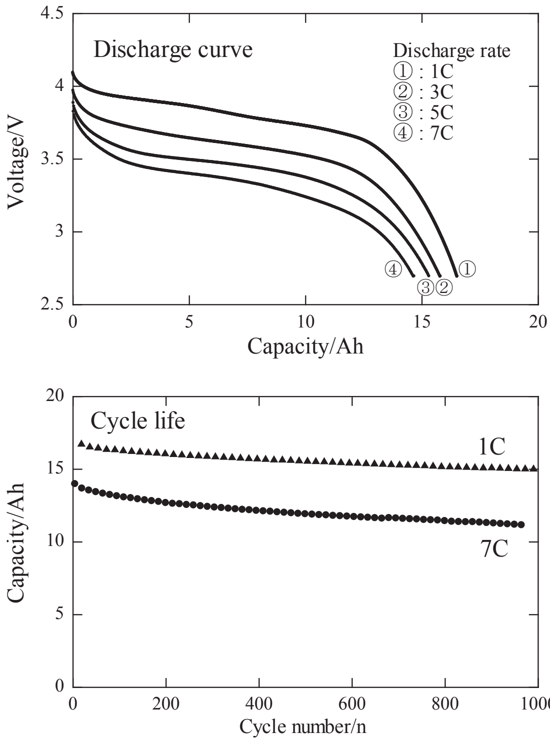
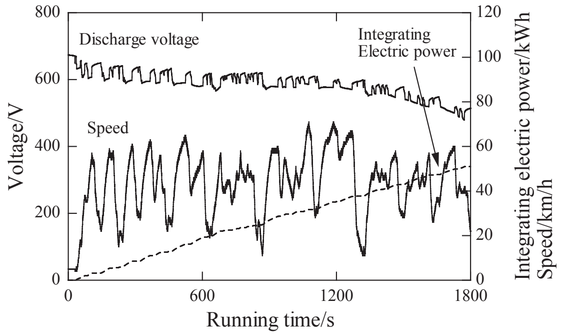
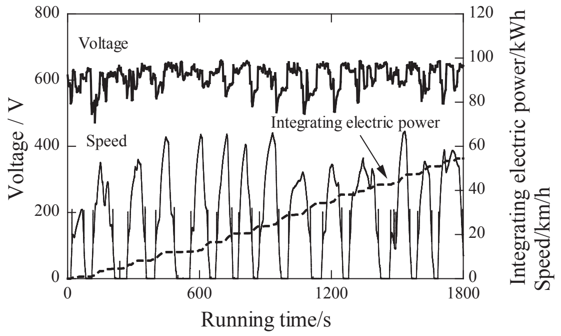



**Fig. 3** Discharge curves and cycle life of laminate sheet type of lithium ion cell

Figure 4 shows the running characterization of railcar powdered by lithium ion battery and contact-wire, respectively. The running test was done without the use of air-conditioner. The railcar was run for 1800 s when lithium ion battery module was discharged be-




(a) Lithium ion battery




(b) Contact-wire

**Fig. 4** Running characterization of railcar powered by lithium ion battery and contact-wire

tween 670 V and 510 V. The railcar could be run for 25 km for 1800 s at one charge, while power running, coasting and stopping were repeated. The voltage curves of lithium ion battery and contact-wire showed that the voltage fluctuation of lithium ion battery was less than that of contact-wire during the running. The consumed energy power of railcar with lithium ion battery was 50 kWh. On the other hand, that of railcar with contact-wire was 54.4 kWh.

About 9 % of mileage (4.4 kWh) was improved using by lithium ion battery from the difference of consumed energy power. This may be resulted in the voltage fluctuation. It was seen from Figure 4 that the voltage fluctuation of lithium ion battery was less than that of contact-wire. In the contact-wire, it is considered that few kWh of electric power loss is due to the influence of contact resistance between the contact-wire and pantograph. The contact resistance is not influenced during the running with lithium ion battery. This reflects the difference of consumed electric power between contact-wire and lithium ion battery.

Figure 5 shows the change of voltage, current and temperature of submodule during the running. A current of 450 A flowed to the submodule when the railcar was quickly accelerated up to 60 km/h. After accelerating, the current drastically decreased down to about few A. The temperature of submodule gradually increased with increasing the running time. After 1800

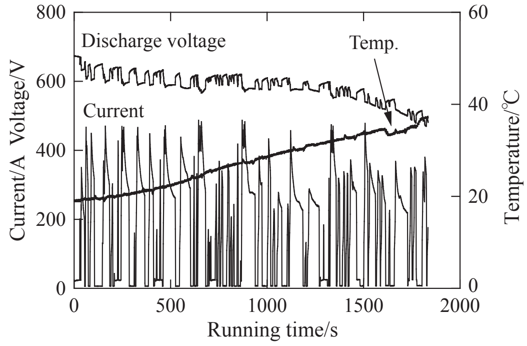



**Fig. 5** Relation between running time and current, temperature

s, the temperature of the submodule reached up to about 40 °C. The rated value for the temperature in the use of submodule has been set at 45 °C. It was found from the running test that the temperature change was in the tolerance of the rated value. Since the submodule case made of aluminum had an excellent permeability of air, the submodule was cooled in the interval to next running and returned to within 30 °C.

Figure 6 shows the running characterization of railcar powered by lithium ion battery for a round trip. The running test was done with the use of air-conditioner. The electric power for air-conditioner was supplied from lithium ion battery. The railcar arrived at the terminal for 1600 s. The railcar stopped from 1600 s to 2400 s for preparations to return from the terminal. The train stopped for waiting at a stoplight by the single line from 3500 s to 3800 s. It was found that the railcar could be run for 50 km for 4800 s at one charge. When the railcar was quickly accelerated up to 65 km of maximum speed, a current of 500 A flowed at the maximum for few times. 78 kWh of electric power was consumed after the running of 50 km. The railcar powered by lithium ion battery is expected as the replace of diesel type railcar in the local line which was run by a service diagram without high frequency.

78 kWh of electric power was charged to lithium ion

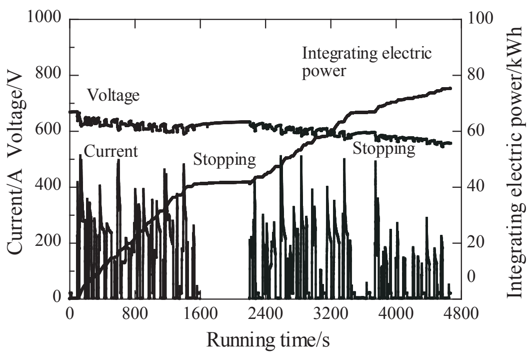



**Fig. 6** Running characterization of railcar powered by lithium ion battery for a round trip (50 km)

battery module after the running by the quick battery charger apparatus (Daiken Chemical, 84 Ah, 700 V) in which the electric power was received from 600 V of contact-wire. The charge test was examined at several times.

Figure 7 the typical change of voltage, temperature and integrating electric power for charge time. In several charge tests, the abnormal behavior for the temperature was not observed. The voltage of charge ranged from 550 V to 660 V. The temperature of lithium ion battery module increased from 5 °C to 17 °C when the integrating electric power of lithium ion battery module was reached to 74 kWh for 3600 s. It was considered from the change of temperature that lithium ion battery module was safely charged because the rated value of submodule was 45 °C.

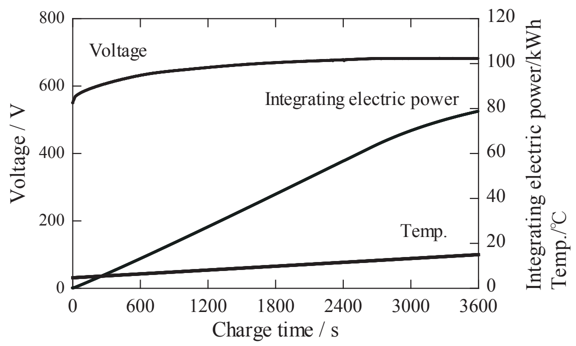



**Fig. 7** Relation between charging time and voltage, temperature and integrating electric power

## 4. CONCLUSION

90 kWh class Mn type lithium ion battery was used for the running of DC type railcar. They consisted of 54 submodules, in which laminate sheet type lithium ion cells were connected in 3 series and 10 parallel, were constructed. The running test of DC type railcar was carried out at business line of local railway in Japan. The results were obtained as follows;

(1) Laminate sheet type lithium ion cell exhibited stable cycle performance at high discharge rate.
(2) The running performance of railcar with lithium ion battery was equivalent to that of railcar which the electric power was supplied from contact-wire.
(3) 90 kWh of lithium ion battery led to the 50 km of running at one charge.
(4) The temperature increased with increasing the running time, but it was less than 40 °C during the running of railcar.
(5) 9 % of mileage was improved by lithium ion battery during the running.
(6) Lithium ion battery module was safely charged at 600 V by quick battery charger apparatus.

## Acknowledgements

This work was supported by Strategic Development of Technology for Efficient Energy Utilization, Fundamental Technology Development for Energy Conservation, New Energy and Industrial Technology Development Organization (NEDO).

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(Received November 12, 2009; accepted December 15, 2009)