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100 Wh Large size Li-ion batteries and safety tests

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Abstract

100 Wh large size Li-ion battery with safety structures were developed. Specific energy and energy density of the battery were 110 Wh/kg and 200 Wh/l, respectively. Safety tests: nail penetration test, external short circuit test, overcharge test and externally heating test were carried out to determine the fundamental safety level of the battery. Behavior such as ignition and explosion of the battery were not observed during the safety tests. The battery is considered to be applicable to electric vehicles and hybrid electric vehicles.

Keywords: Li-ion battery; Safety test; Electric vehicle

1. Introduction

Large size Li-ion battery with high energy and high power are intensively being developed world wide for electric vehicle (EV) and hybrid electric vehicle (HEV) [1,2]. Battery safety is a key issue for such applications because a number of cells are installed inside. 100 Wh large size Li-ion cylindrical battery with safety structures has been developed in NGK. Safety tests, such as nail penetration test, external short circuit test, overcharge test, and externally heating test were carried out to know fundamental safety level of the battery.

2. 100 Wh large size Li-ion battery

Materials used for the battery and battery properties obtained are summarized in Table 1. High specific energy over 100 Wh/kg and high energy density 200 Wh/l were achieved. In order to obtain good safety, several safety structures are designed and installed in the battery, such as micro-porous separator, temperature fuse, current fuse and safety vent. Each safety structure is expected to cover each safety item independently when the battery is misused or abused.

3. Safety tests

Safety guideline [3] and safety standard [4] are widely adopted for small size Li-ion battery, 18 650 for example. However, for large size Li-ion battery, more than 100 Wh for example, intensive effort by safety specialists is still made to determine safety item and test procedure. So, we applied the SBA guideline [3] to our safety tests tentatively. Four principal safety tests; nail penetration test, external short circuit test, overcharge test and externally heating test were carried out. Standing these four tests is considered to be minimum requirement to ensure practical use of the large size battery for EV and HEV.

3.1. Nail penetration test

Nail penetration test is a test that a metal nail is pierced at center of a battery with certain nail speed, and consequently, internal electrical short circuit happens inside the battery. This test must be the severest test for Li-ion battery in the SBA guideline.

A fully charged 100 Wh battery was provided for this test. A sharp stainless steel nail was penetrated by a motor mechanism into the center of the cylindrical battery body with a speed of 1 mm/s. Two safety vents opened suddenly soon after the nail was inserted slightly into the body, and then, large volume of electrolyte vapor was jetted from the vents. Temperature of surface of the battery

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Table 1
Materials and properties of NGK batteries

Cathode	Lithium manganese oxide
Anodes	Meso-phase pitch based carbon
Electrolyte	$LiPF_6$ + mixed carbonates
Separator	Microporous polyolefin
Energy	95 Wh
Capacity	25 Ah
Average voltage	3.8 V
Energy density	200 Wh/l
Specific energy	110 Wh/kg

reached to maximum 380°C in 1 min, as shown in Fig. 1. This rapid increase of temperature resulted from abrupt conversion of the charged electric energy into heat due to internal short circuit of the battery through the nail. The electrolyte vapor and the battery did not ignite even at such high temperature of the battery. Adiabatic expansion of the vapor may avoid ignition of the vapor.

3.2. External short circuit test

External short circuit of a battery would happen when the battery is misused during wiring batteries. Result of this test is expected to depend on value of external short circuit resistance. Too high resistance of short circuit could act as a simple load, and too low resistance could lead to self heating of tested battery. Therefore, three different values of external short circuit resistance were selected for this test. Average internal resistance of tested batteries was 5 mΩ typically.

Fully charged batteries without temperature fuse were used for this test. As assumed before, external circuit resistance affected test results. When short circuit resistance was 0.2 mΩ far less than the battery internal resistance, short circuit current was cut immediately by a current fuse installed in the battery. Temperature rise of the battery was negligibly small. So, safety vents didn't open.

When short circuit resistance was 6 mΩ almost equal to the battery internal resistance, temperature of the battery reached 120°C after making short circuit, as shown in Fig. 2. Safety vents opened at 80 s after the short circuit was made, and then, electrolyte vapor came out very slightly from the vents. The battery discharged thoroughly in 10 min, because both the voltage and the current decreased almost to zero, as shown in Fig. 2.

When short circuit resistance was 11 mΩ about twice of the battery internal resistance, the battery discharged normally, and maximum temperature of battery was below 100°C.

Based on these results, if temperature fuse were installed in the battery, much more safety could be promised for this external short circuit test.

3.3. Over-charge test

Overcharge state of battery would happen when battery charger, voltage control function for example, is out of order. On the contrary, good durability of battery against overcharge could simplify electronic circuit of the battery charger.

A fully charged battery was provided for this test. With a constant current source (maximum voltage 10 V), 1 C current was applied to the battery. When temperature of the battery reached 85°C, the current was cut by a temperature fuse installed inside the battery. Safety vents did not open at the temperature. Without a temperature fuse, 1 C current decreased rapidly when temperature of the battery approached 95°C, as shown in Fig. 3. This current decrease is caused by increase of battery internal resistance due to separator shutdown. Separator shutdown happens when temperature of separator reaches melting point of polyolefin.

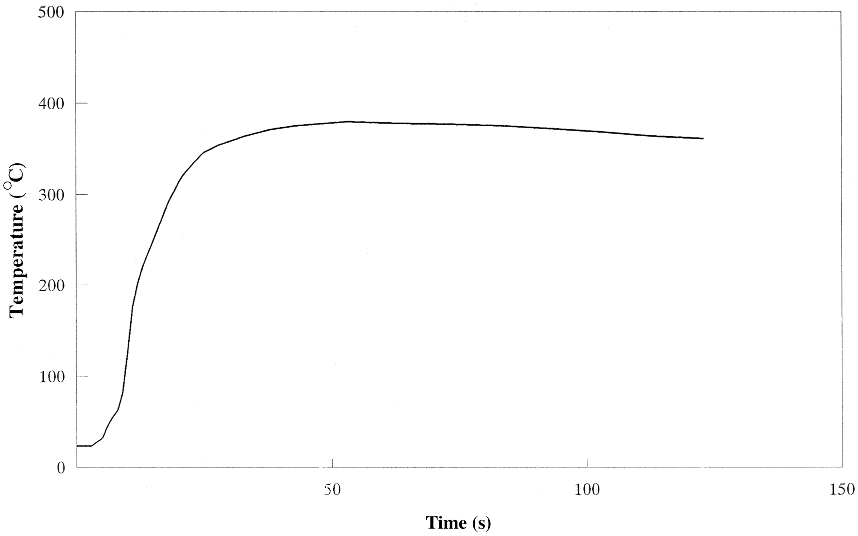

Fig. 1. Surface temperature of battery during nail penetration test.

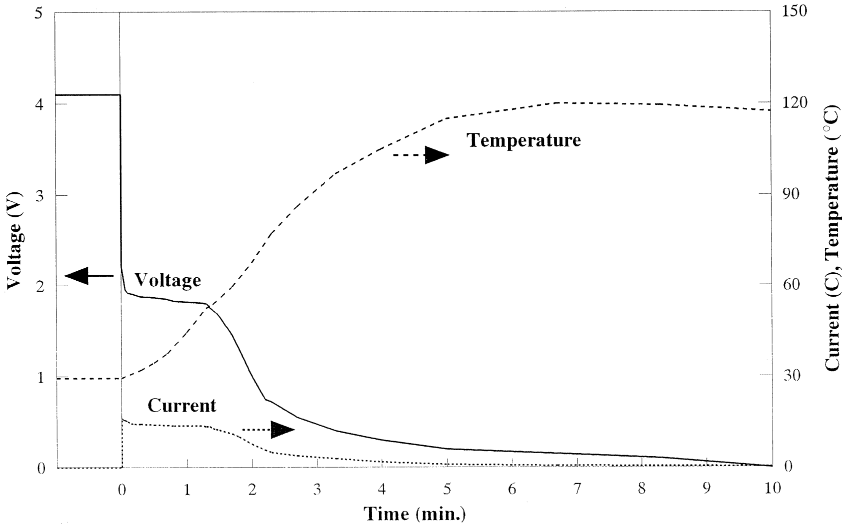

Fig. 2. Voltage, current and surface temperature of battery during external short circuit test. Resistance of external circuit was almost equal to battery internal resistance. Current is normalized by nominal capacity as 1 C.

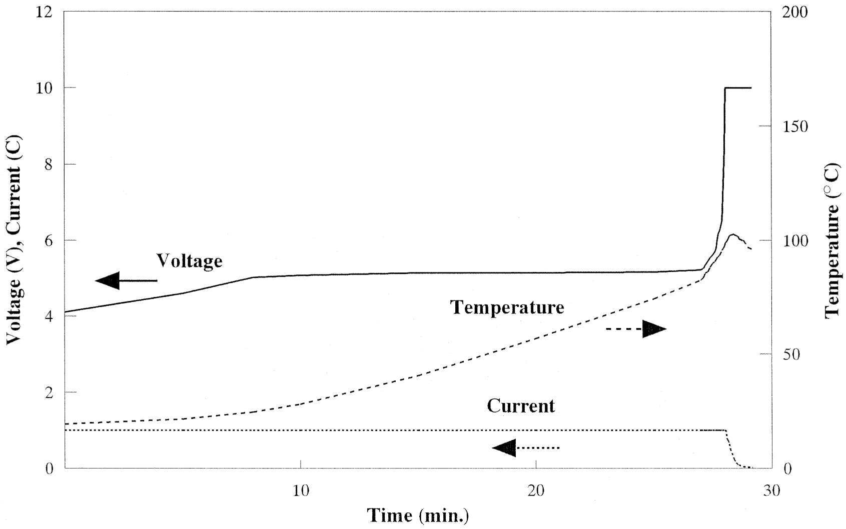

Fig. 3. Voltage, current and surface temperature of battery during overcharge test.

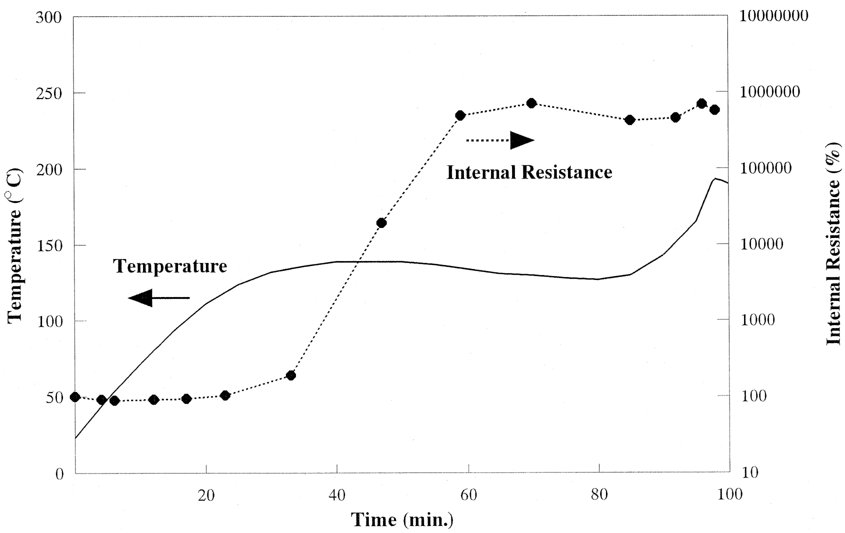

Fig. 4. Surface temperature and internal resistance of battery during heating test.

3.4. Heating test

Battery would be heated externally when the battery is installed near heat generator such as engine. According to the SBA guideline, battery must withstand in a storage condition at 130°C for 1 h.

A fully charged battery without temperature fuse was used for this test. The battery was heated with an electric heater which was wound around the battery. Battery internal resistance was checked by applying a DC current to the battery during the heating test. Temperature and internal resistance of the battery vs. time are shown in Fig. 4. When temperature of the battery reached 130°C, separator inside the battery was gradually shut down, and consequently, internal resistance of the battery increased. The battery was heated further after 1 h storage at 130°C. Safety vents opened at 190°C, and electrolyte vapor came out very slightly. However, the battery did not ignite.

4. Summary

100 Wh large size Li-ion battery developed by NGK shows high energy and good safety. Safety test results of the battery suggest that careful design of safety structures, such as micro-porous separator, temperature fuse, current fuse and safety vent, can promise good safety even for large size battery. The battery is expected to be applicable to EV and HEV if the safety structures installed inside the battery. However, a problem of large volume of electrolyte vapor coming from battery due to nail penetration should be solved for such practical applications.

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