

### Technology report

## Safety Testing of In-vehicle Lithium-ion Secondary Batteries: Temperature Dependence of External Short-Circuit Current

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### 1. Introduction

In step with the widespread adoption of hybrid vehicles and plug-in hybrid vehicles, electric vehicles are expected to increase in number. It is therefore critical to confirm the safety of the batteries mounted in electric vehicles in light of the harsh operating environments such products are exposed to. This report discusses the necessity of safety tests that simulate operating environment as technical challenges in performing safety testing for in-vehicle secondary batteries in order to satisfy various testing requirements for in-vehicle batteries.

### 2. Safety testing secondary batteries for electric vehicles: New technical challenges

In addition to the technical testing requirements that have been stipulated for public standard testing and certification testing, a variety of tests are conducted to determine the safety of electric vehicle secondary batteries in consideration of their actual usage environment. In the nail penetration test, for example, lateral penetration testing has been widely conducted that reflect the travelling direction of the vehicle and the direction of gravitational force of the battery. Likewise, some tests simulate the various environments that a vehicle may be subjected to, such as the sink test, which assumes submersion of the vehicle. Moreover, there are challenges facing batteries that have become larger: testing the heat-discharge characteristics of a single cell differs from that of a cell mounted in a module pack; consequently, it is necessary to conduct tests that assume the use of module pack. Simulations of battery usage in winter conditions require testing at a temperature of  $-40^{\circ}\text{C}$ ; however, few examples exist of actual safety tests conducted at this temperature. The following section will discuss the study results and technical challenges of safety tests conducted at controlled environmental temperatures.

#### 2-1. Present approach to environmental temperature simulation in safety testing

In the present testing specification for vehicle batteries, safety testing is usually performed under a single stress; in addition, the structure and mechanisms of testing devices have made it difficult to conduct safety testing at an extreme temperature such as temperatures of  $-30^{\circ}\text{C}$  to  $-40^{\circ}\text{C}$ . Conducting a safety test at a specific environmental temperature requires that the battery be placed in a temperature chamber, that the temperature be lowered, and that the battery then be moved to a different testing device for the actual safety test. As a result, the battery temperature

## Batteries' reliability

changes during the testing due to the warmer ambient temperature of the testing device and the battery self-heating effect; clearly, such an approach to testing fails to achieve sufficient reproducibility. To address this challenge, we have manufactured testing equipment that is capable of performing various safety tests while controlling the temperature of the battery itself, thus allowing us to examine the effects of environmental temperature on the results of the safety tests.

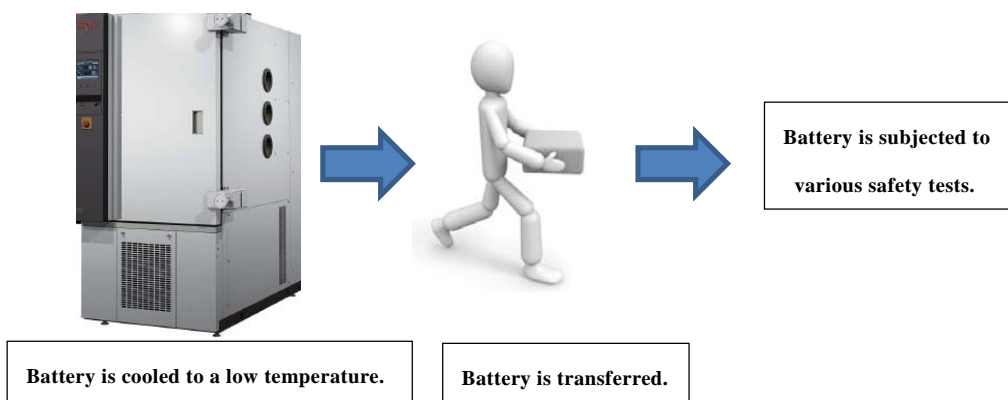


Figure 1. The conventional approach is to test environmental stress and safety separately.

### 2-2. Example of an external short-circuit test under controlled environmental temperatures

To examine the safety of lithium-ion batteries, various tests are conducted including external short-circuit, overcharging, over-discharging, overheating, crushing, drop impact, and nail penetration testing. Here, in consideration of the temperature dependence of short-circuit current, we examined the temperature dependence of the external short-circuit test. This test was conducted with a lithium-ion battery used in an electric motorcycle (3.3 V x 4 [13.2 V in total], 12 Ah) as the sample. The test was performed inside a temperature chamber at environmental temperatures of -40°C, 0°C, 25°C, and 55°C. This test evaluated surface temperature and the short-circuit current of the battery.

### 2-3. Test results and considerations

Figure 2 shows the generation of gas due to a short circuit at a given temperature. The time from the start of the short circuit to gas generation increased in order from -40°C to 0°C and 25°C, while no gas was generated at 55°C. The gas yield at -40°C was especially notable compared to the yields at 0°C and 25°C. Figure 3 shows the surface temperature of the battery and the behavior of the short-circuit current.

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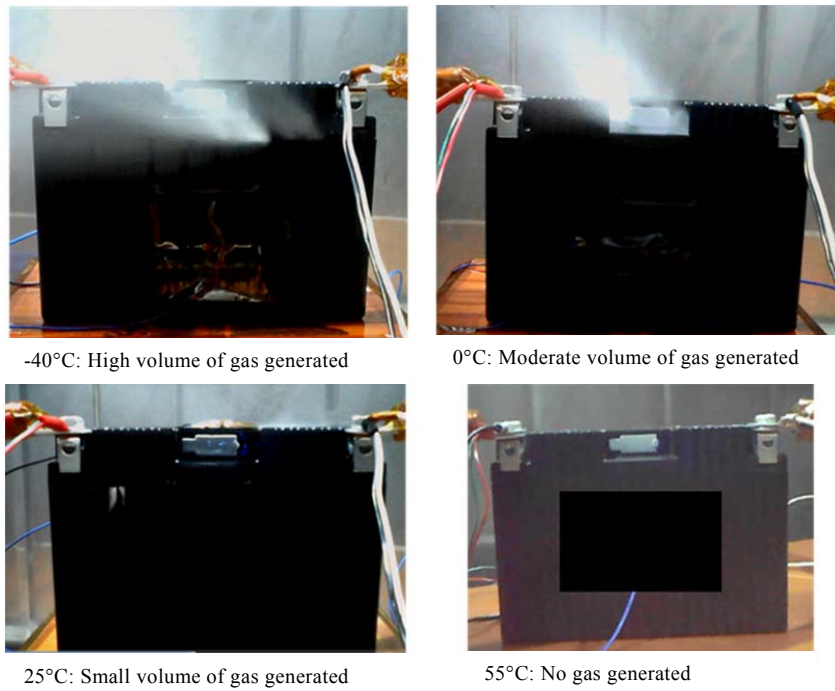


Figure 2. Gas generated under short circuit at given temperatures

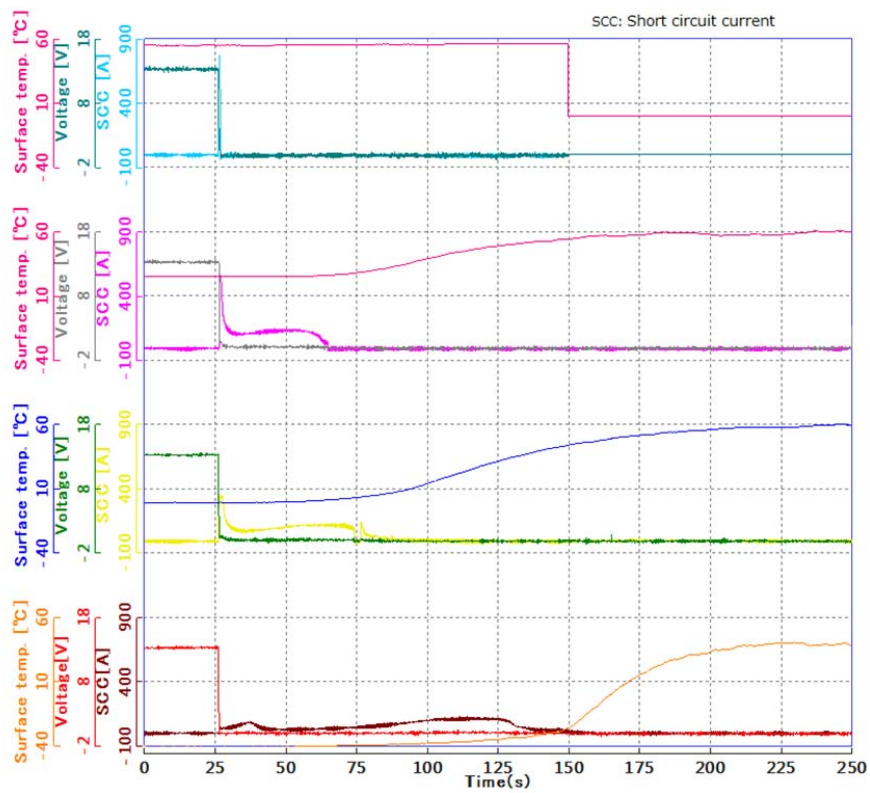


Figure 3. Battery surface temperature and short-circuit current behavior

## Batteries' reliability

At lower environmental temperatures, the increase in the battery surface temperature was greater and the time from short-circuit to convergence of current to 0 mA was longer. Moreover, these results indicate that, in this test, the lower the battery temperature during the external short-circuit test, the greater the increase in battery temperature and the larger the volume of gas generated. Generally, a protection element is used as a short-circuit protection circuit; this element changes the resistance value according to temperature and can cut off the current. At temperatures of 0°C, 25°C, and 55°C, the measured current represented the maximum peak current immediately after the short circuit, and then declined. From the results, it is assumed that the temperature of the protection element reaches the cut-off temperature at the moment of the short circuit, with the current declining thereafter. Meanwhile, at -40°C, the current measured immediately after the short circuit was less than those measured at other temperatures, and the current increased thereafter. From these results, it is assumed that the protection element did not interrupt the current, or that it behaved differently at other temperatures. The lower the temperature, the greater the internal resistance of the battery, suppressing the current; therefore, the lower the temperature, the longer it takes for the protection element to activate based on the relation between the ambient temperature (battery temperature) and the current value and Joule heat generated. As a result, the current converged after a longer period of time, which was likely to result in an increase in the heat generated and the gas generation behavior. In addition, the fact that the rise in current peaked twice at temperatures of -40°C, 0°C, and 25°C is likely associated with the behavior of the protection element. As confirmed in this test, the change in the surface temperature of the battery lags that of the internal temperature of the battery; therefore, further consideration of measurement methods is necessary to confirm the heat generation behavior of such batteries. As battery sizes increase, testing of vehicle batteries will require technologies capable of accurately measuring or estimating internal battery temperatures.



Main chamber (made by ESPEC)



Special terminal with battery connections

### **Major specifications**

Short-circuit resistance: 1 mΩ minimum

Short-circuit current: 16 kA

Temperature range: -40°C to 80°C

Figure 4. Equipment for testing external short circuits  
(Accepts battery packs as specified under ECE R100; installed in ESPEC's Battery Safety Testing Center.)

### 3. Conclusion

As efforts to improve regulatory compliance have been spreading in the U.S.A., Europe, and China, the trend toward electrification of automobiles is likely to continue into the future. The ability to conduct safety tests on in-vehicle lithium-ion batteries in simulated usage environments will become essential. ESPEC will make possible testing under controlled environmental temperatures to enable safety testing of large in-vehicle batteries and will study the behavior of such batteries during the actual tests.



Figure 5. Equipment for conducting nail penetration test at controlled environmental temperatures (Made by ESPEC; installed in ESPEC's Battery Safety Testing Center.)