# Thermal Propagation test

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# Introduction

**The purpose of thermal propagation test is to demonstrate that battery pack or battery system preventing fire propagation phenomenon and achieve occupant protection in the case of thermal runaway of single cell caused by internal short-circuit.**

**1) Considerations of the initiation method in the test procedure:**

- **the initiation method simulating thermal runaway of single cell caused by internal short-circuit**
- **the effect of the initiation method should be minimized as possible, especially to adjacent cells.**
- **Target module should be able to be applied to any position within DUT.**
- **repeatability and reproducibility**

**2) Considerations of the manipulation of DUT in test procedure:**

- **the manipulation of DUT should be as easy and simple as possible. If not, only battery manufacturer can manipulate DUT when target module needs to be disassembled and modified for securing the space of heating pad or wires)**
- **the effect of the manipulation should be minimized as possible through a definite method related to standization (Different manipulation methods can make the difference of test results.)**
- **repeatability and reproducibility**

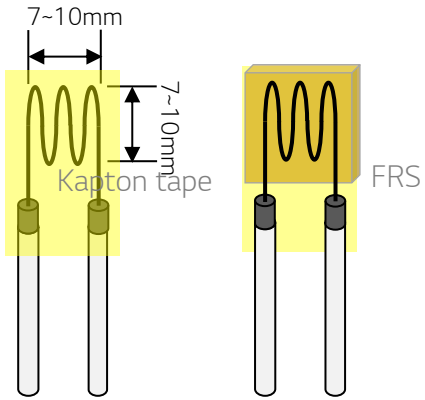
# Applicability and preparation of test device

We provide details of the proposed test procedure and test device which is a kind of small sized heater using high power and attached on cell body. The proposed test method has several properties related to the initiation method and the manipulation.
Firstly, It is easy to attach on the cell body without physical barriers within module or pack levels because it is small enough.
Secondly, it is not necessary to disassemble target module or remove a component for securing the space of heating device. (DUT can be manipulated without dangerous re-manufacturing works.)
Finally, heating device does not affect adjacent cells apart from initiation cell. It is heated on only localized area within an initiation cell.

❑ Heater description

This heater is made of Ni-Cr materials covered with kapton tape and FRS(Fire Resistant Sheet) to withstand in high temperature. The minimum size of heater is 7mm x 7mm and thickness is 0.3mm without FRS. It has a resistance range of1.6~2.0Ω and allows to withstand a power approximately 100W. It can be reached up to 800 ℃ locally within 5 minutes by using heater controller.

Figure 1. Example of micro heater



# Test Description (Procedure)

1) At the beginning of manipulation, the state of charge(SOC) of device under test(DUT) shall be adjusted 0%.

2) Select an initiation module after disassembling DUT. An initiation module has maximum planes to propagate thermal effect toward adjacent modules within DUT. (Generally center location)

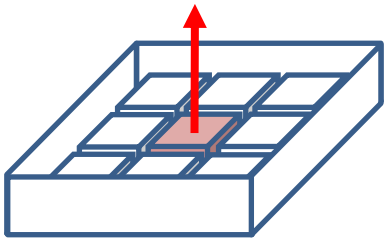


Figure 2. Disassemble DUT for selecting an initiation module

3) Manipulation method of an initiation module is differed according to whether cell body is externally exposed within the module. Attach micro heater on most outer located cell if it is externally exposed. If not, it is recommended to create small hole of 30mm diameter on the module case using milling machine for the exposure of cell body. The hole size is conditioned by heater size, and the thickness should be checked through the manufacturer for preventing the damage of cell surface.

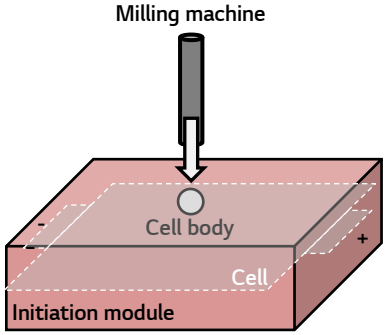
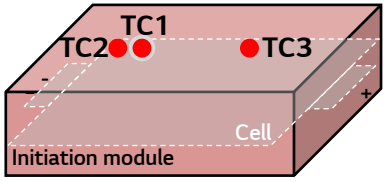



Figure 3. Create small sized hole on the module using milling machine

# Test Description (Procedure)

4) Create the hole of 20mm diameter on the pack case for all wires pass of heater, thermocouple, voltage sensor, and so on.

5) The micro heater is attached on the cell surface using kapton tape. It can prevent heat loss if the heater is tightly attached on the cell surface without the air space between the cell surface and the heater. Refer to figure 4 related to position of thermocouples.




TC 1 attached on the heater inside the hole
TC 2 attached on the cell surface nearby the heater
TC 3 attached on the cell surface far from the heater

Figure 4. Position of thermocouples attached on an initiation module

6) The hole of an initiation module is filled up with heat-resistant silicon(FUOCO 1500) that can withstand up to 1500 ℃ to prevent the inflow of oxygen or the flame coming out from the hole during the test.

7) Thermocouples are attached on not only an initiation module but also the surface of adjacent modules to observe thermal propagation between modules.

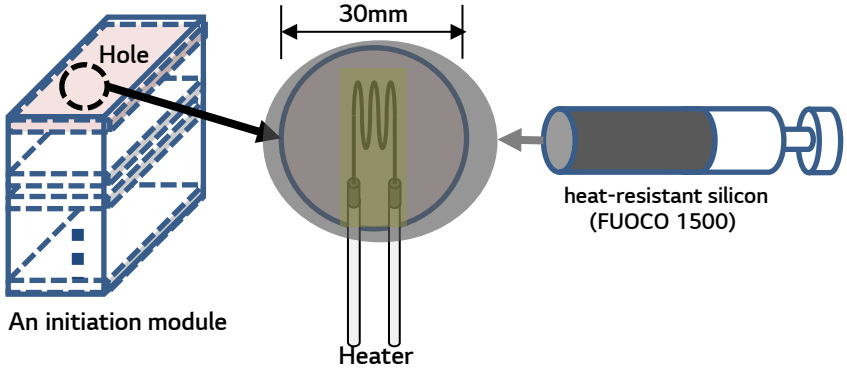



Figure 5. Heat-resistant silicon filled to the hole

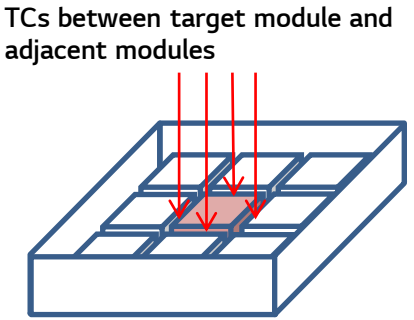



Figure 6. Position of thermocouples attached on adjacent modules

# Test Description (Procedure)

8) DUT is re-assembled to the initial state and sealed. All wires of heater, thermocouple, voltage sensor are connected to outside of the pack through created holes of battery module and pack. The hole of DUT is also filled up with heat-resistant silicon. Charge DUT up to SOC 95% during silicon stabilization time. (Silicon stabilization time: 24hrs)

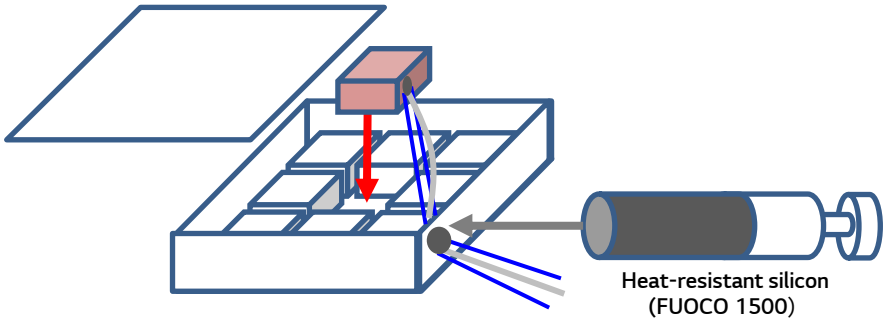



Figure 7. DUT is re-assembled to the initial state and sealed.

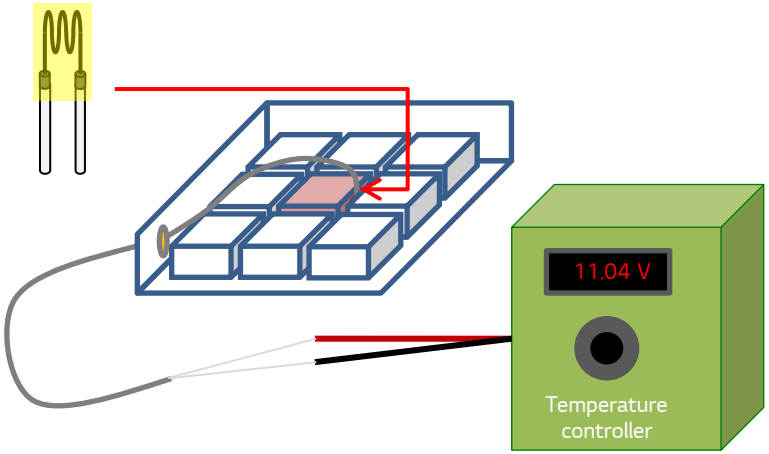



Figure 8. Example of test set-up

9) Begin recording all voltages and temperatures data measured within DUT including BMS data.

10). Turn on the heater controller after measuring the resistance of the heater. The constant power of 100W is applied to the heater.

11) When thermal runaway is detected through extremely rapid rise of temperature measured on the cell surface far from the heater, turn off the device.

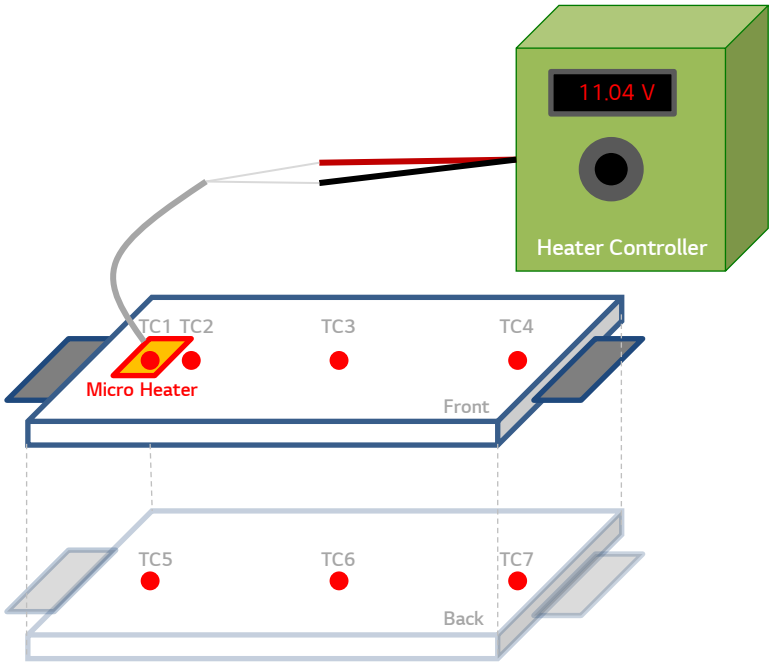
12) Observe until all temperatures within DUT return to ambient temperature and DUT is stabilized.

# Test results – Cell level

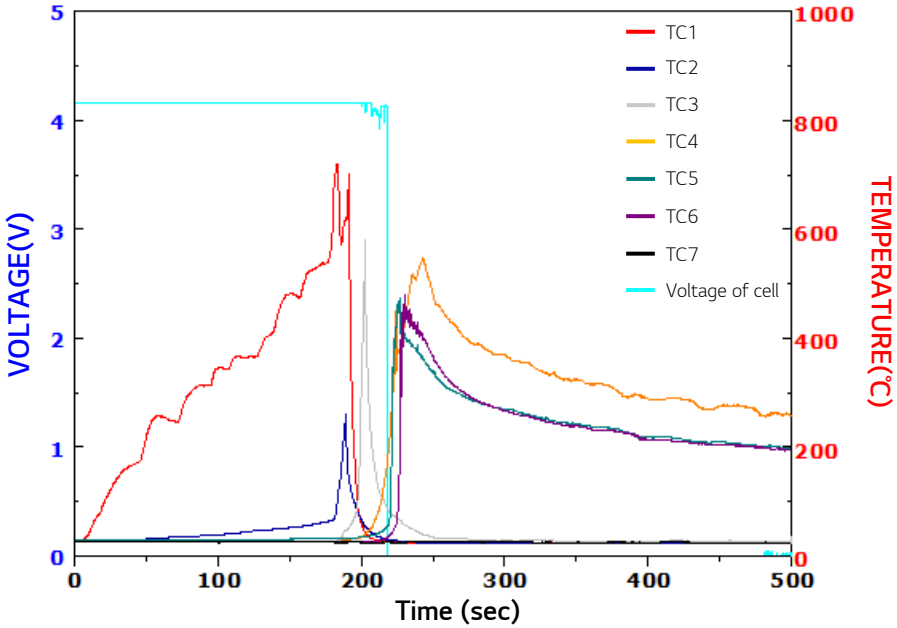
## 1) Sample information

| | |
|---|---|
| Type | Pouch cell |
| Nominal Voltage | 3.6 V |
| Capacity | 60 Ah |
| Energy | 216 Wh |
| SOC | 100% |

## 2) Test set-up




## 3) Test results



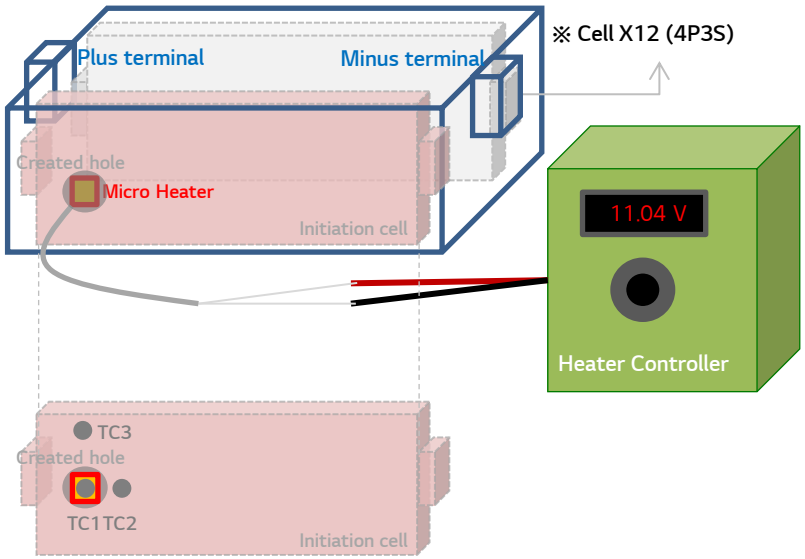

- Thermal runaway occurred within 200 seconds from the start with cell venting and extremely rapid rise of temperature measured in TC3.
- Thermal propagation within the cell is observed from the front side to the back side in progression.
  TP direction: TC1 → TC2 → TC3 → TC4→ TC5 → TC6 → TC7
- There were continuous flames after cell venting.

# Test results – Module level

## 1) Sample information

| | |
|---|---|
| Type | Module (EV) |
| Nominal Voltage | 10.8 V (4P3S) |
| Capacity | 240 Ah |
| Energy | 2.6 kWh |
| SOC | 100% |

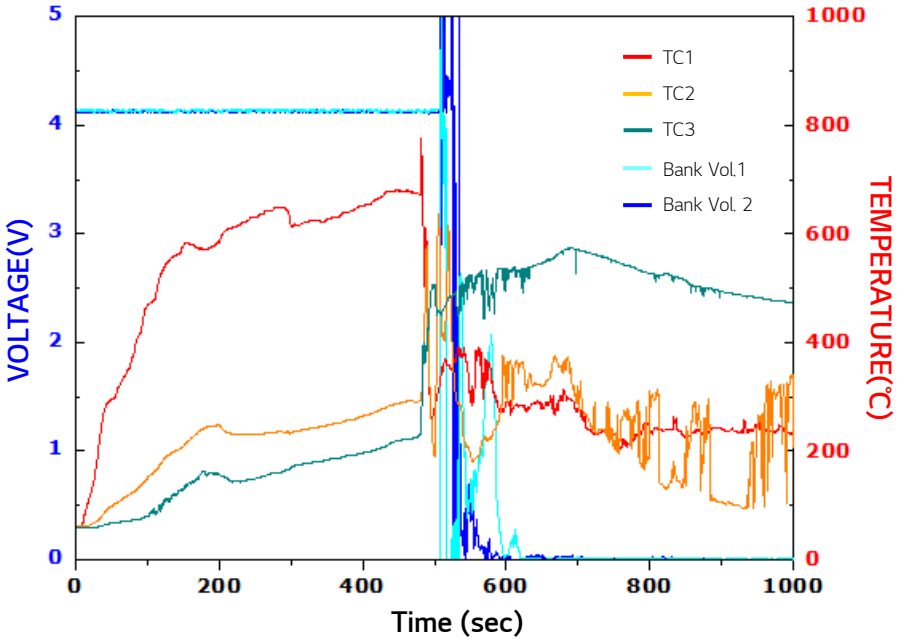
## 2) Test set-up




※ Bank voltages are measured through LV cable in module terminals. (Bank Voltage 1, 2)

## 3) Test results

※ Voltage sensing lines were disconnected




- Thermal runaway occurred within 600 seconds from the start with cell venting and extremely rapid rise of temperature measured in TC3.
- There were continuous flames with gas venting in module terminals after thermal runaway was achieved by the initiation method.

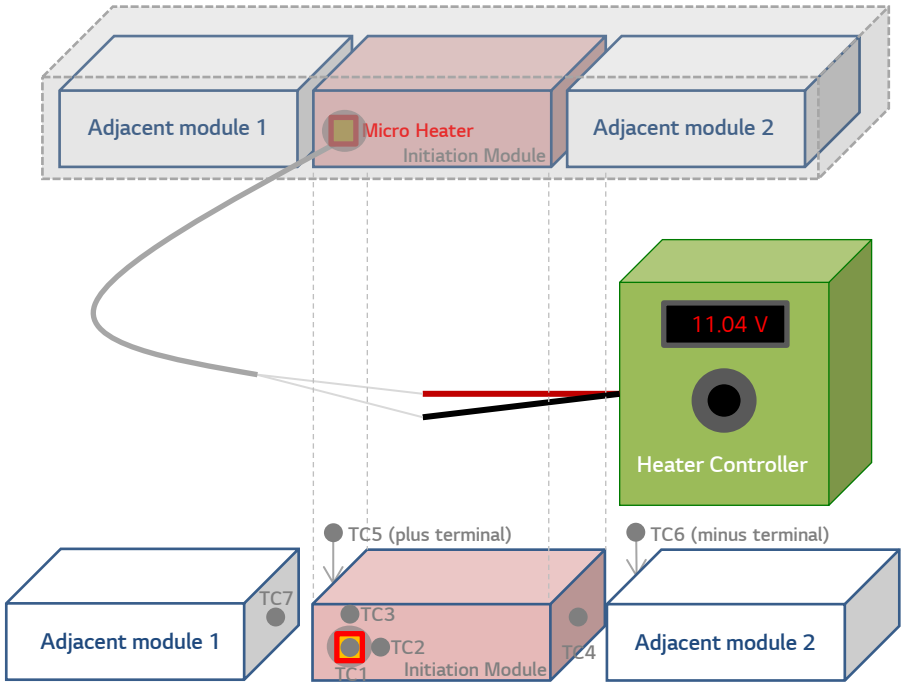
# Test results – Pack level

## 1) Sample information

| | |
|---|---|
| Type | Pack for testing (3 modules) |
| Nominal Voltage | 32.4 V (4P9S) |
| Capacity | 240 Ah |
| Energy | 7.8 kWh |
| SOC | 100% |

## 2) Test set-up

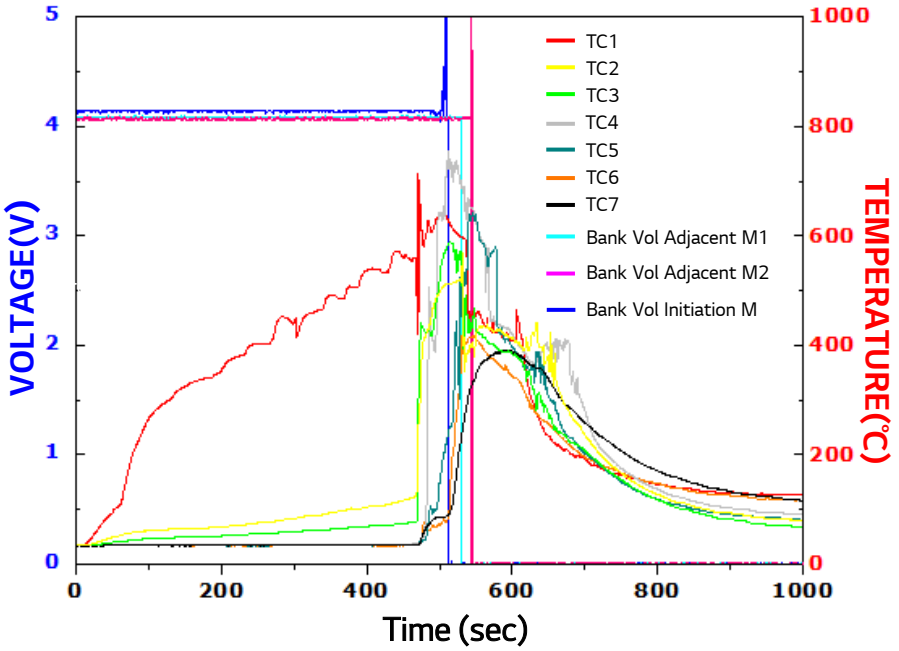
※ Pack surrounded with steel frame




※ Bank voltages are measured through LV cable in module terminals. (Vol. Bank 1, 2)

## 3) Test results

※ Voltage sensing lines were disconnected




- Thermal runaway occurred within 500 seconds from the start with cell venting and extremely rapid rise of temperature measured in TC3.
- There were only continuous venting and smoke without external fire, explosion in the pack level for 24 hours after thermal runaway was achieved by the initiation method.
- After the teardown of pack, adjacent modules didn't catch fire and voltages were normally measured without the drop. (No thermal propagation to adjacent modules)

# Conclusion

**The initiation method and manipulation procedures of thermal propagation test should be refined according to their considerations in the introduction chapter.**

**We demonstrated that this initiation method makes the initiation cell occur thermal runaway in a short period of time and it does not heat up the adjacent cell or surroundings within the target cell apart from the locally specified area.**

**It is more proper to simulate actual TR occurred in a localized area of single cell caused by internal short-circuit than any other initiation method and easily attached on the cell surface with the minimized manipulation.**

**The reason the effect of the manipulation should be minimized is because it is related to repeatability and reproducibility. It may be confused to conduct the test and demonstrate that battery pack or battery system prevents fire propagation in the real situation if the manipulation procedures are not specified and ambiguous in the standard and differently applied to each DUT.**

**Our considerations of the initiation method and the manipulation should be important criterions for judging the test procedure.**