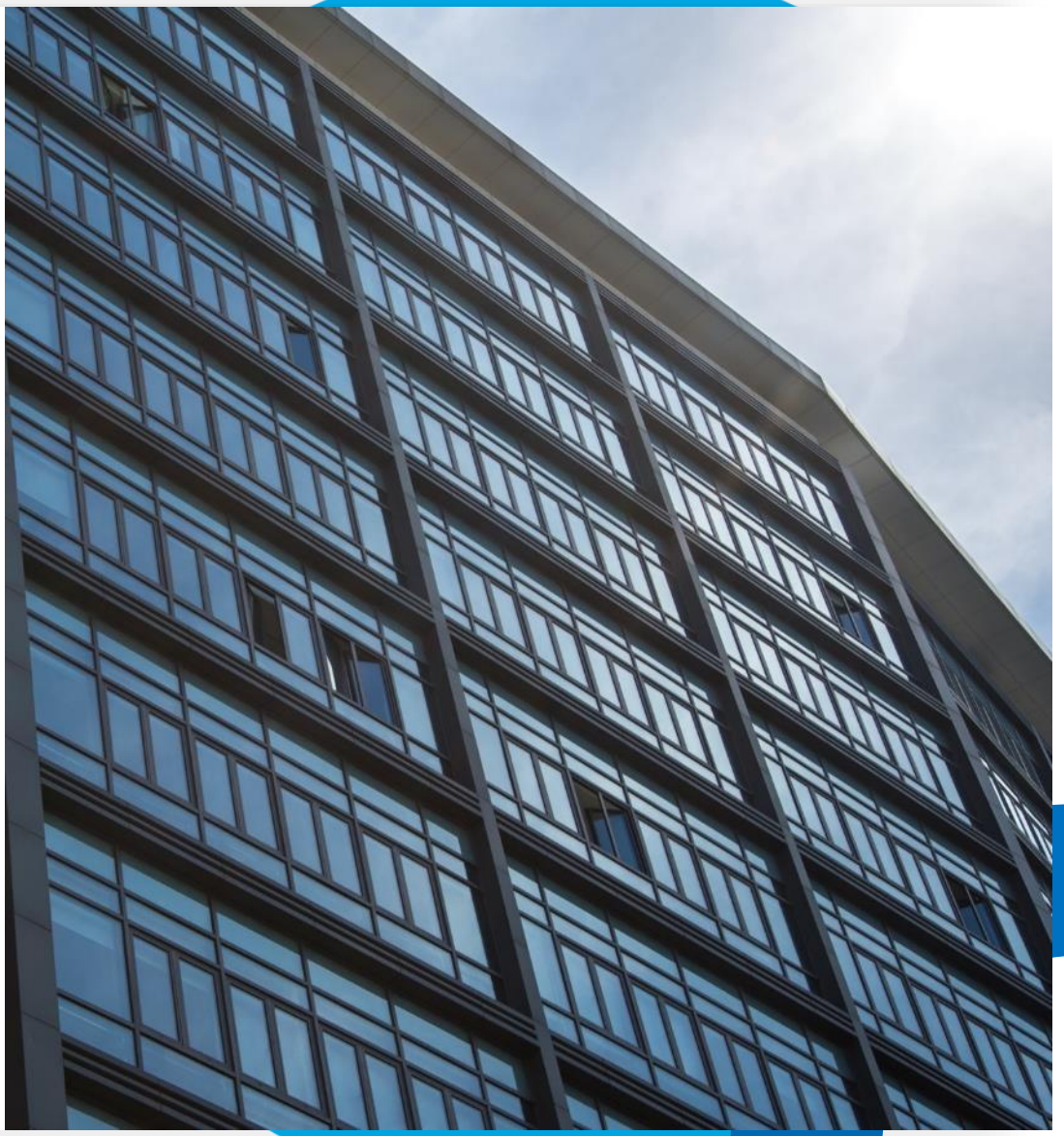
Hazard-based Classification System for Lithium Batteries

Ting Xu, Hong-Hui Wang

Geneva, 2025.12

Shanghai Institute of Chemical Industry Testing Co. Ltd.



Part 2. Thermal propagation tests

2.0 Classification points

4 Hazard factors

① Thermal runaway & thermal propagation;
② Gas flammability;
③ Gas volume: 0.25, 25, 500L;
④ High temperature: ΔT>150℃;

6 Tests

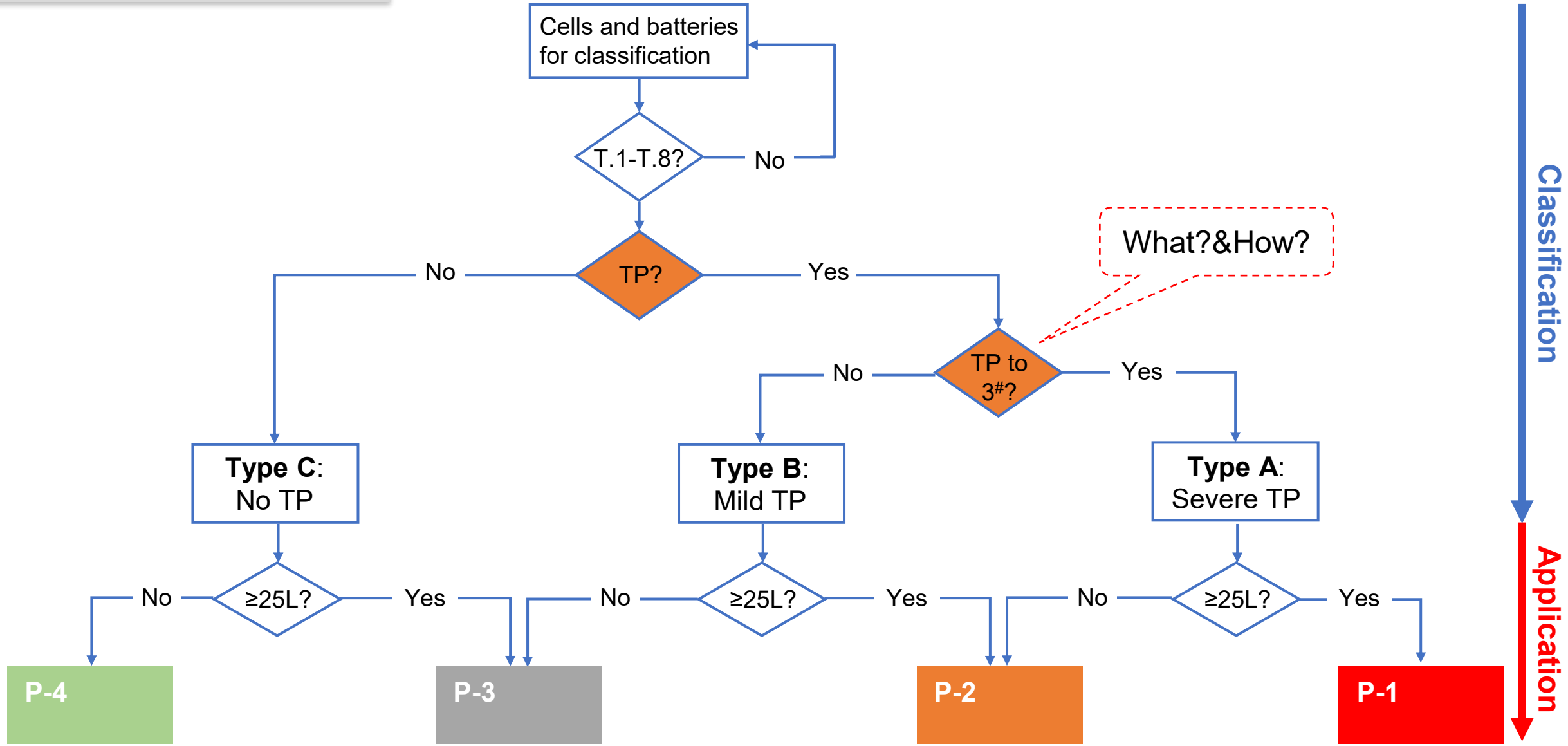
① Test T.9: Cell propagation test
② Test T.10: Cell gas volume determination
③ Test T.11: Battery propagation test
④ Test T.12: Battery gas volume determination
⑤ Test T.13: Cell gas flammability determination
⑥ Test T.14: Air gap determination

Most China experts pointed out that the classification system is **overly complex** and limiting the classification scheme to **three types** is suggested, which is drawn in the document **ST/SG/AC.10/C.3/2025/57**.

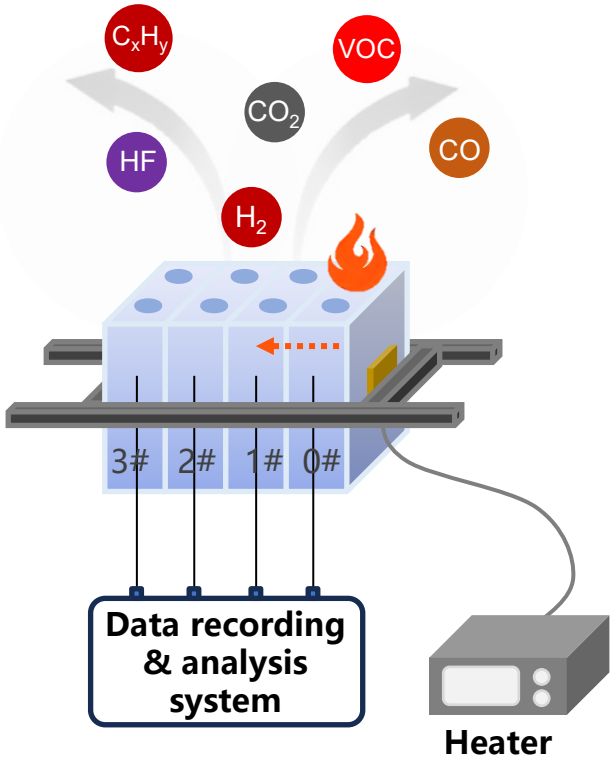
ST/SG/AC.10/C.3/2025/57, Comments on the hazard-based system for classification of lithium batteries, transmitted by the expert from China

2.0 New Classification

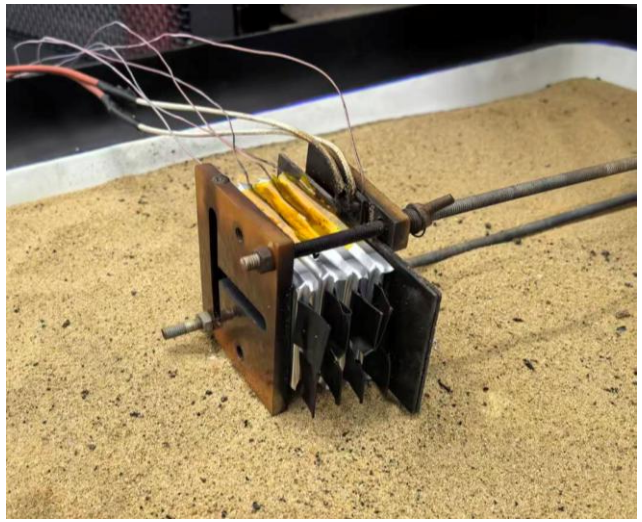
A new hazard classification system (3 types) has been proposed based on cell/battery thermal propagating distance.



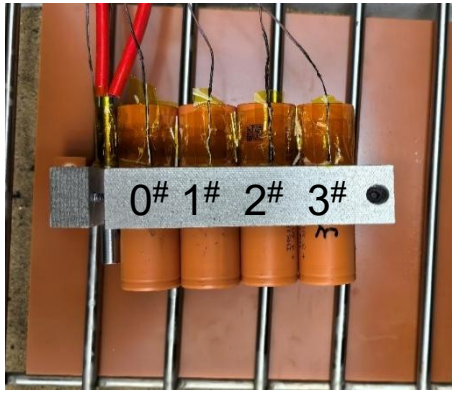
2.1 TP testing platform

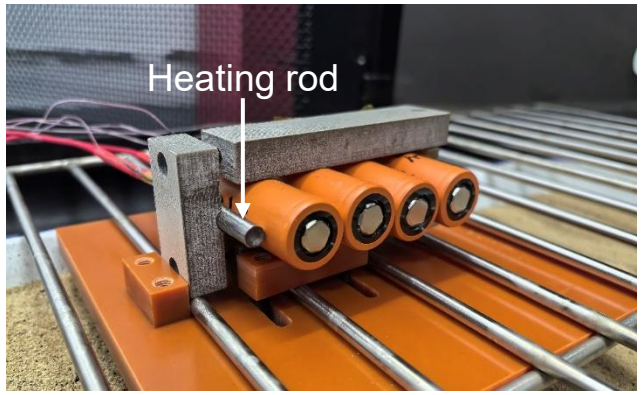


Pouch cell NCM 844770, 3.7V, 4Ah



Cylindrical cell NCM 18650, 3.7V, 2Ah

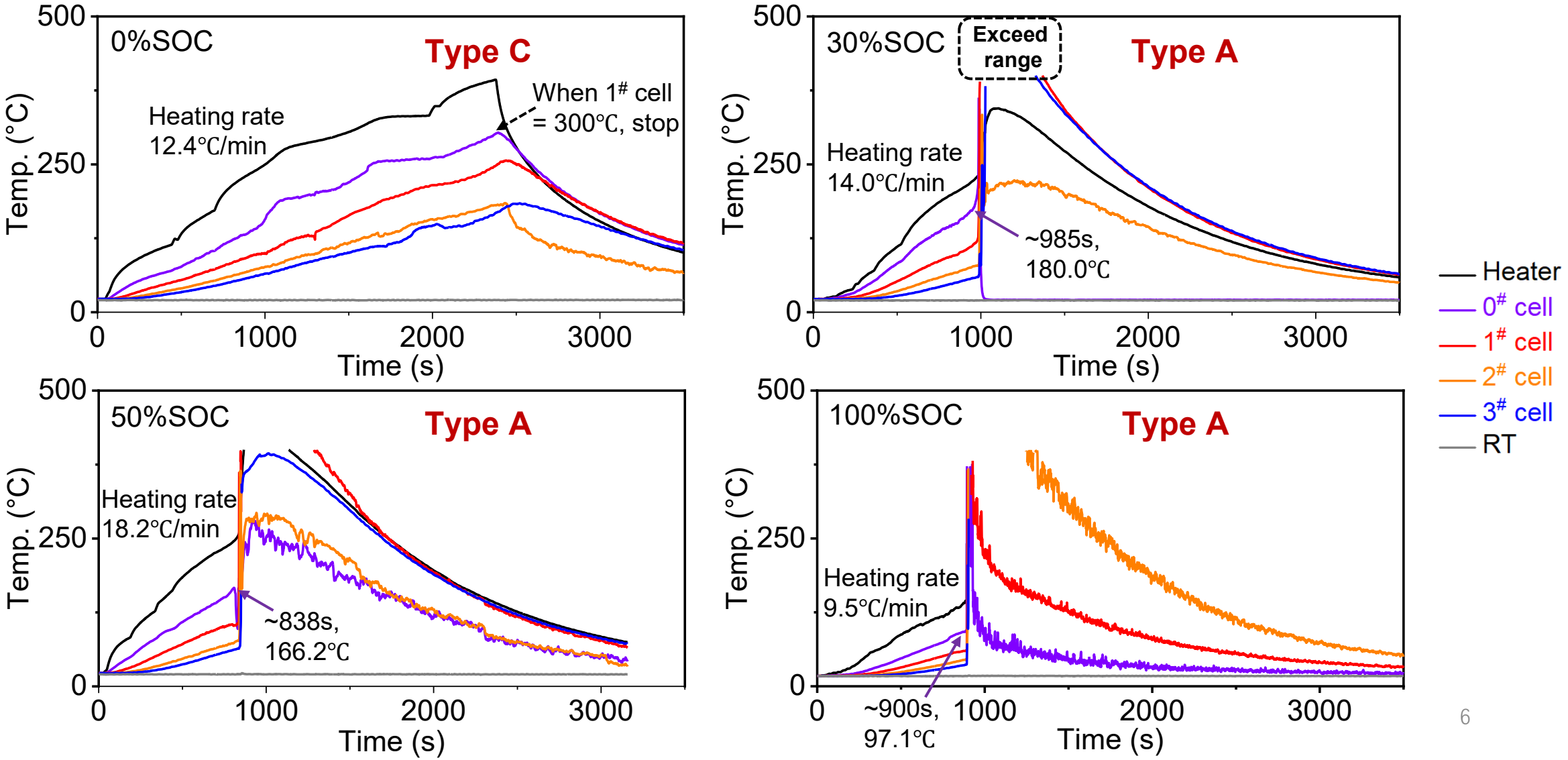




Lithium ion cells thermal propagation (TP) testing platform

2.1a Pouch cell TP results

For these pouch cells, the hazard classification results are Type A if SOC≥30%.

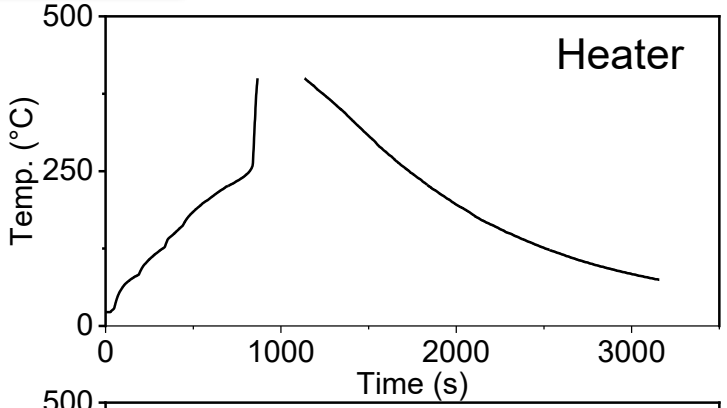


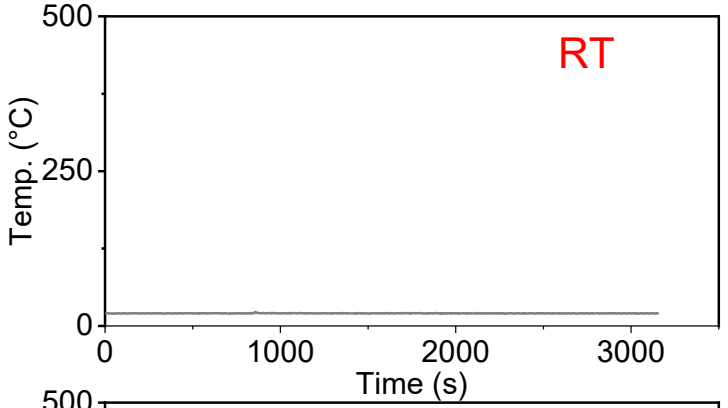
2.1a Pouch cell TP results

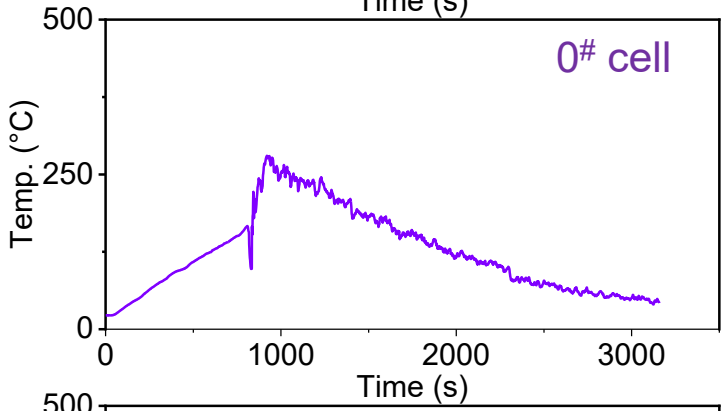
SOC	Average heating rate ($v_{heating}$)	Time and temp. of 0# cell	Average temp. rising rate of 0# cell	TR of 0# cell	TP to 3# cell	Hazard classification	Phenomenon
0%	12.4℃/min	2392s, 300℃	7.0℃/min	No	No	**Type C**	No fire, little white smoke
30%	14.0℃/min	985s, 180℃	9.7℃/min	Yes	Yes	**Type A**	No fire, much white smoke
50%	18.2℃/min	838s, 166℃	10.5℃/min	Yes	Yes	**Type A**	No fire, sparks, much white smoke
100%	9.5℃/min	900s, 97℃	5.1℃/min	Yes	Yes	**Type A**	Fire and violent combustion

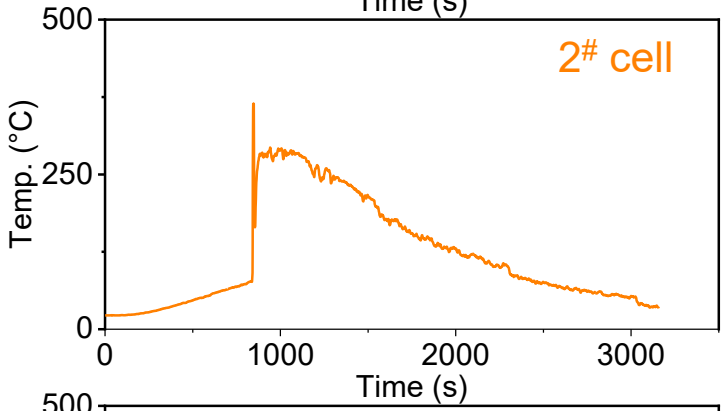
In conclusion, for this model of pouch cells, even the SOC reduced to 30%, severe TP also occurred (**Type A**). The reason is highly likely that because of 1. the thickness is very thin and 2. Large contact heat transfer surface, so the large amount of heat is easy to transfer from one pouch cell to another.

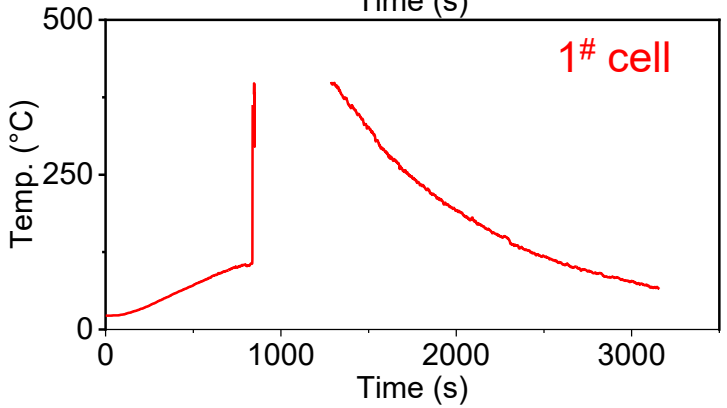
2.1b 50%SOC cell TP

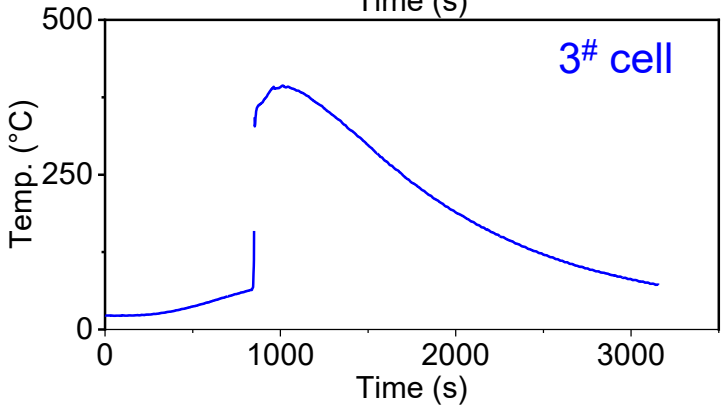




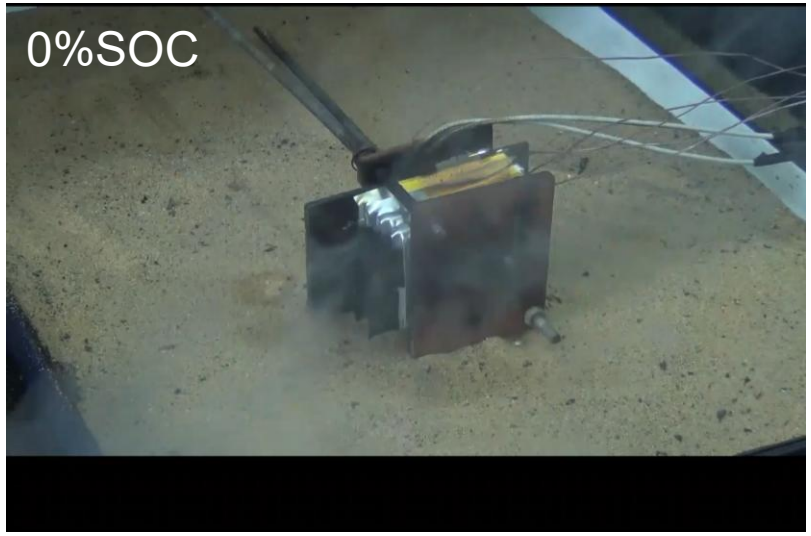


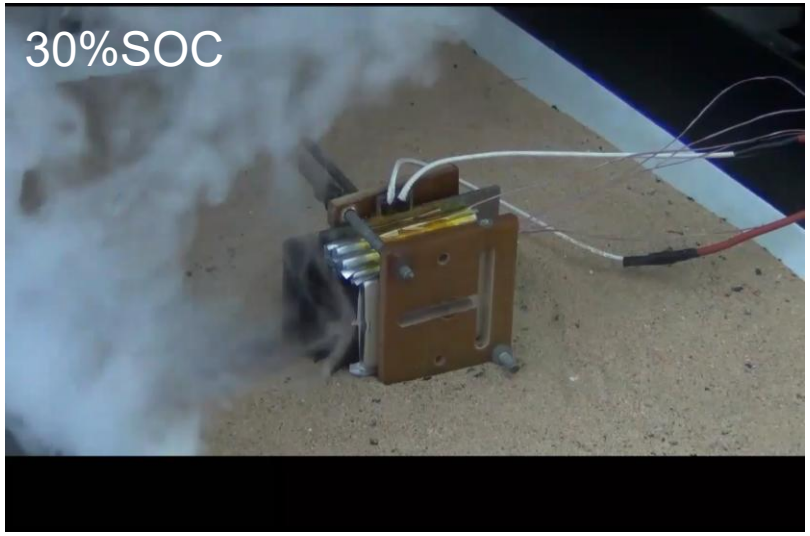


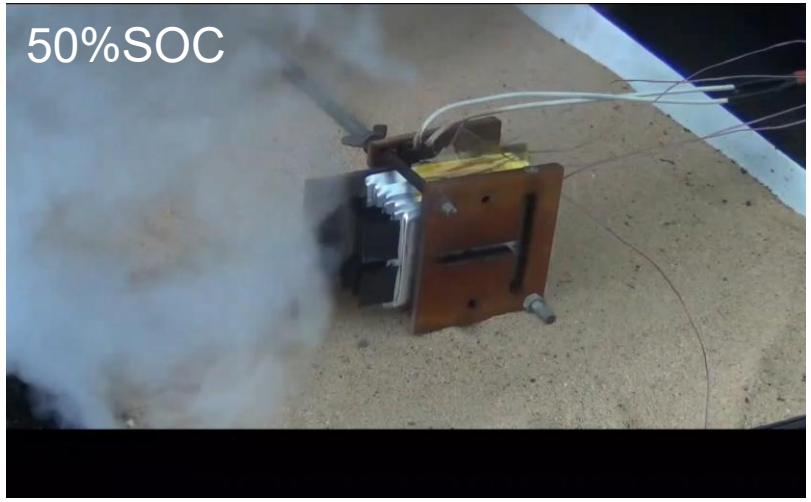


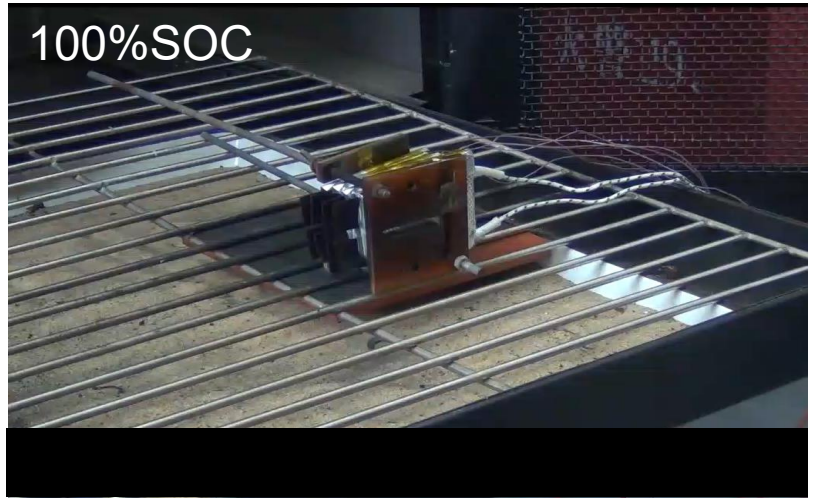


2.1c Pouch cells TP Videos



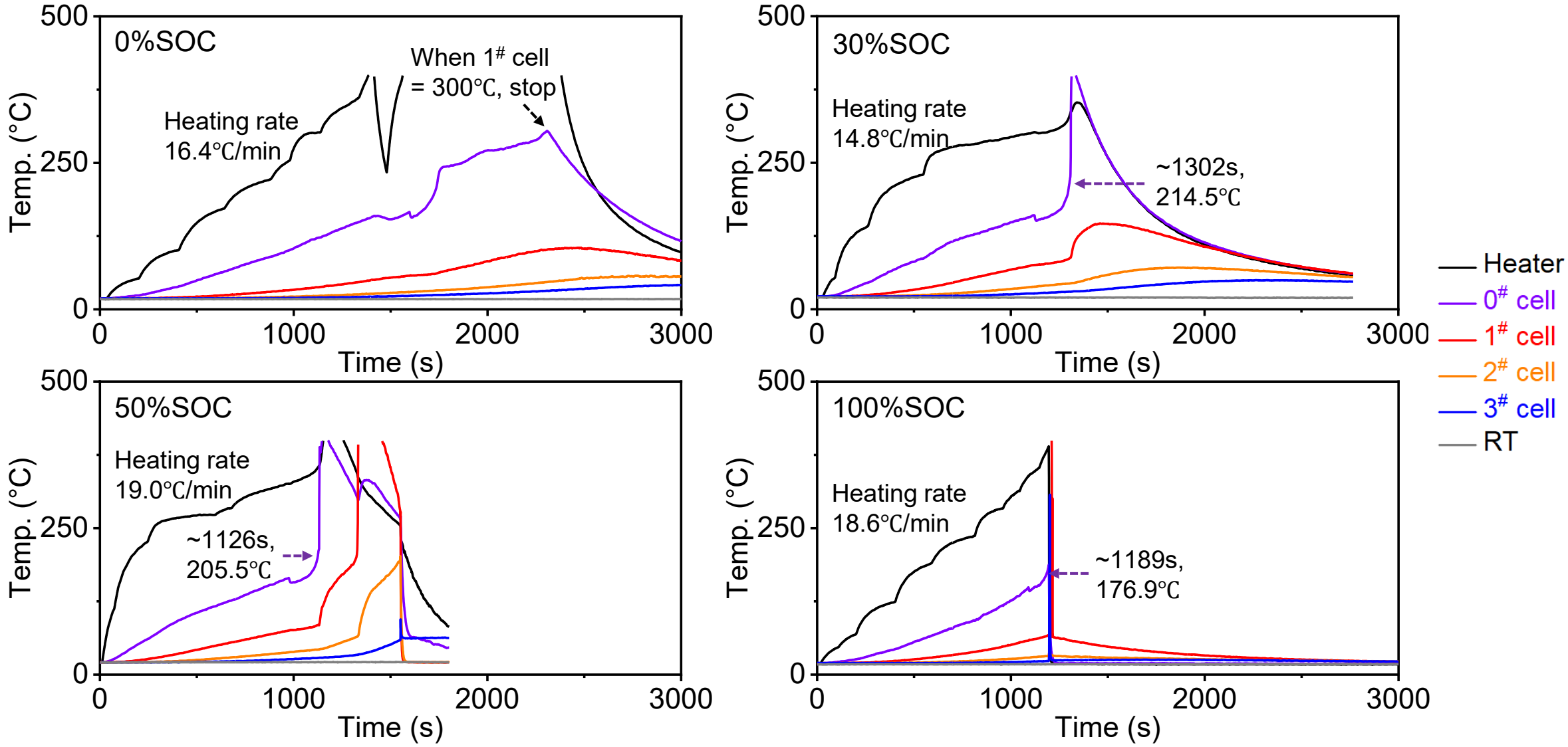






2.1d Cylindrical cell results

Different hazard-classification results for cylindrical cells.



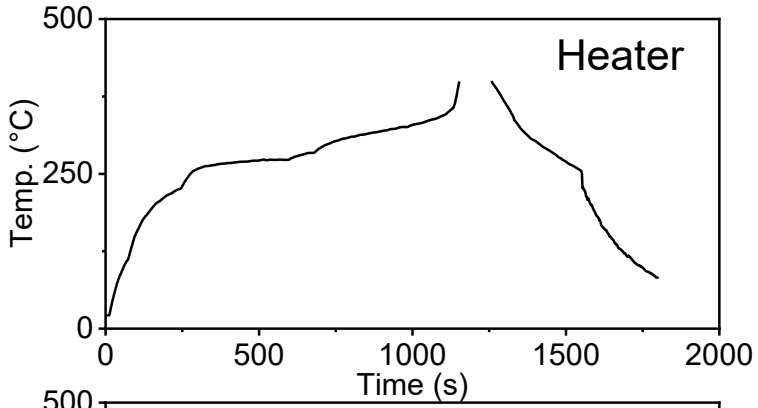
2.1d Cylindrical cell results

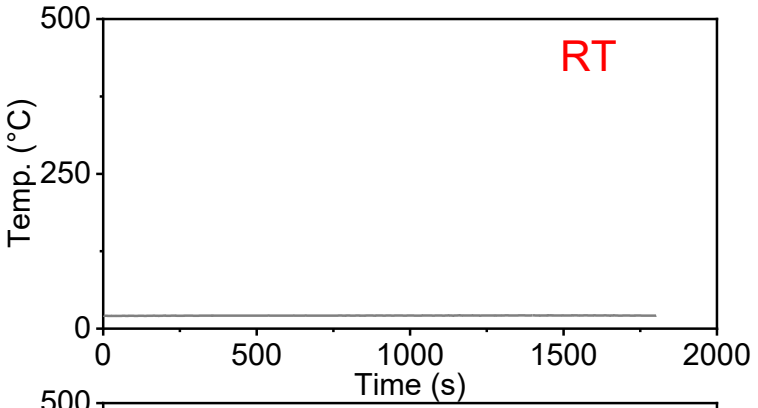
SOC	Average heating rate ($v_{heating}$)	Time and temp. of 0# cell	Average temp. rising rate of 0# cell	TR of 0# cell	TP to 3# cell	Hazard classification	Phenomenon
0%	16.4℃/min	2392s, 300℃	7.0℃/min	No	No	**Type C**	No fire, little white smoke
30%	14.8℃/min	1302s, 215℃	9.0℃/min	Yes	No	**Type B**	No fire, much white smoke
50%	19.0℃/min	1126s, 206℃	9.9℃/min	Yes	Yes	**Type A**	No fire, much white smoke, 2# cell ejected from fixture
100%	18.6℃/min	1189s, 177℃	7.9℃/min	Yes	Yes	**Type A**	No fire, much white smoke, 0-1# cells ejected from fixture

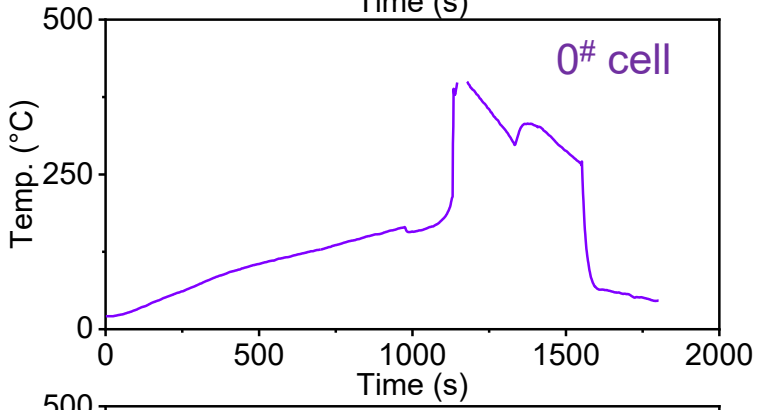
In conclusion, for this model of 18650 cells, when the SOC = 30%SOC, mild TP occurred (**Type B**), it seems that higher SOC (≥50%) means severe TP (**Type A**), which further indicates that the SOC has a significant impact on the classification results.

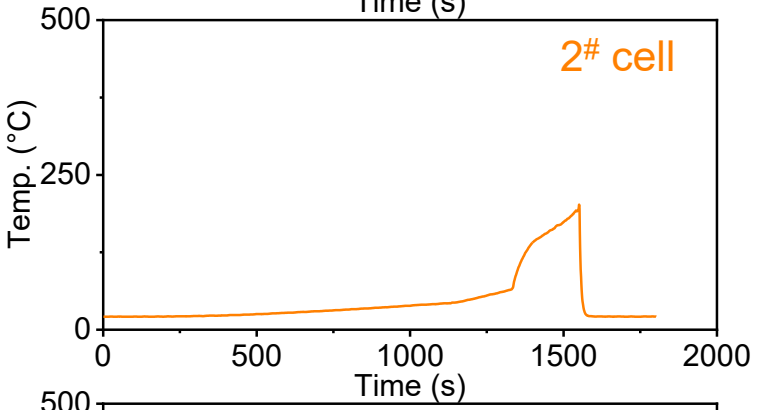
Based on the experiment results, lithium ion cells with 100%SOC can't pass the T.9 test. If most cells are classified as the highest danger level Type A, this may not reflect the actual situations. So, maybe relative lower **SOC (≤50%) is practical**.

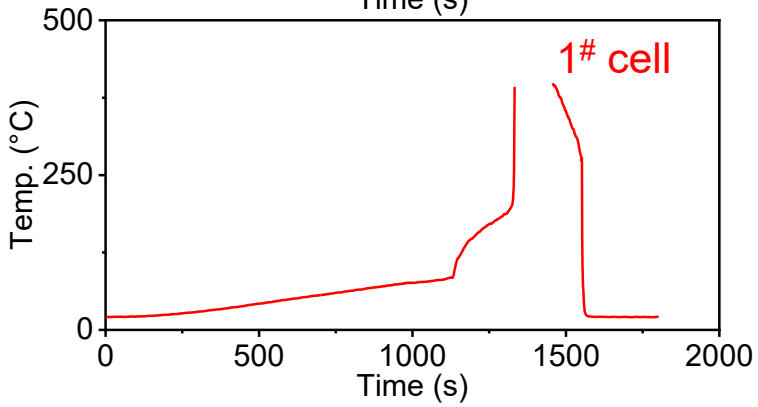
2.1e 50%SOC cell TP

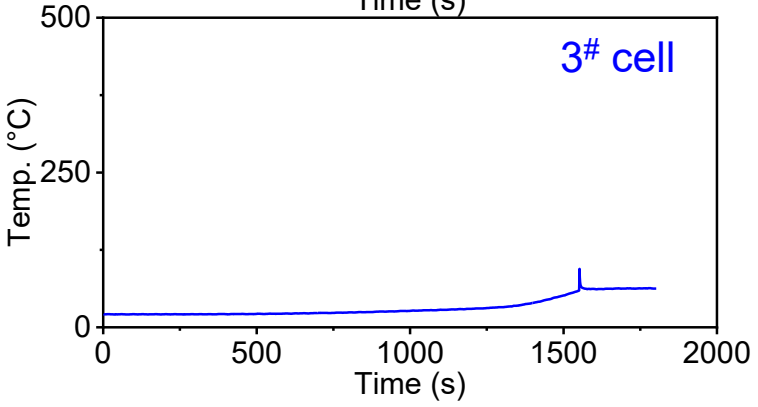




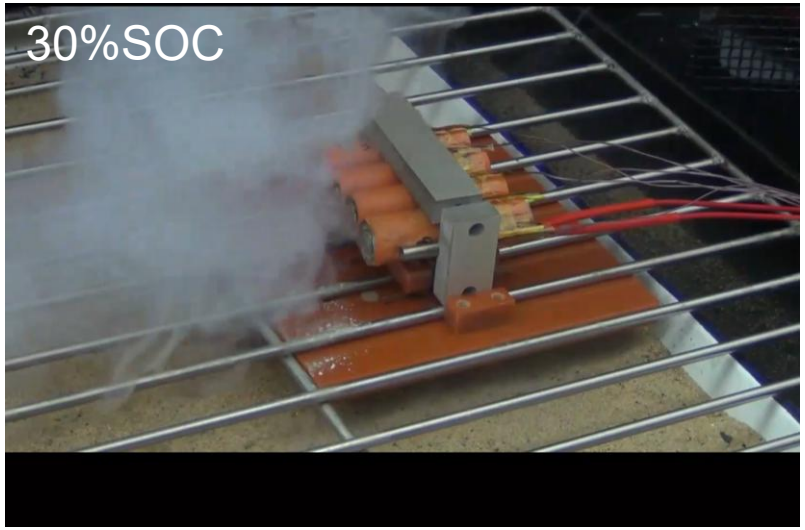


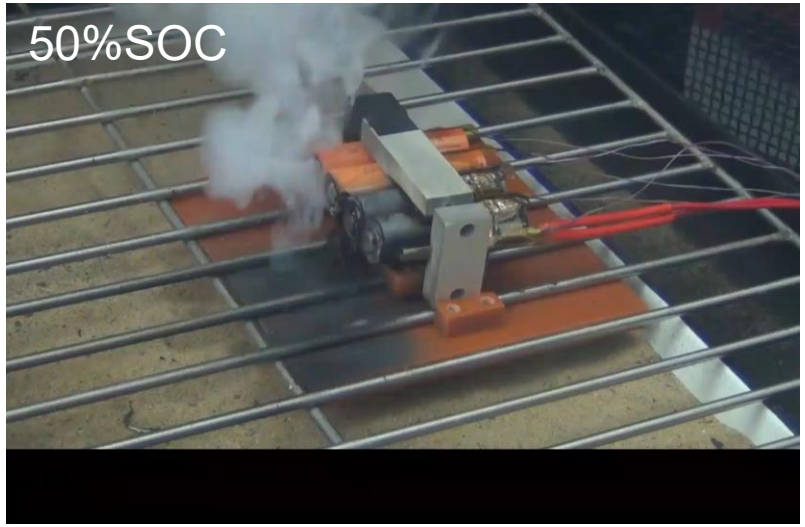






2.1f Cylindrical cell Videos





2.1g TP experiment details

☐ 1. **The control of heating rate** ($v_{heating}$):

a) It needs to real-time adjust the heating power based on the temperature rise of trigger cell ($0^{\#}$).

☐ 2. **The thermal couple** (range, position and fixing means):

a) The measurement range should exceed 800℃ or higher;

b) Sensor should be fixed on cell surface rather than on the creases formed by sealing (the red dash box in right picture).

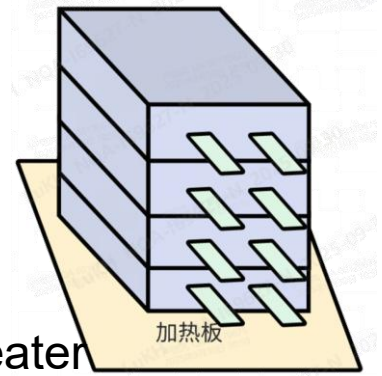
c) Sensor should be fixed tightly, and would not fall off due to cell case deformation or high temperature.

☐ 3. **The cells**

a) Cells should be fixed tightly in case of ejection the cell and roll core.

2.1h TP results from Co-Lab1

TP tests of different capacity and SOC

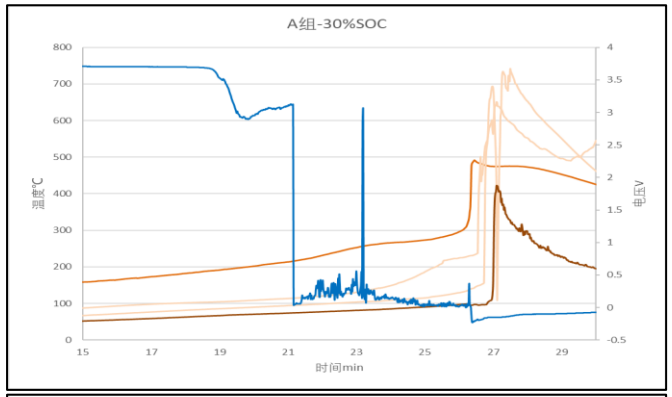


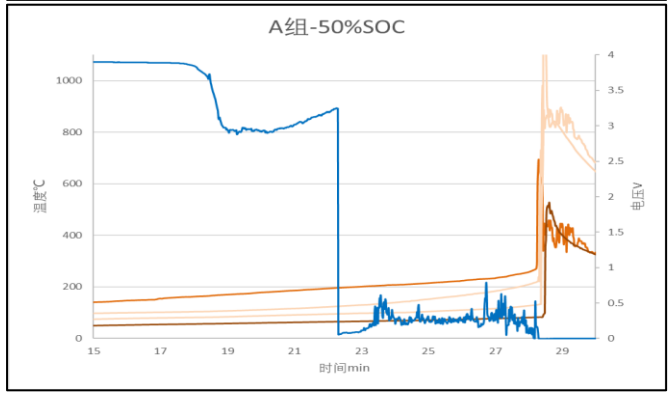
Heater

Model	Capacity	30%SOC	50%SOC
Group A	5.4Ah	TP, but no fire	TP, but no fire
Group B	7.6Ah	TP, but no fire	TP, and fire
Group C	9.7Ah	TP, but no fire	TP and fire

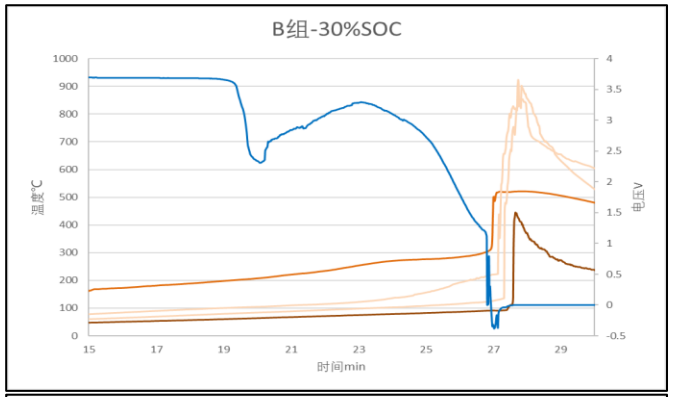
Temp.
1st cell
2nd cell
3rd cell
4th cell
Voltage
1st cell

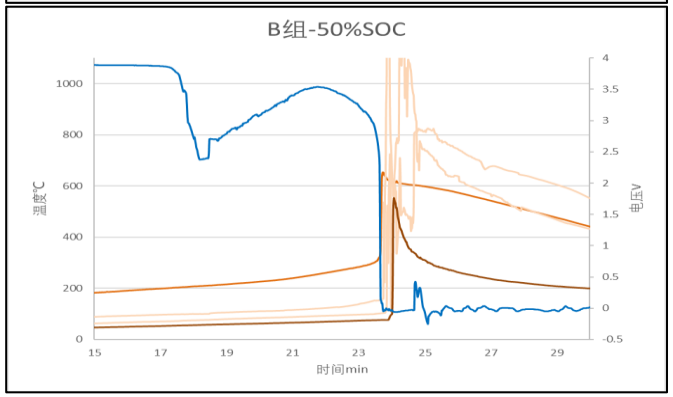
A组



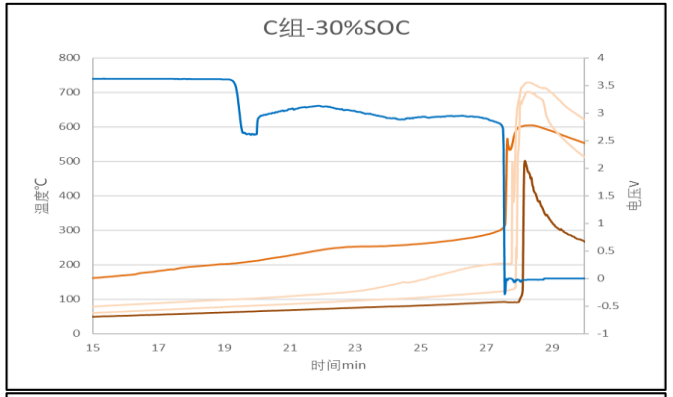


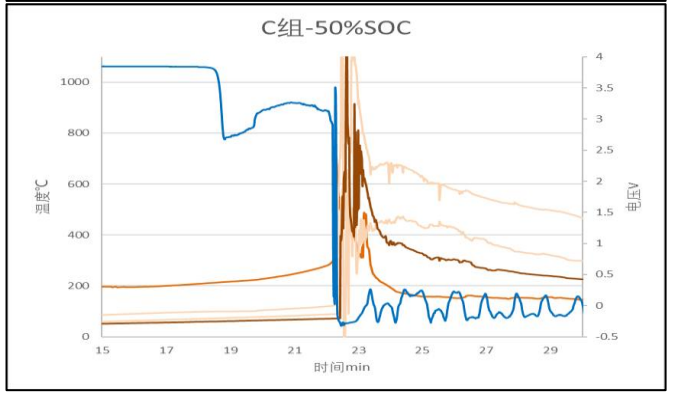
B组





C组





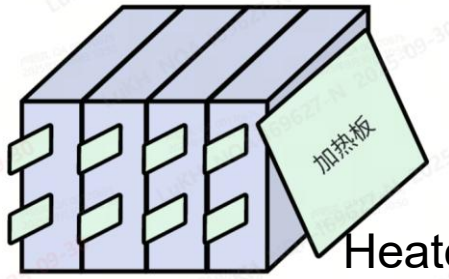
2.1h TP results from Co-Lab1

TP tests with cell's tabs facing different directions

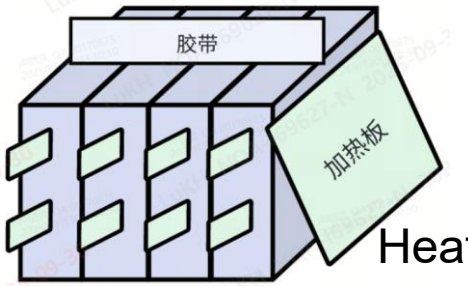
Group A: 5.4Ah 30%SOC

The tabs facing different directions have little effect on the TP results.

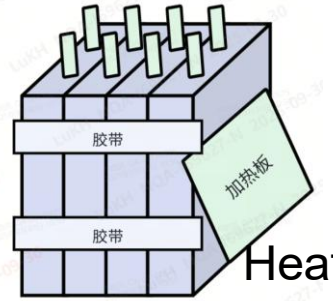
Group 1: tabs facing front with fixture

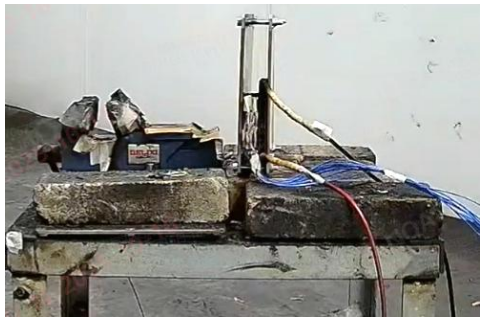


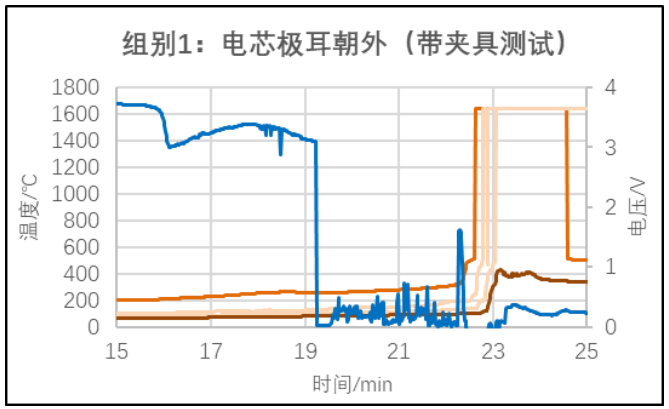
Group 2: tabs facing front with no fixture

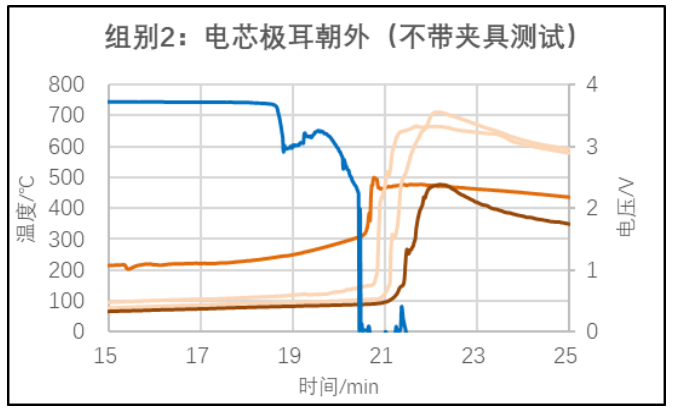


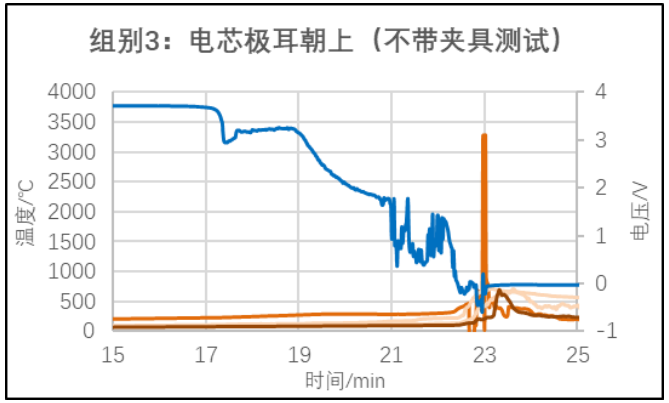
Group 3: tabs upwards with no fixture

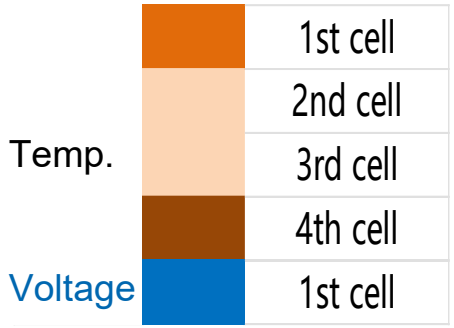










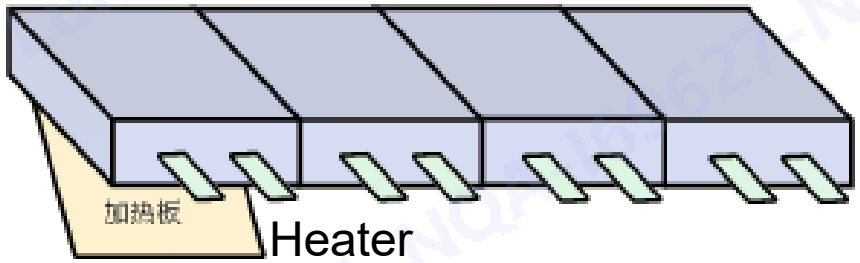


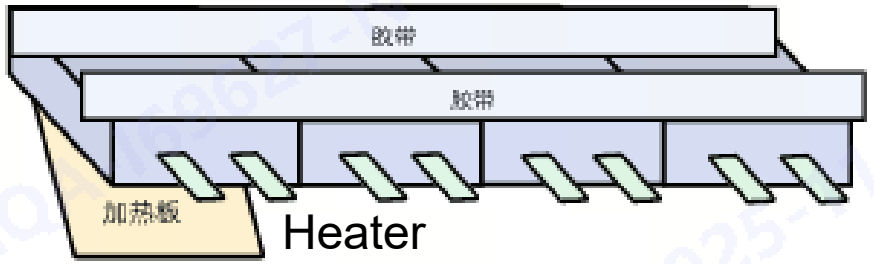
2.1h TP results from Co-Lab1

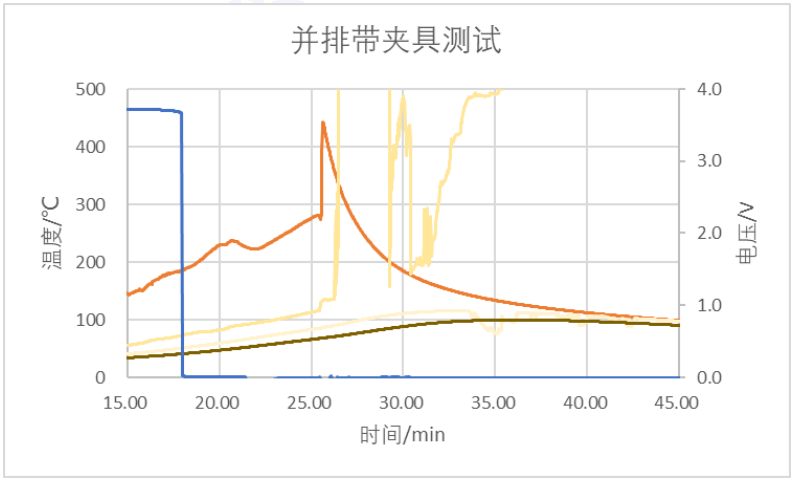
TP tests of cells with small side face contact

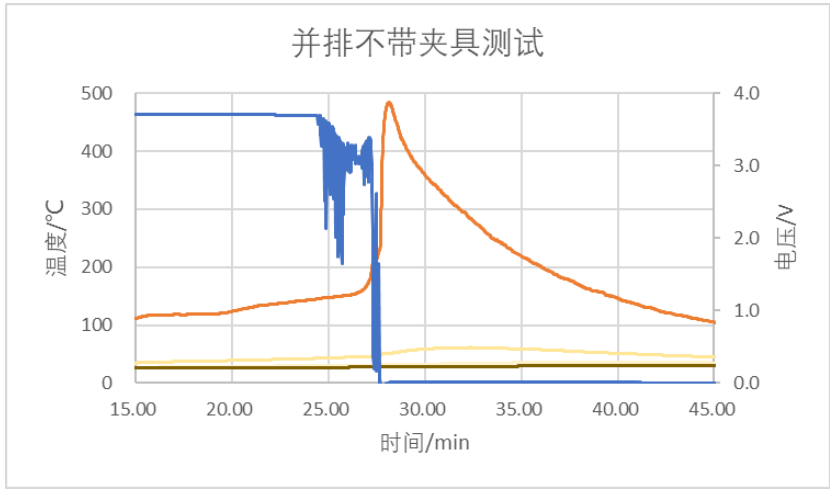
Group A: 5.4Ah 30%SOC

Four cells were placed side by side with the **side surface** used as the contact surface, no thermal propagation occurred. (Maybe more in line with actual scenarios)



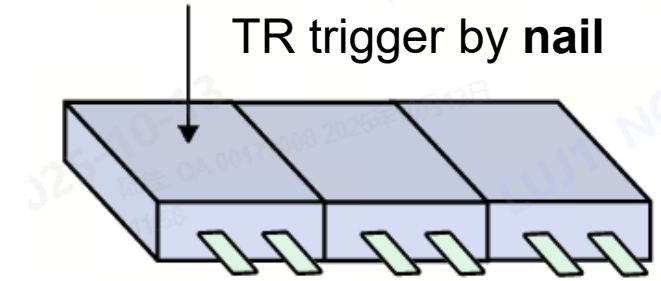






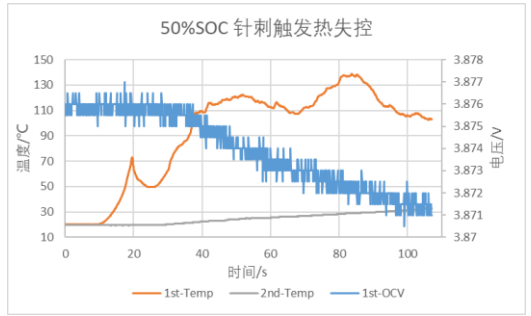
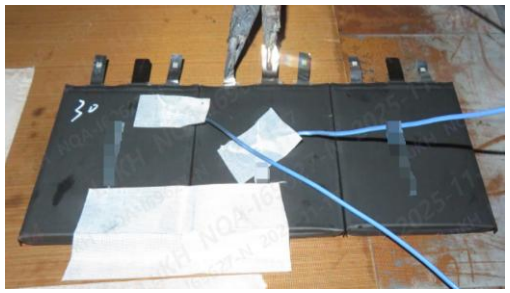
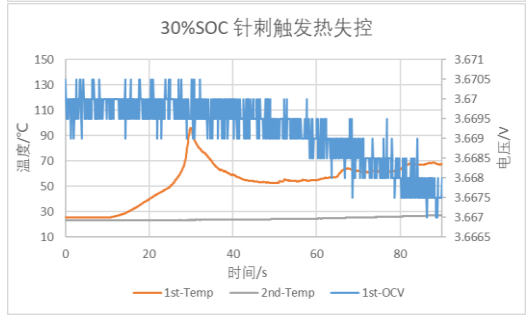
2.1h TP results from Co-Lab1

TP tests triggered by nail with small side face contact



Diameter: 4mm; 30mm/s

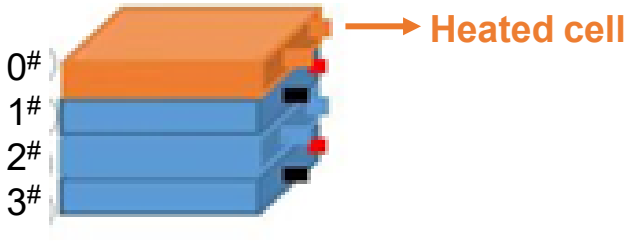
Capacity	50%SOC	30%SOC
5.4Ah	First cell TR, but no TP	First cell TR with large smoke, but no TP

	Before	After	Test data
50%SOC			
30%SOC			

2.1h TP results from Co-Lab2

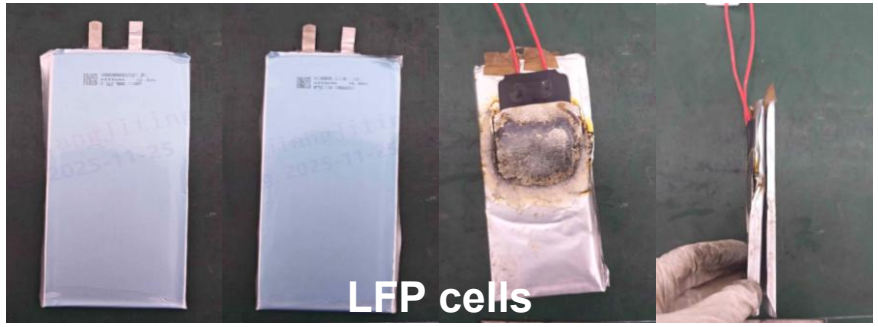
TP tests of different electrochemical systems

Cell	Capacity (Ah)	SOC	Result
LFP	4.646	50%	No TP
LCO	3.170	50%	TP and fire
NCM	6.654	50%	TP and fire



Before test

After test



Before test

After test

2.1h TP results from Co-Lab2

TP tests in actual transportation conditions

TP tests were carried out in the battery blister tray (for transport) made from PET (plastic) with 10mm gaps to simulate actual transportation scenarios.

Cell	Capacity	SOC	Number	Results
LCO	8.8Ah	100%	6	TP, fire
LCO	7.2Ah	50%	6	TP, fire
LCO	8.8Ah	100%	3	TP by the **flammable blister tray**, fire
LCO	7.2Ah	50%	3	TP by the **flammable blister tray**, fire

Before test

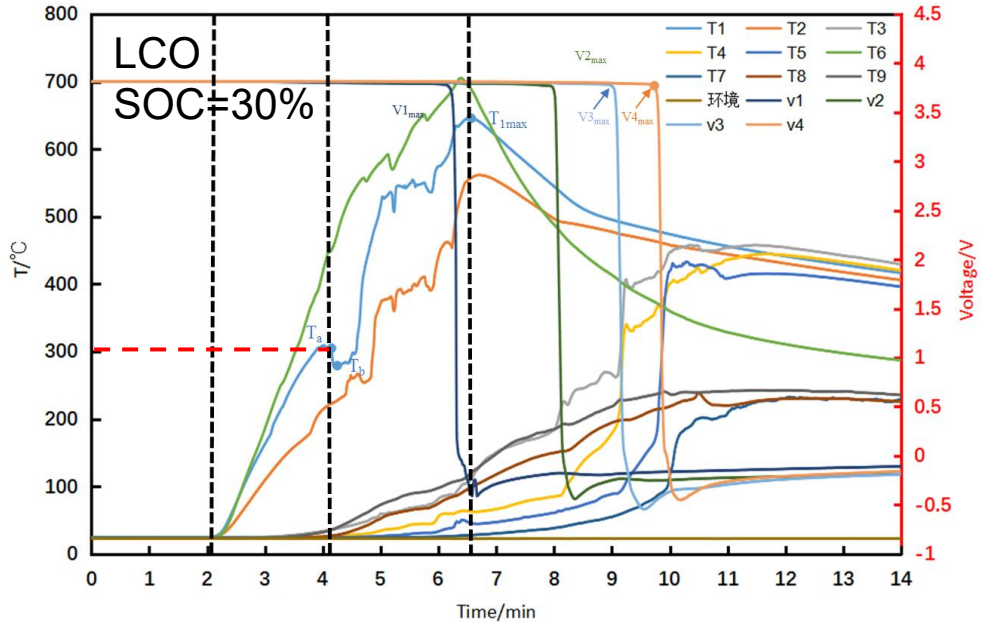
After test

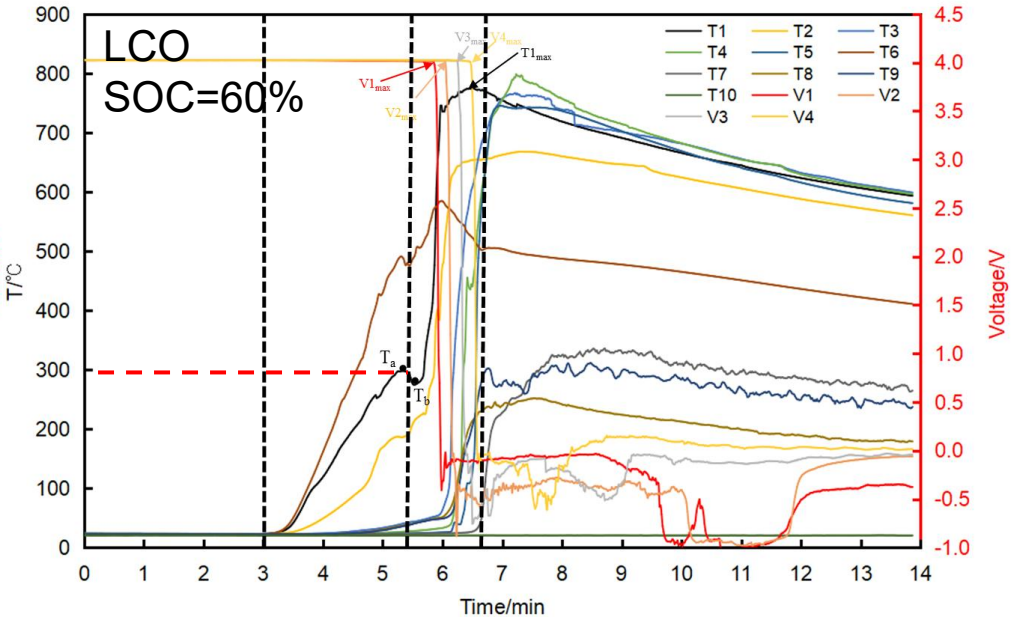
2.1h TP results from Co-Lab3

TP tests of LCO cells with different SOC

Q: Terminating temp. of trigger cell (375℃) is too high?

SOC	Time and temp. of 0# cell	Average temp. rising rate of 0# cell	TR of 0# cell	TP to 3# cell	Hazard classification	Phenomenon
30%	249s, 304.8℃	141℃/min	Yes	Yes	**Type A**	No fire, much white smoke, TP
60%	327s, 291.8℃	119℃/min	Yes	Yes	**Type A**	Fire, much white smoke, TP





2.1h TP results from Co-Lab3

SOC=30%

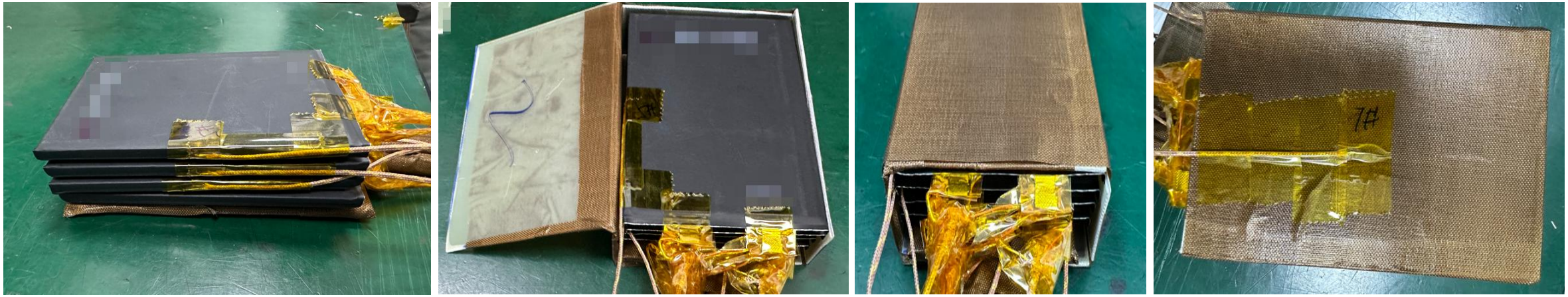
Before test

After test

2.1h TP results from Co-Lab3

SOC=60%

Before test

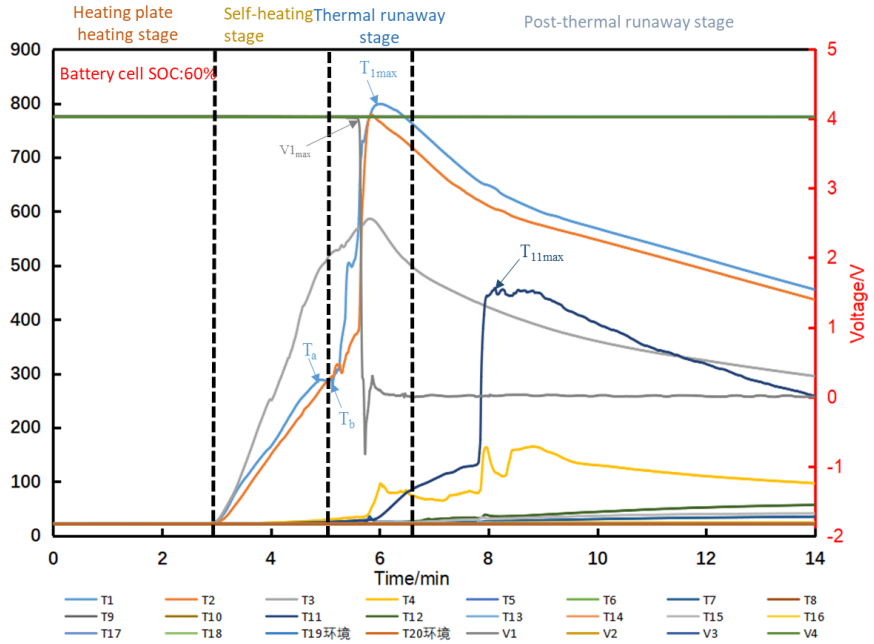


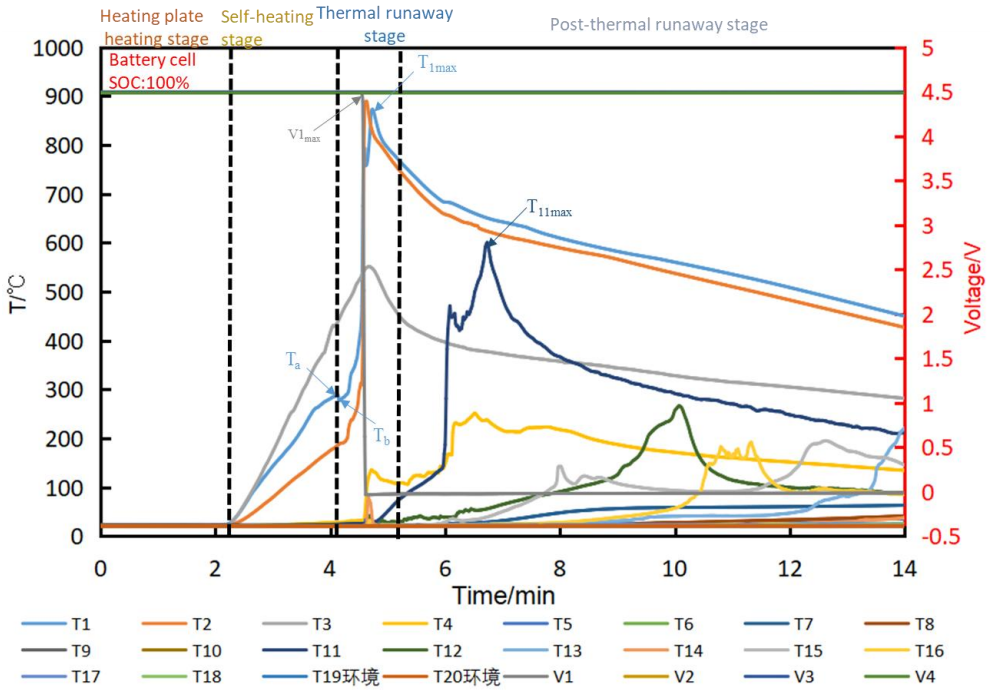
After test

2.1h TP results from Co-Lab3

TP tests were carried out in the blister tray (for transport) made from **flame retardant material**.

SOC	Time and temp. of 0# cell	Average temp. rising rate of 0# cell	TR of 0# cell	TP to 3# cell	Hazard classification	Phenomenon
60%	300s, 287.3℃	130℃/min	Yes	No	**Type C**	Fire, No TP, smoke
,100%	247s, 289.4℃	131℃/min	Yes	No	**Type C**	Fire, No TP, smoke

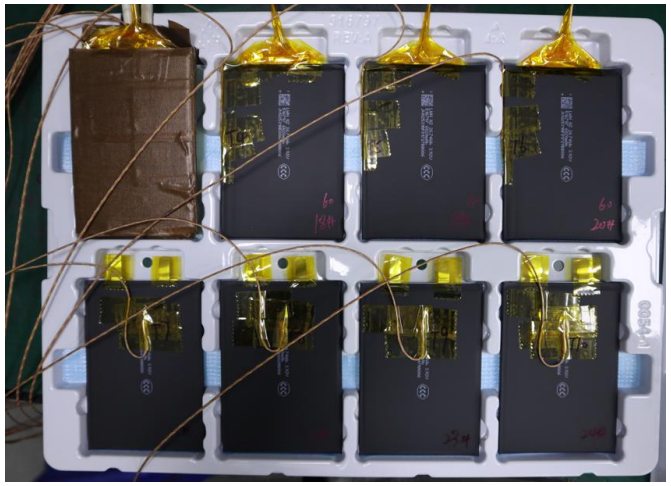


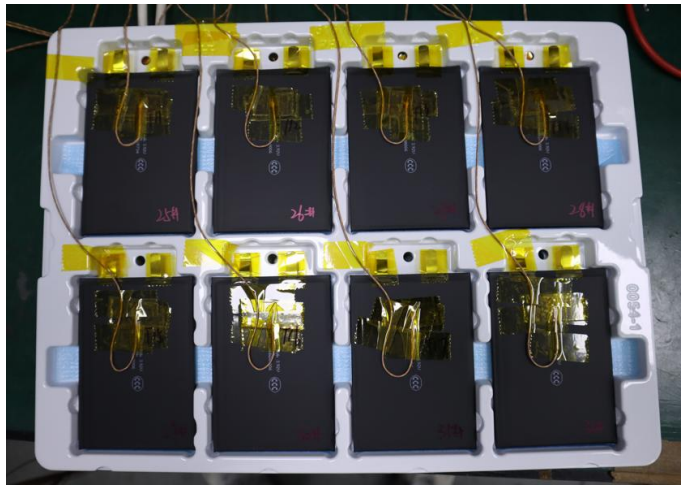


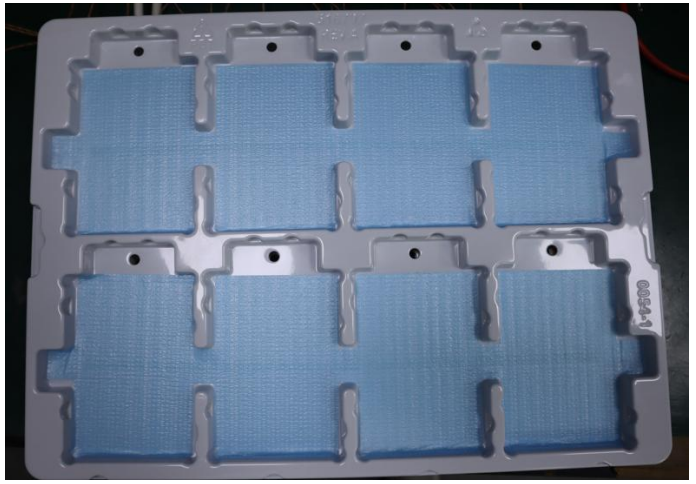
2.1h TP results from Co-Lab3

SOC=60%

Before test







Bottom tray

Middle tray

Upper tray

After test

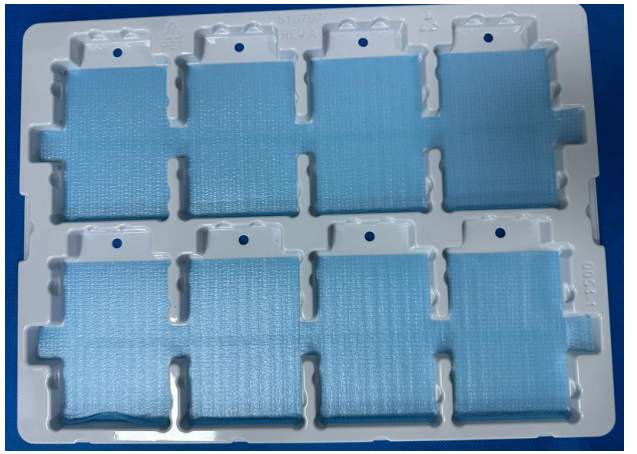
2.1h TP results from Co-Lab3

Witness Better Life
SICIT

Before

SOC=100%

Before test



Bottom tray

Middle tray

Upper tray

After

After test

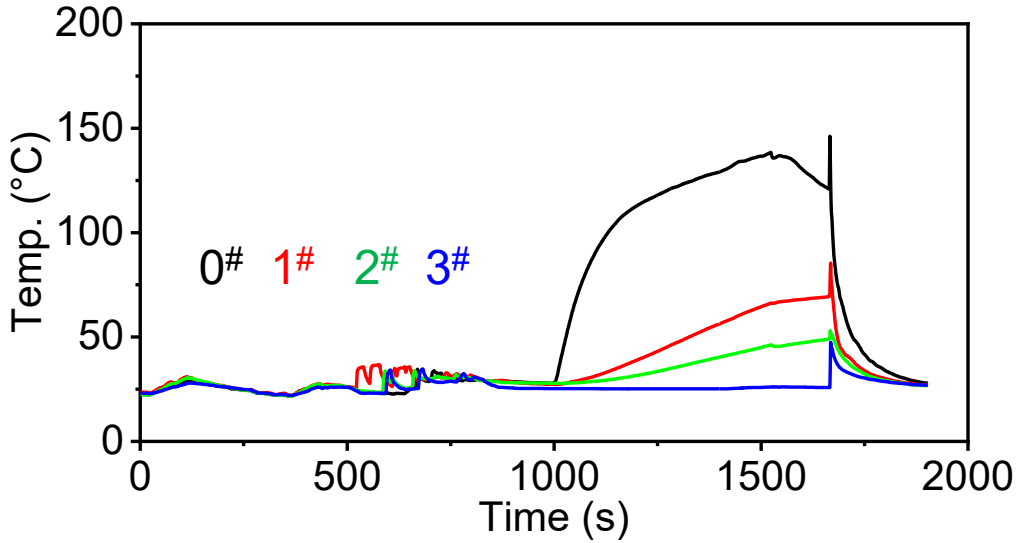
2.1h TP results from Co-Lab4

Four cells were placed side by side and covered by the fire extinguisher blanket, no thermal runaway and thermal propagation occurred as the 0# cell just had been heated to 140℃ when the pressure relief valve opened.

Before test

After test

Cylindrical cell ISR18650-2500, 3.7V, 2.5Ah (100%SOC)



2.1i Brief summary

A lot of cell thermal propagation tests have been carried out in our testing center and co-laboratories, similar conclusions can be drawn:

- The testing requirements or conditions may need to be further optimized for different types of batteries, as pouch cells (LCO, NCM) with SOC≥30% are hard to pass T.9;

a) **SOC:** 30%~50%SOC is worth thinking. Although fail to pass, but no fire and less risk compared to 100%SOC.

b) **TR triggering stop condition**: the termination temp. could be decreased to 300℃ or less?

c) **Contant face between cells**: large face or side face.

d) **Cell arrangement method**: direct contact or simulation of transportation conditions (in blister trays).

- In order to secure the validity of the test results, there are many details should be concerned or specified for the consistency of tests among different laboratories.

How to choose SOC for tests, hazard evaluation & classification?

For safety transportation

- Lower SOC (≤30%):

  More safety, but power runs out for long-distance transportation;

- Higher SOC (>30%):

  Less safety, enough power.

vs

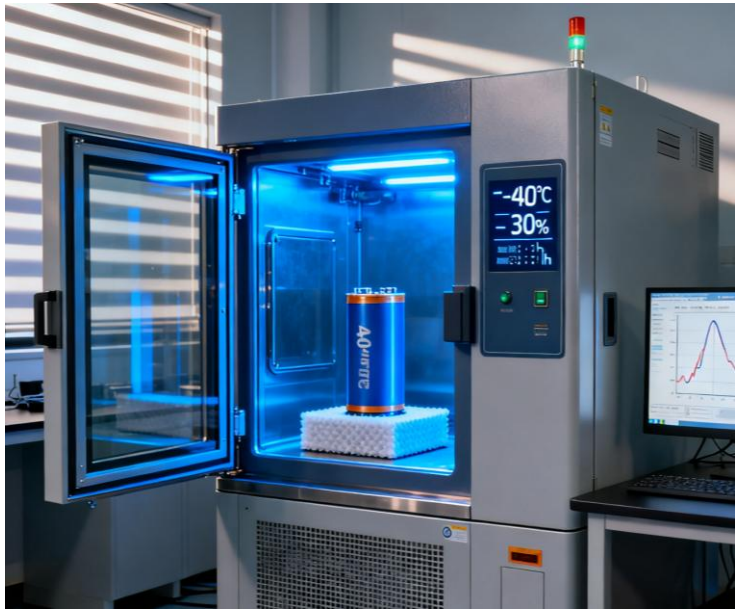
For safety tests

- Lower SOC (<30%):

  Maybe pass easily;

- Higher SOC (100%):

  Most cells fail to pass.



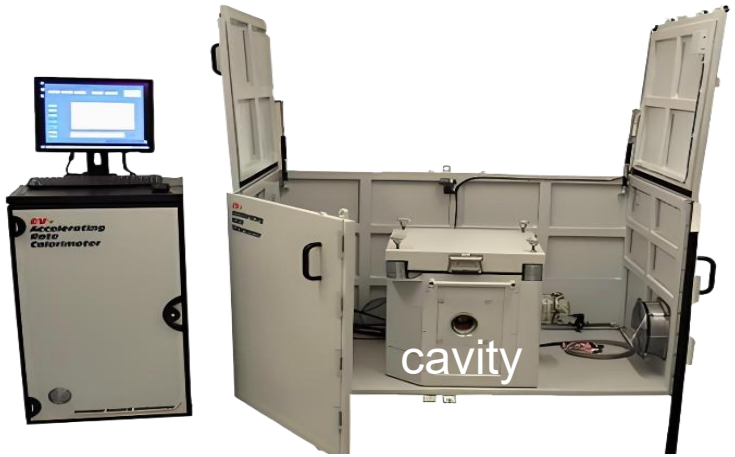
Most China experts believe that **SoC is an intrinsic property which can change the classification of cells or batteries**. Moreover, the addition tests proposed need only be conducted at the selected SoC for actual transport scenarios, and classification at a certain SoC can be used for the transport of same cells or batteries at lower SoCs, without more tests. But competent authorities may require tests to be conducted under a specific SoC, as appropriate.

ST/SG/AC.10/C.3/2025/57, Comments on the hazard-based system for classification of lithium batteries, transmitted by the expert from China

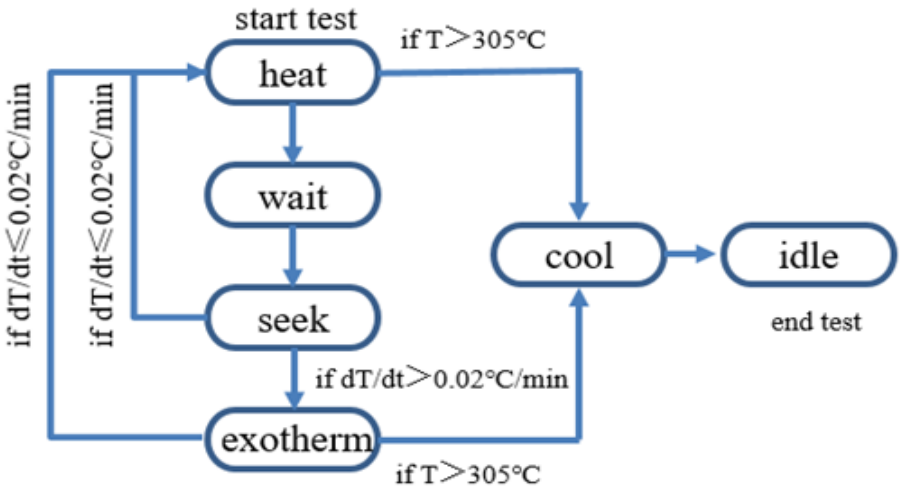
2.2a ARC test mechanism

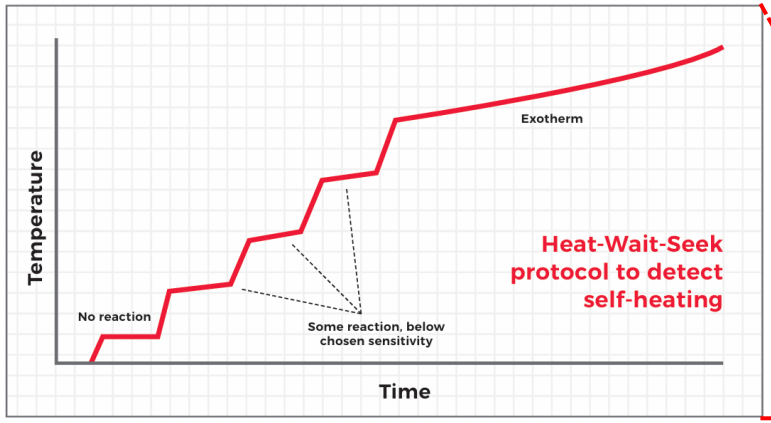
ARC is applied to study the intrinsic/inherent hazard of lithium ion cell or battery quantitatively by professionally researchers usually.

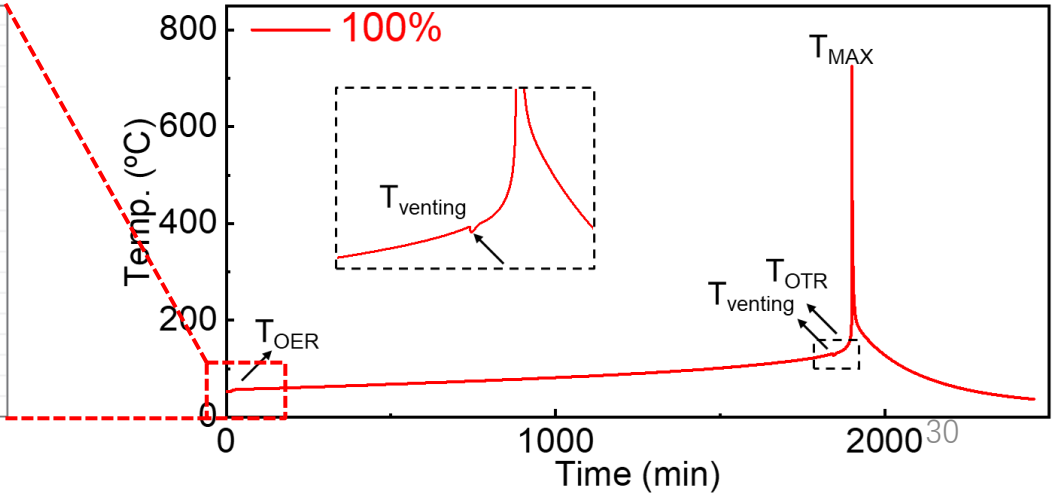
The device will slowly heat the cell/battery until it begins to generate heat itself, then ARC will stop heating, but cell/battery heats itself to thermal runaway or not. The entire process takes place in **an adiabatic cavity**, ensuring that the heat released by the cell does not dissipate into the surrounding atmosphere, but used to heat itself.



Accelerating Rate Calorimeter (ARC) from THT (UK)

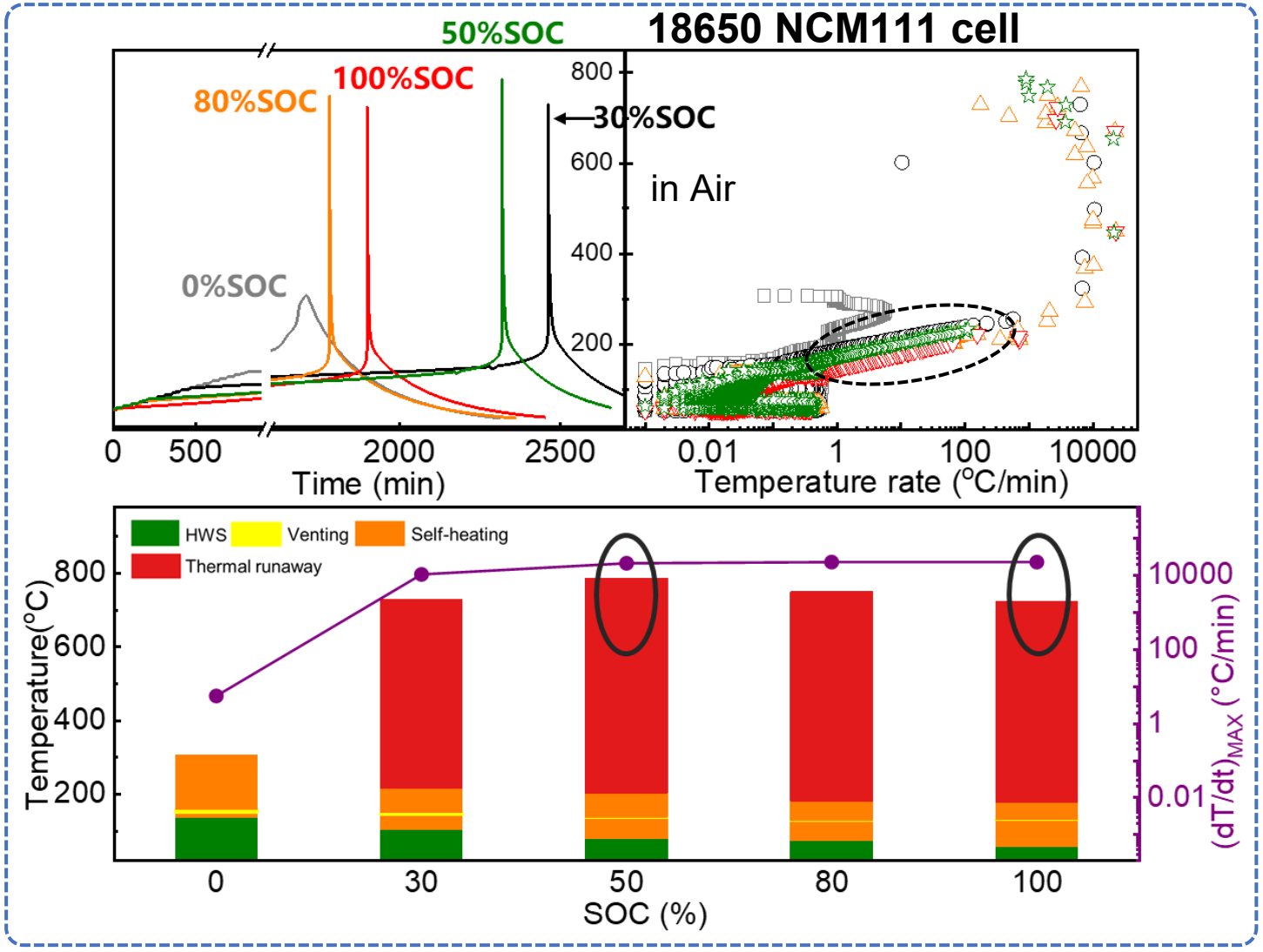






2.2b NCM TR with SOCs

SOC from 30%~50% is appropriate for safety testing.



- Using T_{MAX}, $(dT/dt)_{MAX}$ to evaluate the intensity of the thermal runaway reaction;
- Using E_a to evaluate the difficulty of the occurrence of thermal runaway reaction.

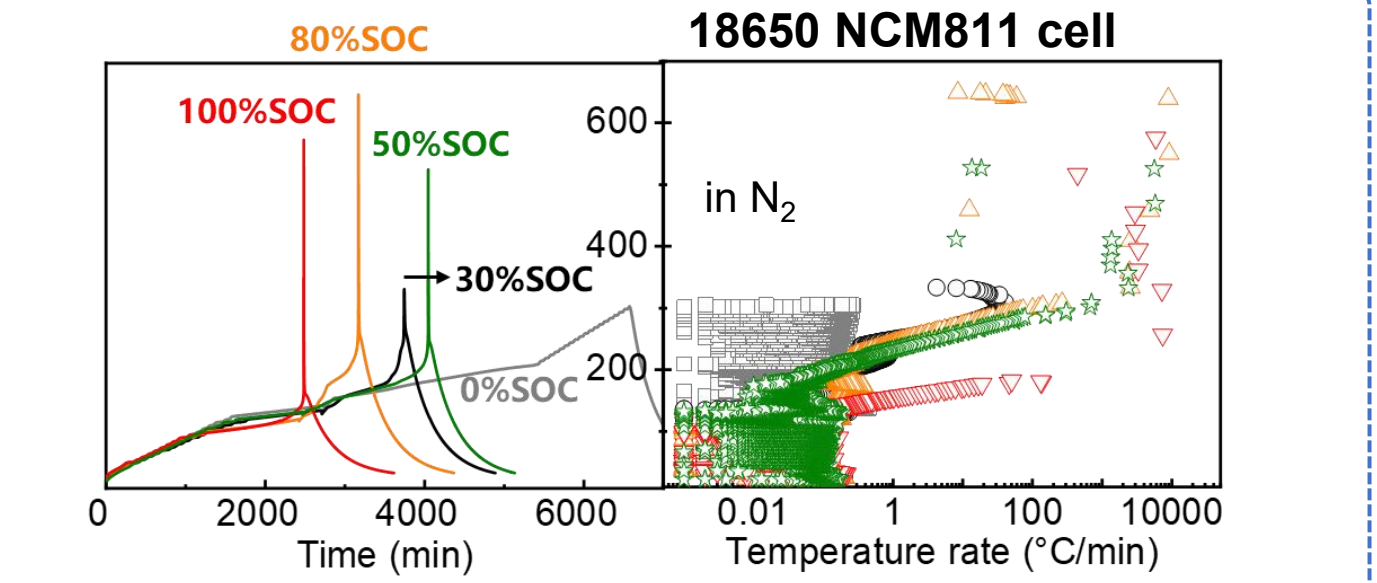
- T_{MAX}, $(dT/dt)_{MAX}$ of 50%SOC ≈ 100%SOC
- E_a 30%SOC > 50%SOC > 100%SOC

Shipping Testing

I	30%	50%	100%
The maximum temperature (T_{MAX})	729.8	786.4	724.5
Temperature rising rate $(dT/dt)_{MAX}$	10654.8	21305.1	22758.7
Apparent activation energy (E_a)	186.11	156.50	126.45

Sun Jiandan, **Wang Honghui**, Chu Deren, **Xu Ting**, Shang Zhaocong. Kinetic study of thermal runaway behaviors of lithium-ion batteries with different SOCs[J]. *Chinese Journal of Power Sources*, 2023, 47 (8): 1040-1045.

2.2b NCM TR with SOCs



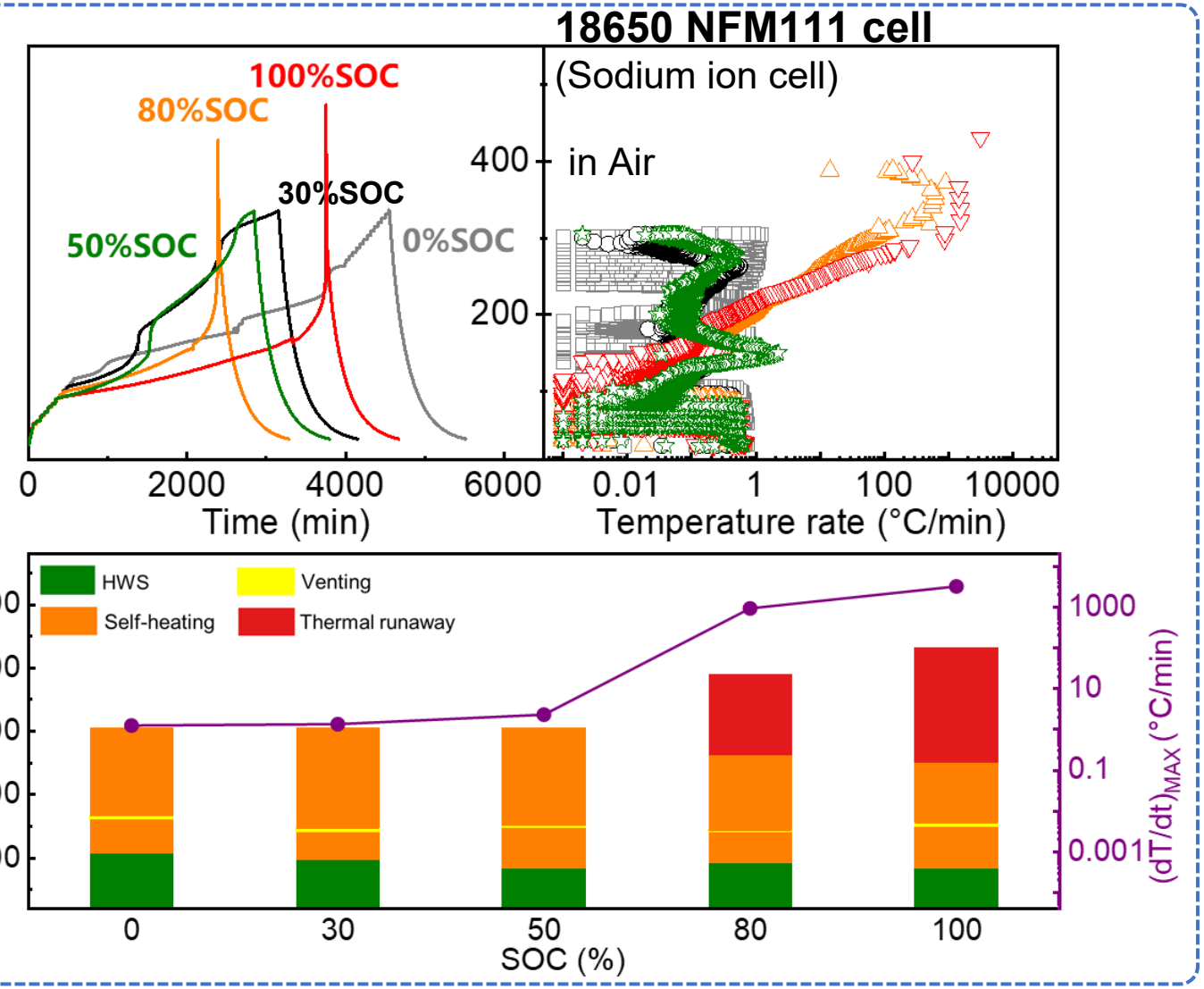
- T_{MAX}, $(dT/dt)_{MAX}$ of 50%SOC are a little bit less than 100%SOC; but more than those of 30%SOC;
- 30%SOC > 50%SOC > 100%SOC

  Shipping Testing

/	30%	50%	100%
The maximum temperature (T_{MAX})	333.5	527.7	575.6
Temperature rising rate $(dT/dt)_{MAX}$	40.6	5790.8	7401.9
Apparent activation energy (E_a)	/	/	/

Li Jiaxin, **Xu Ting**, Xiao Qiuping. Research on Thermal Runaway and Gas Generation Characteristics of High-Nickel Ternary Lithium-ion Cells[J]. *Energy Storage Science and Technology*, 2025, under review

2.2c MFM TR with SOCs



- NFM111 with SOC≤50% won't be triggered to be thermal runaway;
- 30%≤SOC≤50% is an appropriate and safety SOC for transportation and testing of this model sodium ion cells.

/	30%	50%	100%
The maximum temperature (T_{MAX})	305.0	305.0	431.3
Temperature rising rate $(dT/dt)_{MAX}$	1.3	2.3	3152.4
Apparent activation energy (E_a)	/	/	/

Note: 305℃ is a stop condition if no TR.

Under research.

2.2d Brief summary

Fully charged batteries (100% SOC) are of high-risk and fail to pass safety tests (TP) easily. So, the requirements or test conditions are too rigorous. On the other hand, shipping lithium ion cells/batteries with only 30% SOC leaves too little safety margin for testing and classification. A balanced solution to choose **30~50%SOC** for testing to evaluate the TP hazard to match the packing instruction for safety transportation may be feasible.

Witness Better Life
SICIT

Thanks for your listening!

Ting Xu xt@ghs.cn
+86 158-0061-6132
Hong-Hui Wang whh@ghs.cn
+86 130-7213-9895