Initiation Methods for Thermal Propagation and Proposal on Test Procedure

21st EVS-GTR IWG

April 2021

Japan Automobile Standards Internationalization Center

1. Initiation Methods for Thermal Propagation (Test Results)

2. Proposal on Test Procedure

Key message

- **It has been found that each method has advantages and disadvantages depending on the type of battery.**
- **We are researching both nail penetration and heating as initiation methods; we introduce some test data.**

Advantages and disadvantages

Pro.: Fast heater

- Locality (for pouch cell)
- Vehicle test possible

Pro.: Nail penetration

- Locality (all types of cells)
- Less additional energy input
- Minimum modification

Con.: Fast heater

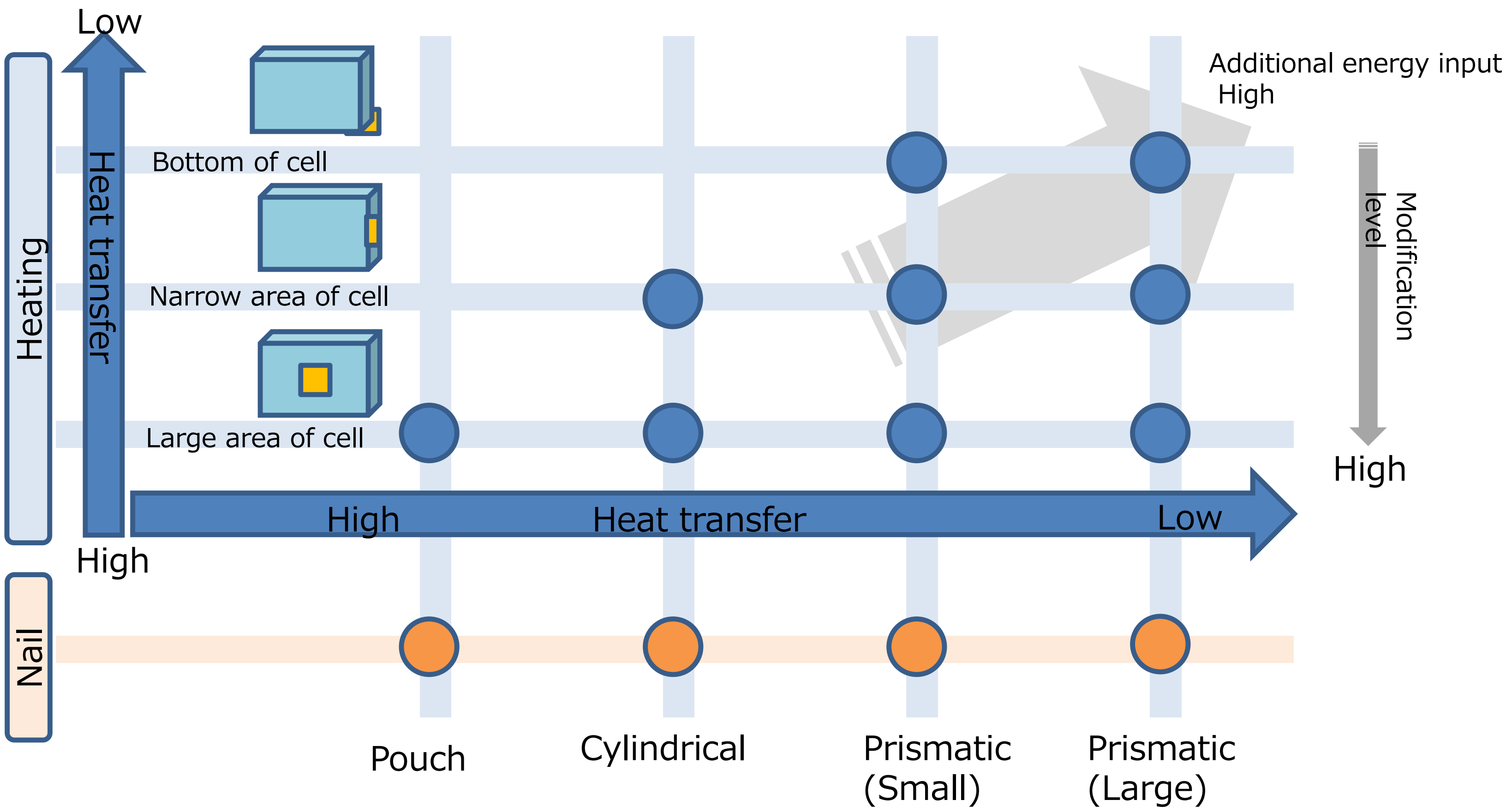
- Less controllability, no locality (for prismatic cell)
- Much additional energy input
- Significant modification required
- Difficult to optimize heating condition

Con.: Nail penetration

- Cannot cause thermal runaway (LTO etc.)
- Vehicle test not possible

Comparison of initiation methods

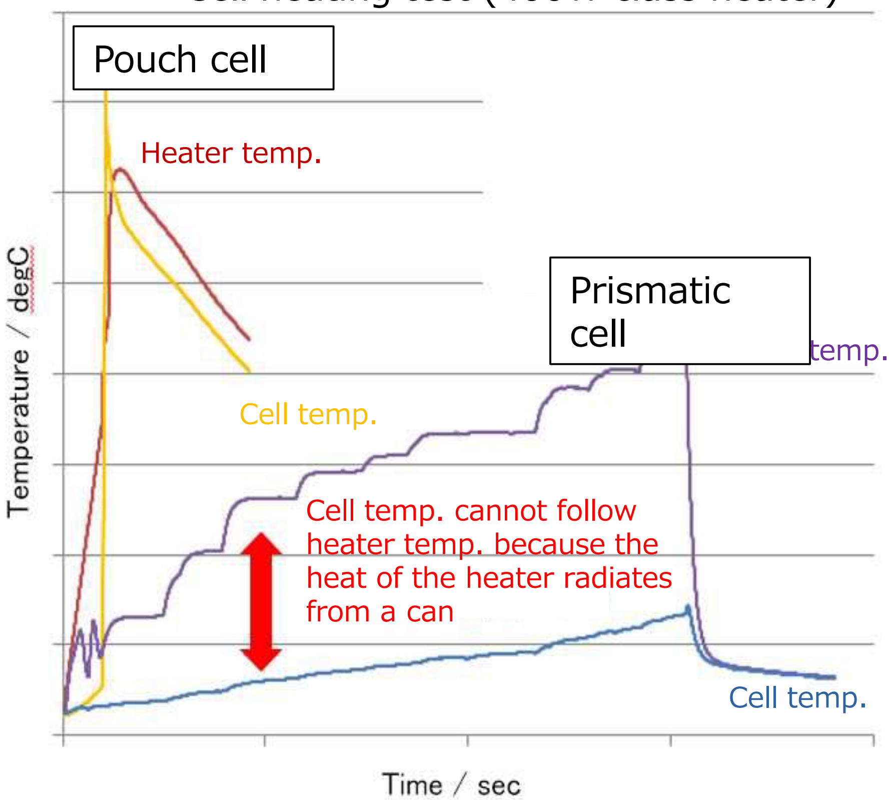
- Too severe conditions might be caused by mismatching combinations of cell type and initiation method.



Trend of heat transfer by cell type

- Additional energy input depends on cell type

Cell heating test (400W class heater)



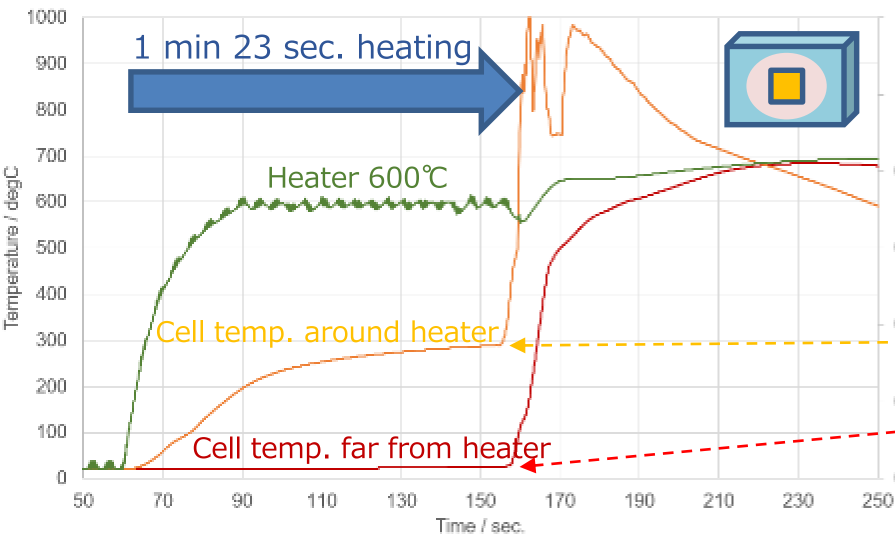
Trend of heat transfer by heater location

- Additional energy input depends on heater location

Large area of cell

- High heat transfer to electrodes because heating is efficient
- Short heating time to thermal runaway because of low thermal radiation and low thermal resistance

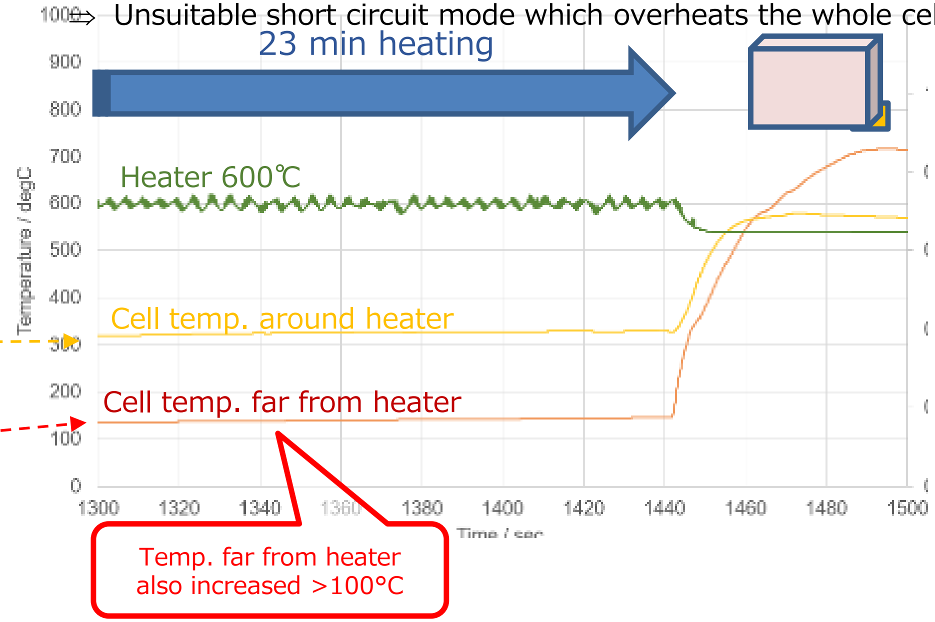
⇒ Ideal local short circuit mode not to overheat the whole cell



Bottom of cell

- Low heat transfer to electrodes because heating is not efficient
- Long heating time to thermal runaway because of high thermal radiation and high thermal resistance

⇒ Unsuitable short circuit mode which overheats the whole cell



【Test result】 High-power heater

- In some heating tests, the heaters lost control and were not able to heat due to external short circuit of the heaters.

1) The electrical insulating layer of the heater was inferior
2) The heat transfer paste used for the test also had electrical conductivity
3) The external case of the prismatic cell was made of aluminum
4) The heater insulation was broken by melting aluminum from the external case by 600°C heating

When heaters are used out of specification there are additional barriers to solve.

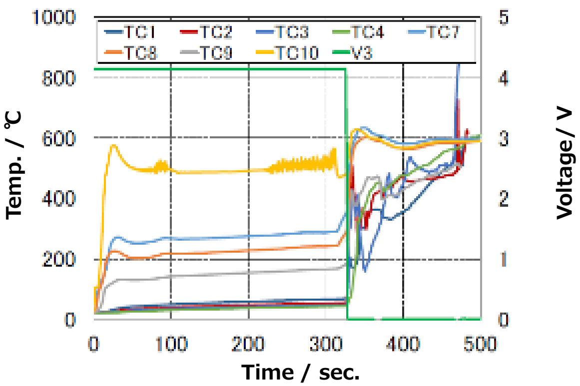
These phenomena might occur often with prolonged heating of a prismatic cell because of high heat resistance.

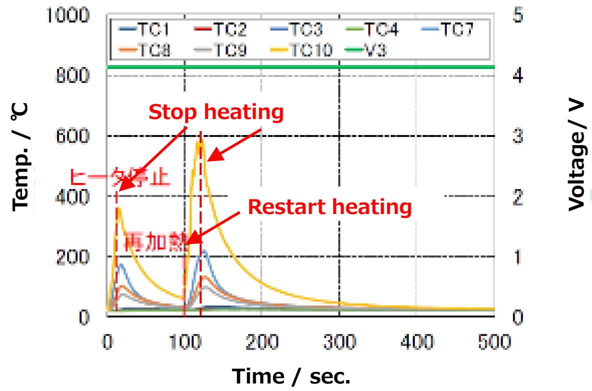
Sample	#	Target temp.	Result	
Battery A	Test 1	600°C	Thermal runaway occurred	
	Test 2*	600°C	Heater: loss of control	No smoke, venting
	Test 3*	600°C	Stop the test after heating for 2 hours	No smoke, venting
Battery B (LTO)	Test 1	600°C	Heater: loss of control	No smoke, venting
	Test 2*	600°C	Heater: loss of control	No smoke, venting
	Test 3*	800°C	Heater: loss of control	No smoke, venting

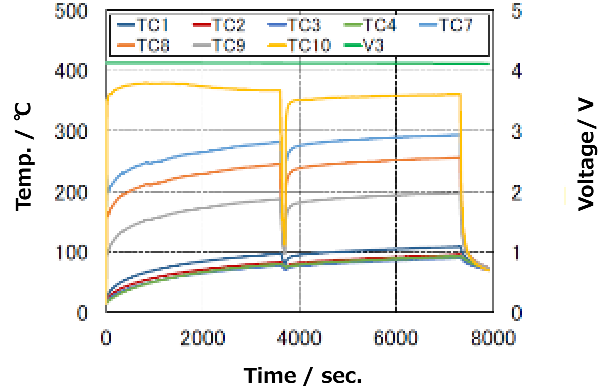
*One layer of ceramic paper was inserted between the heater and the target cell to prevent an external short circuit. This caused insufficient heat transfer to the cell.

Rapid heating is a methodology requiring the PROPER selection of heater for the application. Heater supplier for these large prismatic cell tests suggested another heater should be used since it would not be able to maintain the design conditions of the methodology.

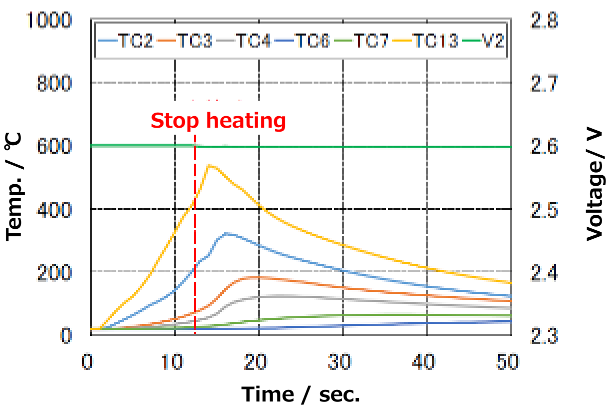
【Test result】 High-power heater - Battery A

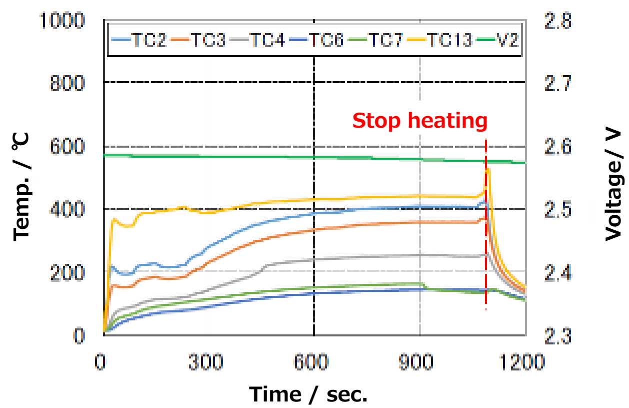


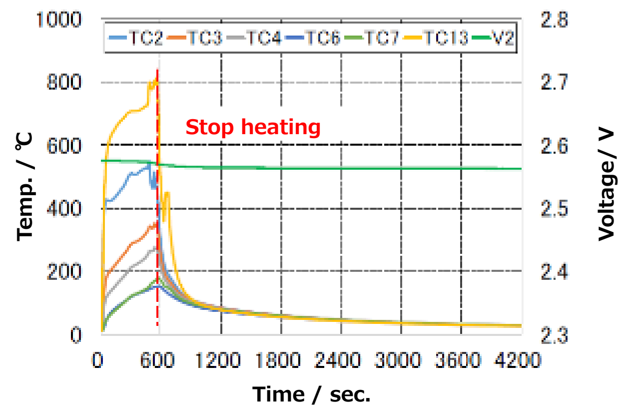


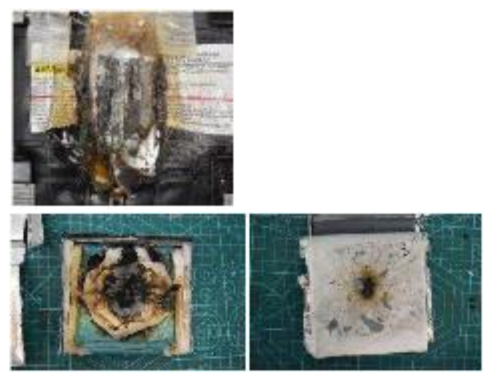


【Test result】 High-power heater - Battery B



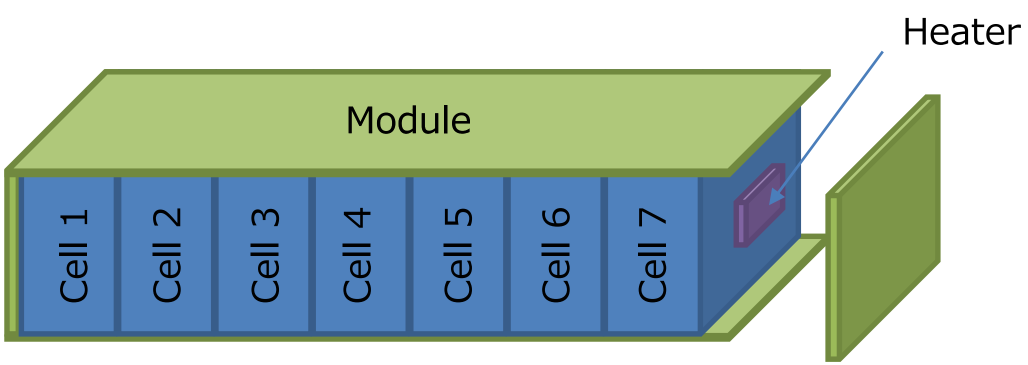






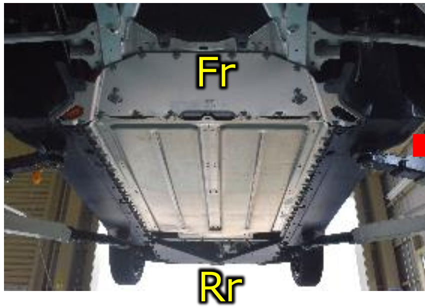
Battery modification

- Some batteries need significant modification for appropriate heater setting.
- These are difficult to make compliant with transport regulations.

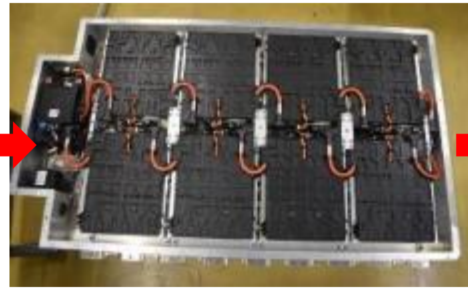


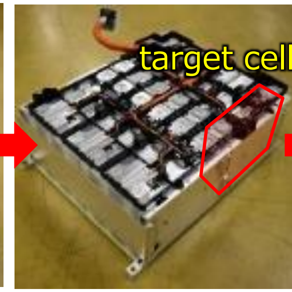
Example: Setting a heater by disassembling a module

Experimental setup in pack level testing

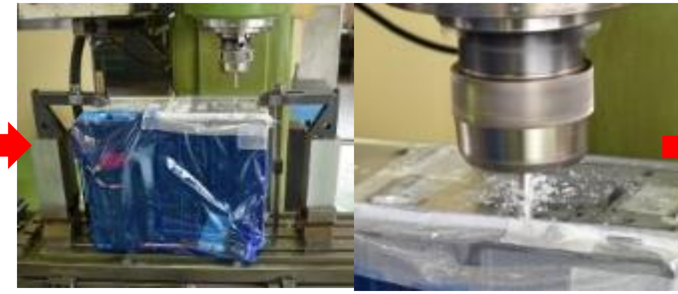


Remove the battery pack





Select the target module and cell



✓Discharge the module to less than 30% SOC
✓Cut the aluminum frame (about 13 mm thick) with a milling machine

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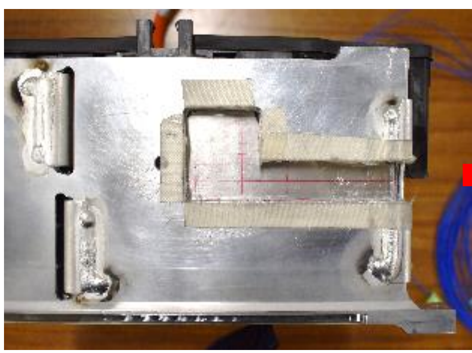
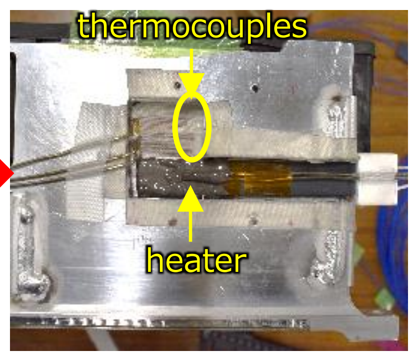
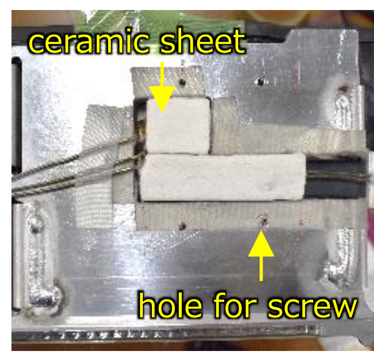


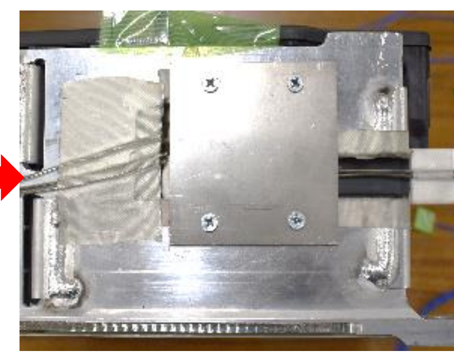
Remove a part of the frame



Attach a heater with thermal paste

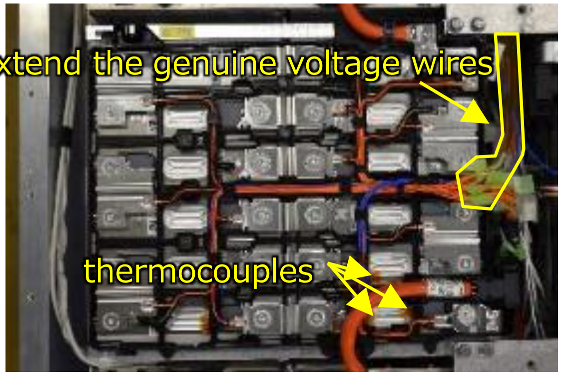


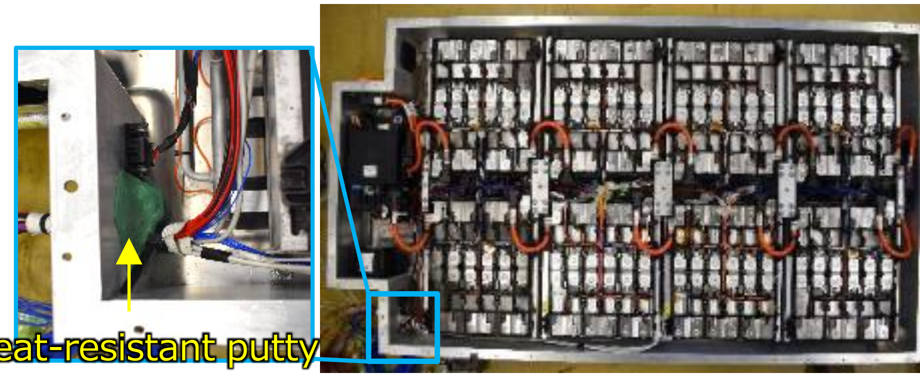
Place blocks of ceramic sheet (the sheet is slightly higher than the aluminum frame)



Attach a metal plate with screws

Experimental setup in pack level testing

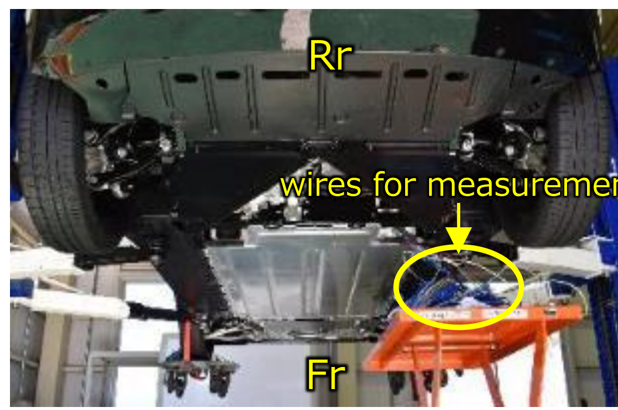




✓Attach thermocouples and wires for voltage measurement
✓Charge the module to 100% SOC

✓Make a hole to pass wires through for measurement
✓Fill the hole with heat-resistant putty

Attach the upper case

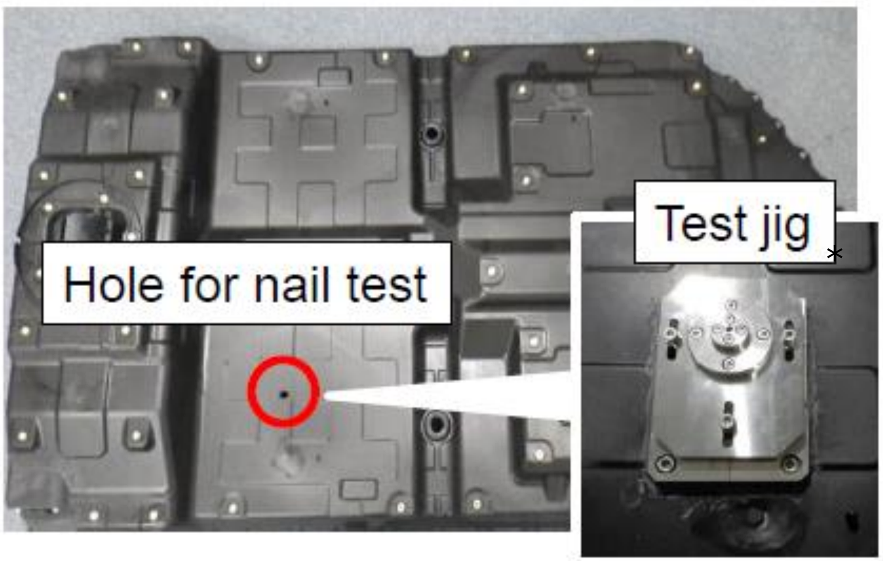


Assemble the battery pack carefully

Pro.: Nail penetration

Battery modification

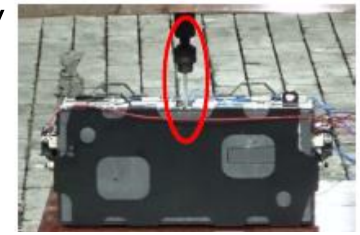
- Some batteries would need less modification for the nail test.

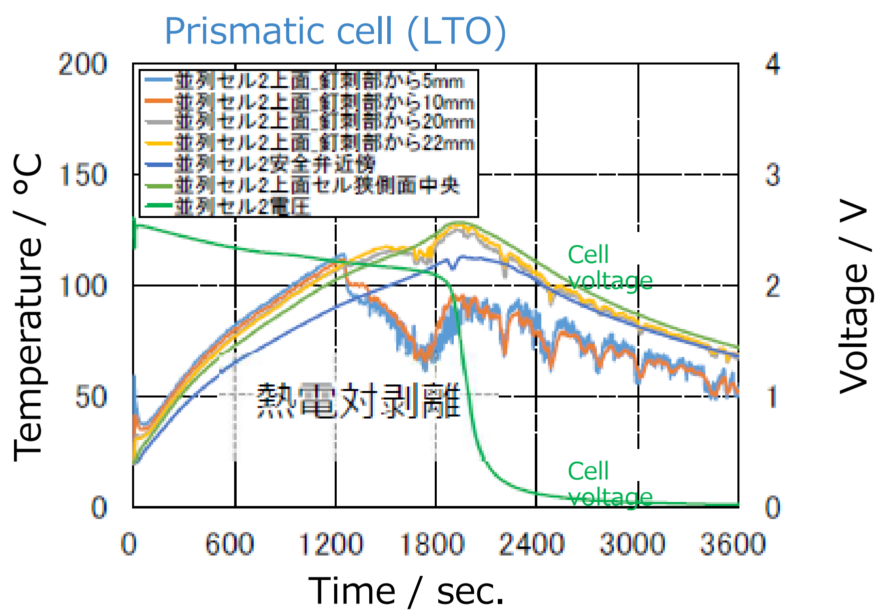


*To prevent gas emission from nail hole

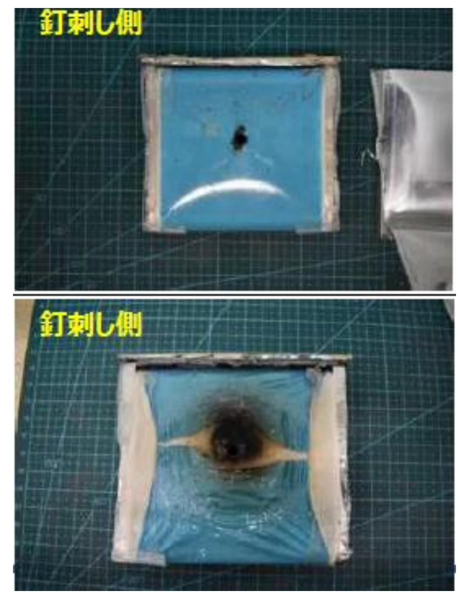
No thermal runaway

- Some batteries would not reach enough thermal runaway
  (Definition of thermal runaway is under discussion.)





Internal cell structure after nail penetration

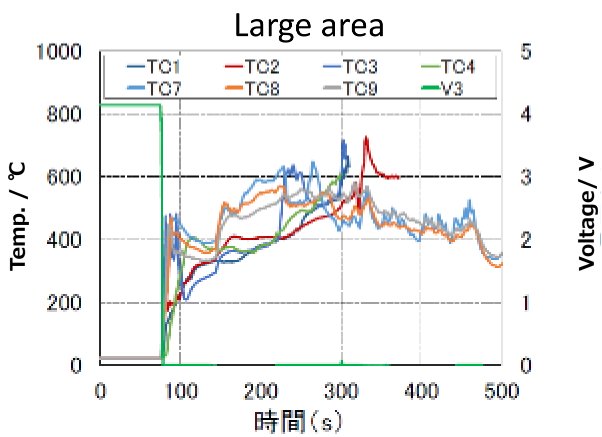


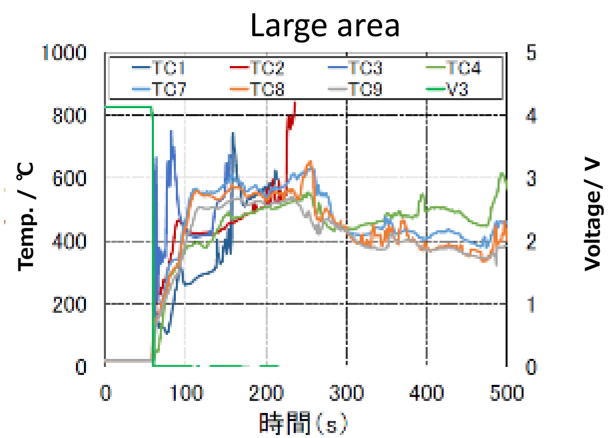
【Test result】 Nail penetration

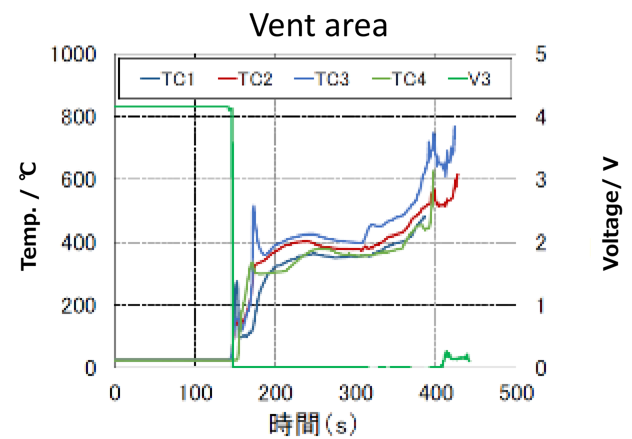
- With Battery A, thermal runaway occurred in each test.
- With Battery B, the results did not reach enough thermal runaway; most of the events were only a small amount of smoke.

Sample	#	Condition	Result
Battery A	Test 1	Φ3, 0.1 mm/s, penetrating 1 cell, large area	Fire
	Test 2	Φ3, 0.1 mm/s, penetrating 1 cell, large area	Fire
	Test 3	Φ3, 0.1 mm/s, penetrating 1 cell, vent area	Fire
Battery B (LTO)	Test 1	Φ3, 0.1 mm/s, penetrating 1 cell, large area	(only voltage drop), the nail broke
	Test 2	Φ5, 0.1 mm/s, penetrating 1 cell, large area	Smoking
	Test 3	Φ5, 0.1 mm/s, penetrating 1 cell, large area	Smoking
	Test 4	Φ5, 0.1 mm/s, penetrating 1 cell, large area	Smoking
	Test 5	Φ5, 10 mm/s, penetrating to the next cell, large area	Smoking

【Test result】 Nail penetration - Battery A








約81秒後

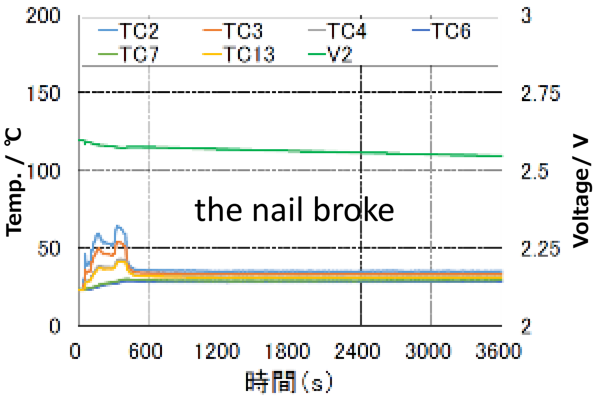

約223秒後


約328秒後

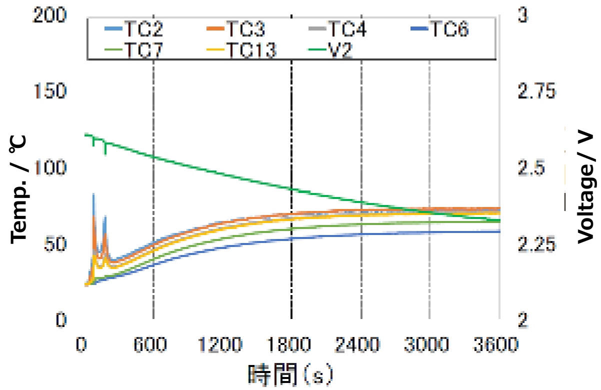

約375秒後

【Test result】 Nail penetration - Battery B

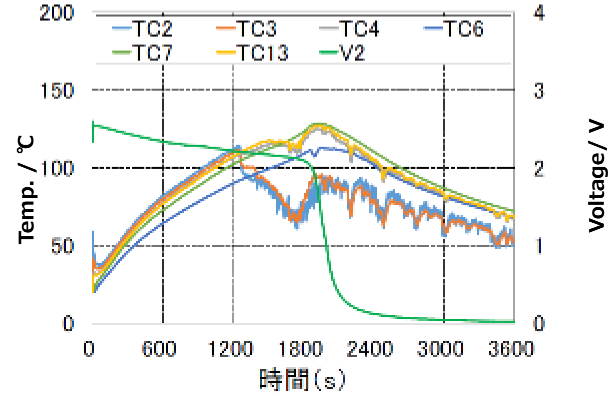
#1: Φ3, 0.1 mm/s, penetrating 1 cell large area

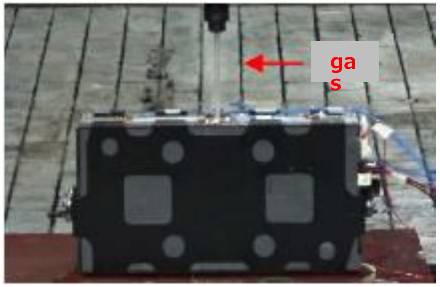


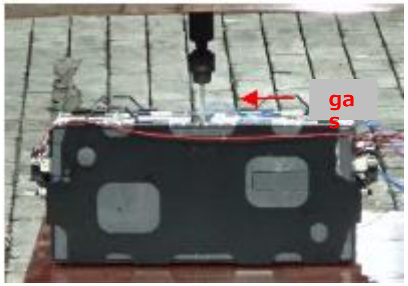
#2: Φ5, 0.1 mm/s, penetrating 1 cell large area



#5: Φ5, 10 mm/s, penetrating to the next cell, large area







Heater specifications

Type	Dimensions	Heat flux	Rated capacity	Tested battery
High-power heater	W × L = 5.6 cm^2, t = 1.2 mm	>1×10^6 (W/cm^2)	-	See p.7-9
Silicone nitride heater	W 17 × L 118 × t 4 mm (heating part: L 50 mm)	-	400 W (47 W/cm^2)	See p.6, 11-12

Silicone nitride heater

1. Initiation Methods for Thermal Propagation (Test Results)

2. Proposal on Test Procedure

- Japan understands that Fig. 1 is a simplified and schematized test procedure on thermal propagation, based on Article 5.4.12. on EVS-GTR-Phase 1.

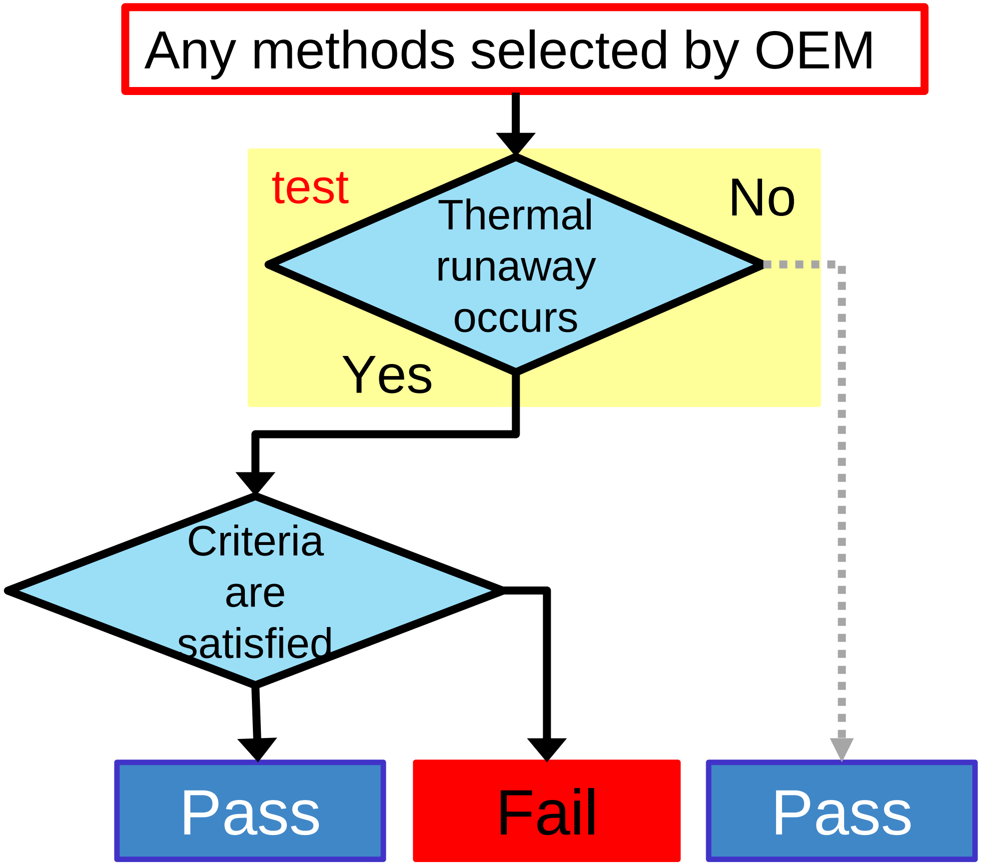
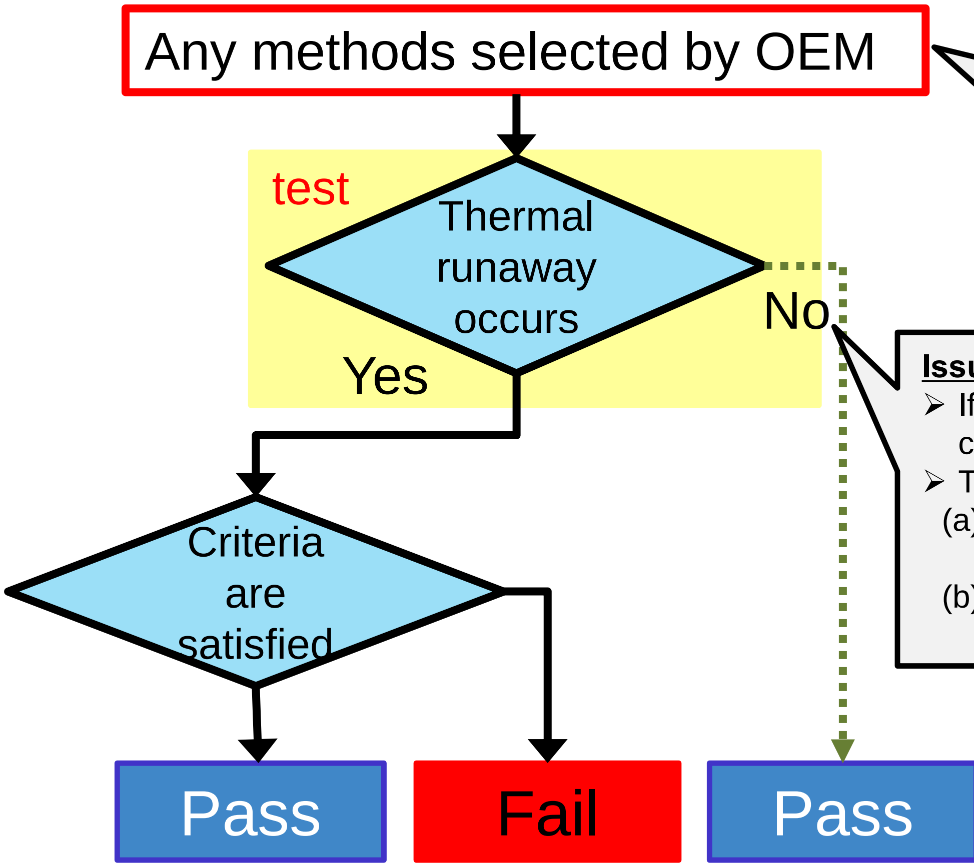


Fig. 1 Visualized Test Flow on Thermal Propagation based on EVS-GTR-Phase 1

Current Test Procedure and Challenging Issues under GTR-Phase1

- IWG has mainly focused on discussions to identify and develop (one or a few) optimum test method(s) for various types batteries/vehicles.
- Challenging issues associated to the discussion should be taken care of:



Issue 2: Technology(Method) neutrality:

- ➢ We need to eliminate methods that have enough potential to initiate adequate thermal runaway in a particular battery, if we narrow down to only one (or a few) methods.

Issue 1: Possible risks on "false judgement" on TR:

- ➢ If thermal runaway does not occur then "Pass", how can we mitigate possible risks on false judgement?
- ➢ Two main estimated reasons for no thermal runaway;
  - (a) The safety of the battery system might be sufficiently ensured.
  - (b) The combination of the battery and the test method might be inappropriate.

Fig. 1 Visualized Test Flow on Thermal Propagation based on EVS-GTR-Phase 1

- One possible testing procedure is to apply initiation test successively until thermal runaway occurs, if trying to mitigate the risks associated to Issue 1.
- However, further issues arise:
  - If there is a battery system which would be sufficiently safe and does not to cause thermal runaway with any test methods, it needs to take many tests.
  - It would then be necessary to run the tests with multiple methods until a method causes thermal runaway, raising a cost-benefit problem.

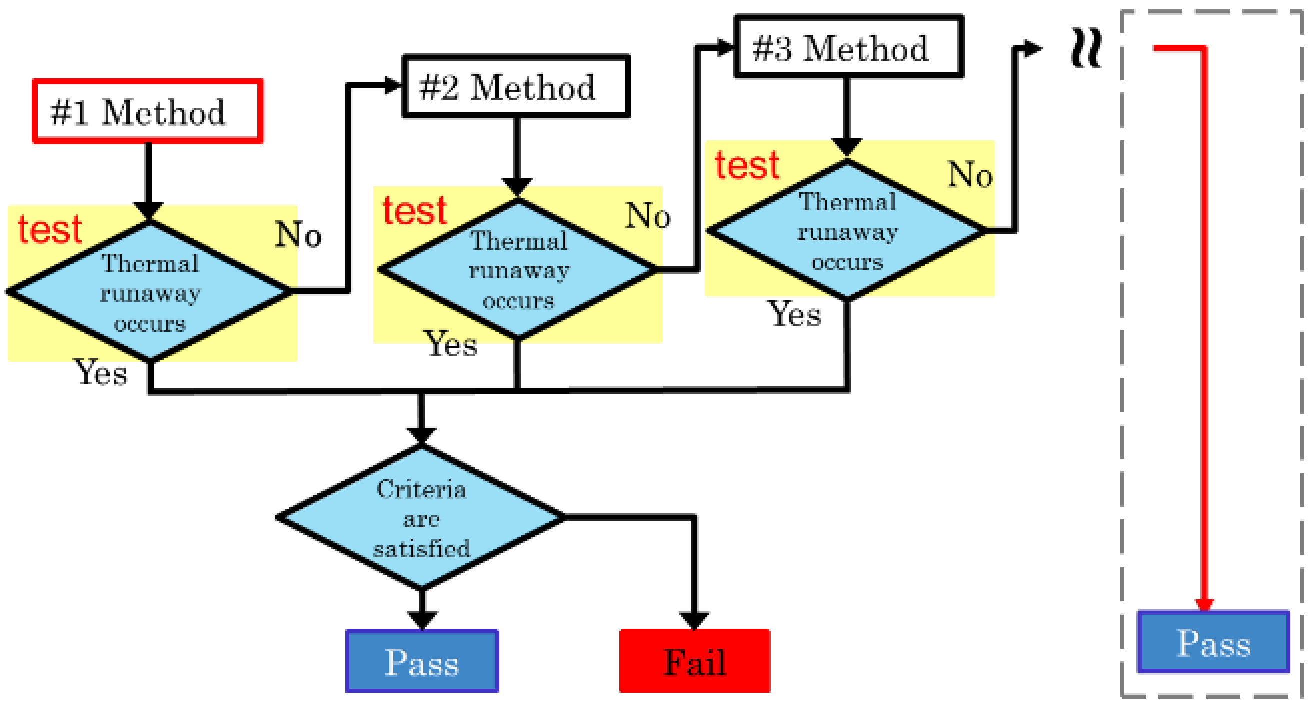


Fig. 2 Test Procedure with multiple methods

- To solve these issues, Japan proposes the modified test procedure (see Fig. 3), dividing the methods agreed upon by the IWG members into two categories (Main/Optional) and changing the test flow accordingly.
- The proposed test procedure would be expected to give answers to the raised challenges:
  - Mitigating the possible risks on false judgement on thermal runaway
  - Maintaining technical(method) neutrality by offering “Optional methods”

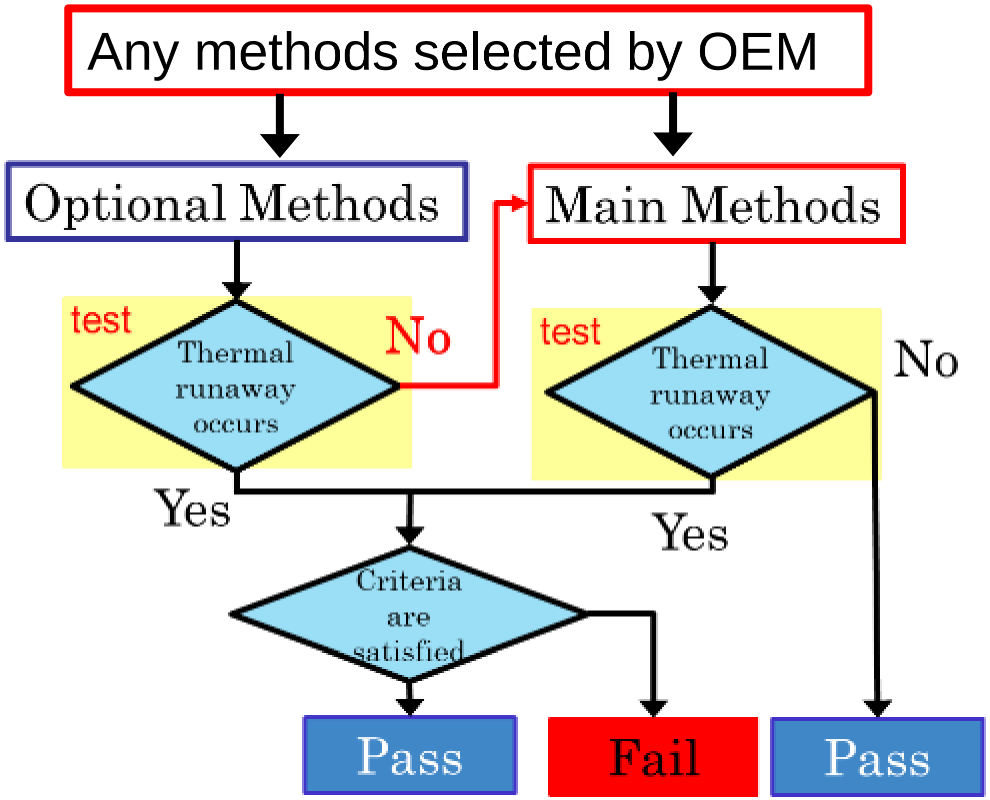


Fig. 3 Proposed Test Procedure

Thank you for your kind attention!