CELL TEST REPORT
UL 9540A
Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems (AACD)

Project Number.....:	**4789764706**
Date of issue.....:	**2021.06.11**
Total number of pages.....:	**36**
UL Report Office .....:	**UL-CCIC Company Limited Guangzhou Branch**
Applicant's name.....:	**Contemporary Amperex Technology Co., Limited**
Address .....:	No.2 Xiangang Road, Zhangwan Town, Jiaocheng Distict Nindde, Fujian, 352100 CN
Test specification:	4th Edition, Section 7, November 12, 2019
Standard.....:	UL 9540A, Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems
Test procedure .....:	7.1 – 7.8
Non-standard test method .....:	N/A

General disclaimer:

The test results presented in this report relate only to the sample tested in the test configuration noted on the list of the attachments.

UL LLC did not select the sample(s), determine whether the sample(s) was representative of production samples, witness the production of the test sample(s), nor were we provided with information relative to the formulation or identification of component materials used in the test sample(s).

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Cell level information	
Model No .....:	001CB0Y0
Ratings (Vdc, Ah) .....:	3.2V, 100Ah
Chemistry of test item……:	Lithium iron phosphate
Original Equipment Manufacturer (OEM):	Contemporary Amperex Technology Co., Limited
Branding Manufacturer (if not OEM):	N/A
Was the cell certified? ……:	yes
Standard test item certified to ……..:	UL 1973
Organization that certified test item …….:	UL (MH62898)
Average cell surface temperature at gas venting, °C:	**153**
Average surface temperature at thermal runaway, °C:	**193**
Gas Volume:	**73.6 L**
Lower flammability limit (LFL), % volume in air at the ambient temperature	**7.05**
Lower flammability limit (LFL), % volume in air at the venting temperature	**6.35**
Burning velocity (S_u) cm/s:	**106.7**
Maximum pressure (P_{max}) psig:	**96.19**

Cell Gas composition

Gas		Measured %
Carbon Monoxide	**CO**	**7.475**
Carbon Dioxide	**CO_2**	**28.598**
Hydrogen	**H_2**	**49.513**
Methane	**CH_4**	**6.654**
Acetylene	**C_2H_2**	**0.156**
Ethylene	**C_2H_4**	**3.685**
Ethane	**C_2H_6**	**1.111**
Propadiene (Allene)	**C_3H_4**	**0.000**
Propyne	**C_3H_4**	**0.000**
Propene	**C_3H_6**	**0.581**
Propane	**C_3H_8**	**0.179**
-	**C4 (Total)**	**0.363**
-	**C5 (Total)**	**0.071**
-	**C6 (Total)**	**0.038**
-	**C7 (Total)**	**0.003**
-	**C8 (Total)**	**0.000**
Benzene	**C_6H_6**	**0.017**
Toluene	**C_7H_8**	**0.000**
Dimethyl Carbonate	**$C_3H_6O_3$**	**1.152**
Ethyl Methyl Carbonate	**$C_4H_8O_3$**	**0.406**
Diethyl Carbonate	**$C_5H_{10}O_3$**	**0.000**
Total	**-**	**100**

Cell failure test method performed (summary of method and test clause):

☒ External heating using thin film with 4°C to 7°C thermal ramp.

☐ Nail Penetration

☐ Overcharge

☐ External short circuit (***X*** Ω *external resistance*)

☐ Flow Battery with 2 active electrolyte methods

☐ Flow Battery with 1 active electrolyte methods

☐ Others

Description of method used to fail cells if other than external thin film heater with thermal ramp, : N/A

Summary of testing:

Performance Criteria in accordance with Clause 7.7 and Figure 1.1:

[ ] Thermal runaway was not induced in the cell; and

[ ] The cell vent gas did not present a flammability hazard when mixed with any volume of air, as determined in accordance with ASTM E918 at both ambient and vent temperatures.

Necessity for a module level test

[X] The performance criteria of the cell level test as indicated in 7.7 of UL 9540A 4th edition has not been met, therefore a module level testing in accordance with UL 9540A will need to be conducted on a complete module employing this cell.

[ ] The performance criteria of the module level tests as indicated in 7.7 of UL 9540A 4th edition has been met, therefore a module level testing in accordance with UL 9540A need not be conducted.

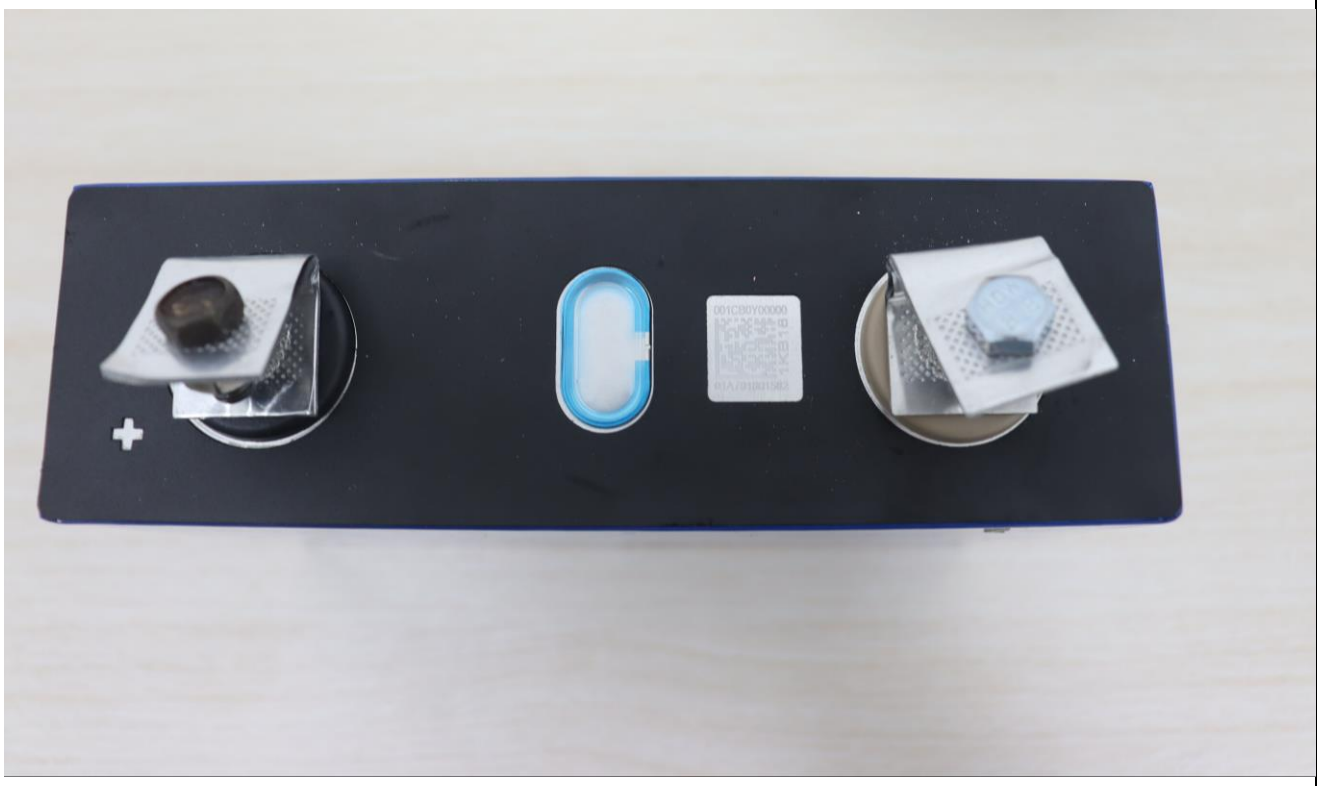
Testing Laboratory information

Testing Laboratory and testing location(s):

Testing Laboratory:	UL(Changzhou) Quality Technical Service Co,. LTD	
Testing location/ address ..... :	21 Longmen Rd, National High-Tech Industrial Development District, Wujin, Changzhou, Jiangsu, China	
Tested by (name, signature)..... :	Jax Gao	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) ..... :	N/A	N/A
Project Handler (name, signature)..... :	Benjamin Liu	
Reviewer (name, signature) ……:	Rebecca Le	
Gas Analysis Testing Laboratory:	DEKRA North America, Inc.	
Testing location/ address ..... :	113 Campus Dr, Princeton, NJ 08540	
Project Handler (name, signature)..... :	Michael F. Carolan	
Reviewer (name, signature) ……:	Jena Dorrin	

List of Attachments (including a total number of pages in each attachment):

Photo of cell/Stack:



Test Item Charge/Discharge Specifications:	
• **Charge current, A:**	**50 A**
• **Standard full charge voltage, Vdc:**	**3.65 V**
• **Charge temperature range, °C:**	**0-60 ℃**
• **End of charge current, A:**	**N/A**
• **Discharge current, A:**	**50 A**
• **End of discharge voltage, Vdc:**	**2.5 V**
• **Discharge temperature range, °C:**	**-20-60 ℃**

Test item particulars .....:	See below for details
Possible test case verdicts:	
- test case does not apply to the test object.....:	N/A
- test object does meet the requirement .....:	P (Pass)
- test object does not meet the requirement.....:	F (Fail)
- test object was completed per the requirement...:	C(Complete)
- test object was completed with modification……:	M(Modification)
Testing.....:	Cell Model 001CB0Y0
Date of receipt of test item .....:	2020.12.20
Date (s) of performance of tests.....:	2020.12.23 to 2021.01.30

General remarks:

"(See Enclosure #)" refers to additional information appended to the report.
"(See appended table)" refers to a table appended to the report.

Throughout this report a point is used as the decimal separator.

Manufacturer's Declaration of samples submitted for test:

The applicant for this report includes samples from more than one factory location and a declaration from the Manufacturer stating that the sample(s) submitted for evaluation is (are) representative of the products from each factory has been provided.....:	☐ **Yes** ☒ **Not applicable**
Name and address of factory (ies) ..... :	Contemporary Amperex Technology Co., Limited No.2 Xiangang Road, Zhangwan Town, Jiaocheng Distict Nindde, Fujian, 352100 CN

General product information and other remarks:

The tested cell is a Lithium-ion battery cell, Model 001CB0Y0. The cell has a capacity of 100 Ah and nominal voltage 3.2 Vdc.

The overall dimensions of the cell are 119 mm (Height) by 160 mm (Width) by 49.91 mm (Depth). The height of the cell includes the terminals.

The weight of this cell is 1950±150 g.

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

5.0	**CONSTRUCTION**		**Verdict**
5.1. 5.4	**Cell/Stack Construction**		—
5.1.1, 5.4.1	Generic Chemistry:	Lithium iron phosphate / C	—
	Electrolyte Chemistry:	LiPF6 with additives	—
	Flow Battery Electrolyte No. 1 Chemistry:	Not flow battery	—
	Max volume of system electrolyte No. 1, L:	Not flow battery	—
	Flow Battery Electrolyte No. 2 Chemistry:	Not flow battery	—
	Max volume of system electrolyte No. 2, L:	Not flow battery	—
	Separator Melt Temperature, °C:	Not used during test	—
	Format: Cylindrical /Prismatic /Pouch Flow Battery Stack	Prismatic	—
	Overall Dimensions, mm	119 x 160 x 49.91 mm	—
	Cell Weight, g	1950±150 g	—
5.1.2	Cell Certification:	See below for details	—
	Standard Used for Cell Certification:	UL1973	—
	Organization that Certified Cell:	UL	—
5.1.1, 5.4.1	Cell/Stack Ratings: • Nominal Voltage, Vdc •Nominal Capacity, Ah	3.2 Vdc 100 Ah	— —
5.4.1	Flow Battery: No. of Cells per Stack:	Not flow battery	—
	Flow battery system manufacturer:	Not flow battery	—
	Flow battery system model:	Not flow battery	—
	Flow battery system ratings, Vdc, Ah:	Not flow battery	—
5.4.2	Flow battery system certified to UL 1973:	Not flow battery	—
	Organization that certified flow battery system:	Not flow battery	—
7.0	**PERFORMANCE**		**Verdict**
7.1	**General**		C
7.2	**Samples**		C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications See also Table 2	C
7.2.2	100% SOC and stabilize from 1h to 8 h before testing		
7.2.3	Pouch Cells constrained per end use during testing.		N/A
7.3	**Determination of thermal runaway methodology**		
7.3.1	**General**		
7.3.1.1	Ambient indoor laboratory conditions: 25 ±5°C (77 ±9°F) ≤50 ±25% RH at the initiation of the test.	See Attachment C See Table 3	C
7.3.1.2	Heat the cell to thermal runaway by externally applied flexible film heaters	See Attachment B	C
	Heater Dimension	two pieces of 152.4 by 101.6 mm for each sample	
	A surface heating rate of 4° C (7.2° F) to 7° C (12.6° F) per minute was applied to the cell.	See Attachment C and D See Table 4.	C
	Maximum surface end point temperature, °C	Not used, the cells are heated until the thermal runaway achieved	
	The following method(s) was employed to cause thermal runaway: ☐ Mechanical (e.g. nail penetration); ☐ Electrical stress in the form of overcharging, ☐ Electrical stress in the form of over discharging ☐ Electrical stress in the form of external short-circuiting ☐ Use of alternate heating sources (e.g. oven). ☐ Other (explain)	Only external heating in the form of using flexible thin film type heaters to cause thermal runaway	N/A
7.3.1.3	Detail of test method when using another cell abuse method to initiate thermal runaway		N/A
7.3.1.4	Monobloc batteries such as a lead acid battery		N/A
7.3.1.5	Estimated surface temperature at which internal short circuiting within the cell will occur that could lead to a thermal runaway condition.	Not used, the cells are heated until the thermal runaway achieved	N/A
7.3.1.6	The cell was heated until thermal runaway has occurred.	Refer to Attachment C	C
	Another external heating method was used to cause cell thermal runaway		N/A
7.3.1.7	The cell's exterior surface temperature was measured	See Attachment B	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.1.8	The temperature at which the cell case vents due to internal pressure rise was documented.	See Table 3 and 4 See Attachment C and D	C
7.3.1.9	The temperature at the onset of thermal runaway was documented.	See Table 3 and 4 See Attachment C and D	C
	If cell venting occurs first, the cell was heated continuously until thermal runaway occurs.	See Attachment C	C
7.3.1.10	When using methods other than the heater method, the stresses were applied to the cell until thermal runaway occurs.		N/A
7.3.1.11	3 additional samples were tested using the same method and exhibited thermal runaway	See Table 3, 4 and 5 See Attachment C and D	C
7.3.2	**Flow battery thermal runaway determination tests**		
7.3.2.1	The test methods of 7.3.2.2 through 7.3.2.6 were used for the flow battery technology.		N/A
7.3.2.2	The flammability of the electrolytes was determined		N/A
	For liquids with anticipated higher flashpoints and viscosities at or below 9.5 × 10−6 m2/s (9.5 cSt) at 25°C (77°F): • ASTM D3828 or • ASTM D93 was used.		N/A
	The flash point temperature was recorded for each electrolyte tested.		N/A
7.3.2.3	For flow battery systems with two electrolytes, each electrolyte was subjected to the appropriate test method outlined in 7.3.2.2.		N/A
	The test of 7.3.2.4 was conducted if a flash point had been observed in 7.3.2.2		N/A
7.3.2.4	The energy reservoir in a test flow battery assembly was charged to 100% SOC, and then the two electrolyte materials were mixed in a closed container within approximately 1 min. The mixed solution temperature was measured during the test.		N/A
	A test battery representative of the flow battery system was subjected to an overcharge test and short circuit test in accordance with UL 1973, the temperature of the energy reservoirs during the testing were recorded.		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.3.2.5	For flow battery technologies with one active electrolyte containing solid metal particles, the appropriate test method of 7.3.2.2 was conducted to determine the flash point temperature		N/A
	If a flash point had been observed in 7.3.2.2, the propensity for thermal runaway was demonstrated by the test methods of 7.3.2.6		N/A
7.3.2.6	If a flash point had been observed, a test battery representative of the flow battery system was subjected to an overcharge test and short circuit test in accordance with UL 1973, and the maximum temperature of the energy reservoir during testing was recorded.		N/A
7.4	**Cell vent gas composition test**		
7.4.1	Cell vent gas was generated and captured by forcing a cell into thermal runaway with the methodology developed in 7.3, inside a pressure vessel	Size of pressure vessel used: 100 L Refer to Attachment E	C
	The test was initiated with an initial condition of atmospheric pressure and less than 1% oxygen by volume.	Refer to Attachment F Atmospheric pressure (psig): 0.138 Oxygen concentration measured (% volume): <0.1% Inert gas used: Nitrogen	C
7.4.2	Cell vent gas composition was determined using Gas Chromatography (GC)	Refer to Table 8 Refer to Attachment F	C
	Hydrogen gas was measured	Refer to Table 8	C
	The initial atmospheric conditions prior to testing were noted.	Refer to Table 3 and 8 Refer to attachment C and F	C
7.4.3	The lower flammability limit of the cell vent gas was determined on samples of the synthetically replicated gas mixture in accordance with ASTM E918, testing at both ambient and cell vent temperatures.	Refer to Table 8 and 10	C
7.4.4	The gas burning velocity of the synthetically replicated cell vent gas was determined in accordance with the Method of Test for Burning Velocity Measurement of Flammable Gases Annex in ISO 817.	Refer to Table 8 and 10	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
7.4.5	P_{max} of the synthetically replicated cell vent gas was determined in accordance with EN 15967.	Refer to Table 8 and 10	C
7.5	**Off gas composition for flow battery systems**		
7.5.1	The off gas composition from the flow battery testing of 7.3.2 was determined by conducting the test method of 7.3.2.2: • In a closed container and capturing the off gasses generated, and • By collecting the off gasses generated at vent openings and vent ducts during the overcharge and short circuit testing of 7.3.2.4 and 7.3.2.6.		N/A
	Gas composition and flammability limit were determined through the methods outlined in 7.4.2 and 7.4.3 at both ambient temperature and the maximum temperature measured.		N/A
7.5.2	The volume of flammable gases measured during the testing were scaled to the maximum energy reservoir for the intended flow battery system		N/A
7.6	**Cell Level Test Report Information**		
7.6.1	Minimum information provided in the report for items a) through m)		C
7.6.2	Minimum information of items a) through k) was provided in the report for flow battery		N/A
7.7	**Performance – cell level test**	The following criteria are used to determine when module level testing will be necessary	
7.7.1	a) Thermal runaway cannot be induced in the cell; and	The thermal runaway was initiated with external heater on the cells during the test	F
	b) The cell vent gas does not present a flammability hazard when mixed with any volume of air, at both ambient and vent temperatures.	As a result of gas analysis, the gas generated from the cell were identified flammable	F
7.8	**Performance – flow battery thermal runaway determination tests**		N/A
7.8.1	a) The electrolyte(s) subjected to the test method in accordance with 7.3.2.2 does not ignite; or		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	b) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature measured on the energy reservoir during the overcharge and short circuit tests of 7.3.2.4 or 7.3.2.6 by at least 5°C (9°F); and		N/A
	c) The flash point temperature(s) measured in the test of 7.3.2.2 exceed the maximum temperature of the mixed solution measured in accordance with 7.3.2.4 by at least 5°C (9°F) for systems with two active electrolytes.		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 1 – Specified conditioning parameters			
Charging:		**Discharging**	
Current (CC), A	50	**Current (CC), A**	50
Standard full charge voltage, Vdc	3.65	**Voltage at start of discharge, Vdc**	3.65
End of charge current, A	2.5	**End of discharge voltage, Vdc**	2.5
Charging Test Ambient, °C	25±5	**Discharging Test Ambient, °C**	25±5
Refer to Attachment A for charge/discharge profiles for each cell.			

Table 2 – Charge completion and cell test initiation times			
Cell Test Number	**Cell Number**	**Charge Completion Date and Time**	**Cell test Date and Time**
1	3548334-001	2020/12/23 04:31 AM	2020/12/23 03:22 PM
2	3548334-002	2021/01/22 04:51 AM	2021/01/23 02:03 PM
3	3548334-003	2021/01/24 05:04 AM	2021/01/25 03:55 PM
4	3548334-004	2021/01/24 05:04 AM	2021/01/26 02:54 PM
5	3548334-005	2021/01/27 04:27 AM	2021/01/30 03:16 PM
Note: cells were charged to full charge voltage before test.			

Table 3 - Test Initiation Details					
	Cell Test 1	**Cell Test 2**	**Cell Test 3**	**Cell Test 4**	**Cell Test 5**
Test Date	2020/12/23	2021/01/23	2021/01/25	2021/01/26	2021/01/30
Test Start Time	03:22 PM	02:03 PM	03:55 PM	02:54 PM	03:16 PM
Initial Lab Temperature	24.0	24.7	24.4	24.7	24.5
Initial Relative Humidity	32%	35%	33%	31%	33%

Table 4 - Thermal Runaway Results					
	Cell Test 1	**Cell Test 2**	**Cell Test 3**	**Cell Test 4**	**Cell Test 5**
OCV at start of test, Vdc	3.41	3.40	3.39	3.40	3.39
Average Heating Rate, °C/min	4.3	4.3	4.3	4.3	4.3
Venting Time after the test start, secs	2505	2595	2634	2616	2098
Venting Temperature, °C	152.0	150.1	155.1	154.8	165.0
Thermal Runaway Time after the test start, secs	3288	3400	3497	3424	2283
Thermal Runaway Temperature, °C	197.5	193.5	186.1	195.3	199.9
Refer to Attachment C for surface temperature profiles during testing					

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 5 – Average Vent and Thermal Runaway Temperatures#	
Average of Cell Vent Temperatures, °C	153.0
Average of Cell Thermal Runaway Temperatures, °C	193.1
#Averages of cell tests other then the gas analysis test	

Table 6 – Parameters Flow Battery
N/A

Table 7 – Results of Flammability Testing of Flow Battery Electrolyte
N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

Table 8 – Results of Gas Analysis (Excluding O_2 and N_2)			
Gas		Measured %	Component LFL[1]
Carbon Monoxide	CO	7.475	10.9
Carbon Dioxide	CO_2	28.598	N/A
Hydrogen	H_2	49.513	4.0
Methane	CH_4	6.654	4.4
Acetylene	C_2H_2	0.156	2.3
Ethylene	C_2H_4	3.685	2.4
Ethane	C_2H_6	1.111	2.4
Propadiene (Allene)	C_3H_4	0.000	1.9
Propyne	C_3H_4	0.000	1.8
Propene	C_3H_6	0.581	1.8
Propane	C_3H_8	0.179	1.7
-	C4 (Total)	0.363	N/A
-	C5 (Total)	0.071	N/A
-	C6 (Total)	0.038	N/A
-	C7 (Total)	0.003	N/A
-	C8 (Total)	0.000	N/A
Benzene	C_6H_6	0.017	1.2
Toluene	C_7H_8	0.000	1.0
Dimethyl Carbonate	$C_3H_6O_3$	1.152	N/A
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.406	N/A
Diethyl Carbonate	$C_5H_{10}O_3$	0.000	N/A
Total	-	100	-

Table 10 – Properties of Vent Gas Analysis	
Lower Flammability limit at Ambient Temperature, 25°C (% vol in air)	7.05
Lower Flammability limit at Vent Temperature, [153°C] (% vol in air)	6.35
Burning Velocity Measurement, S_u cm/sec	106.7
Maximum Pressure P_{max}, psig	96.19

[1] Extracted LFL values from ISO 10156-2017

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict

	TABLE: Critical components information				
Object / part No.	**Manufacturer/ trademark**	**Type / model**	**Technical data**	**Standard**	**Mark(s) of conformity[1)]**
Cell Model	Contemporary Amperex Technology Co., Limited	001CB0Y0	3.2Vdc, 100Ah, LFP	UL 1973	MH62898
Separator*	Vendor code 3971	PZ9	PE	UL 1973	MH62937
Electrolyte	-	/	LiPF6+EC/EMC/DEC/DMC	–	–
Case	-	/	Aluminum	–	–
Insulators/ location in cell	-	/	Insulation Plate (Up), PC, Located between cell terminal and electrode lug. Mylar (PP), used to warp the cell. Insulation Plate(Down), PP Located between cell and bottom of case.	-	-

*Note: detail Separator information refer to file MH62898.

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages **18** through **20***)

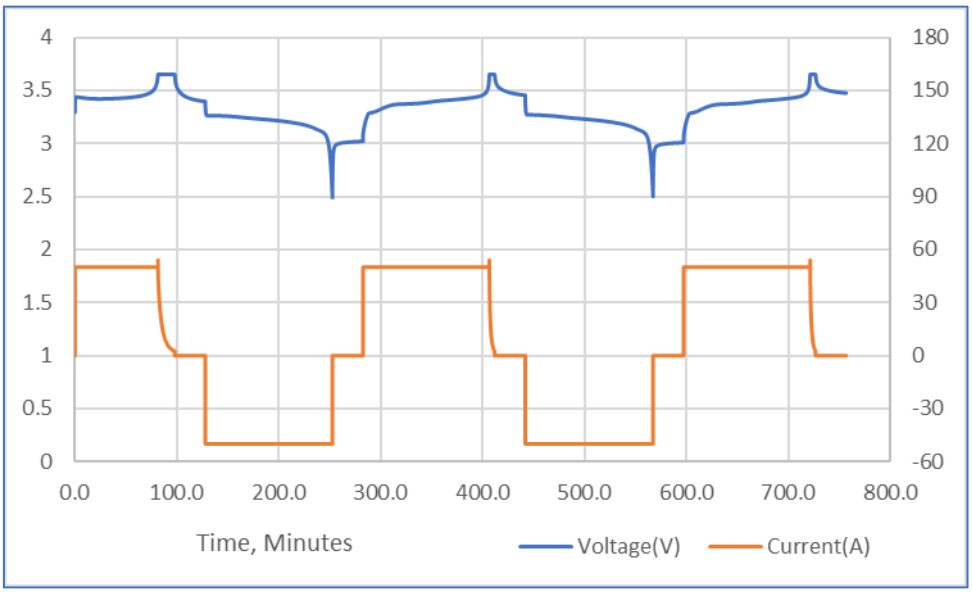


Figure 1: Cell 1 Conditioning (Charge/discharge) Profiles

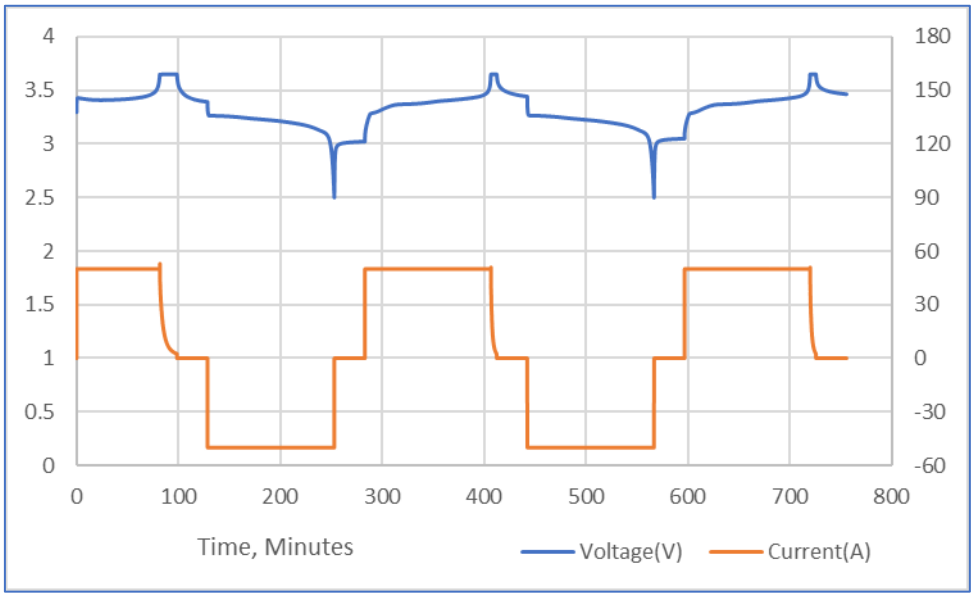


Figure 2: Cell 2 Conditioning (Charge/discharge) Profiles

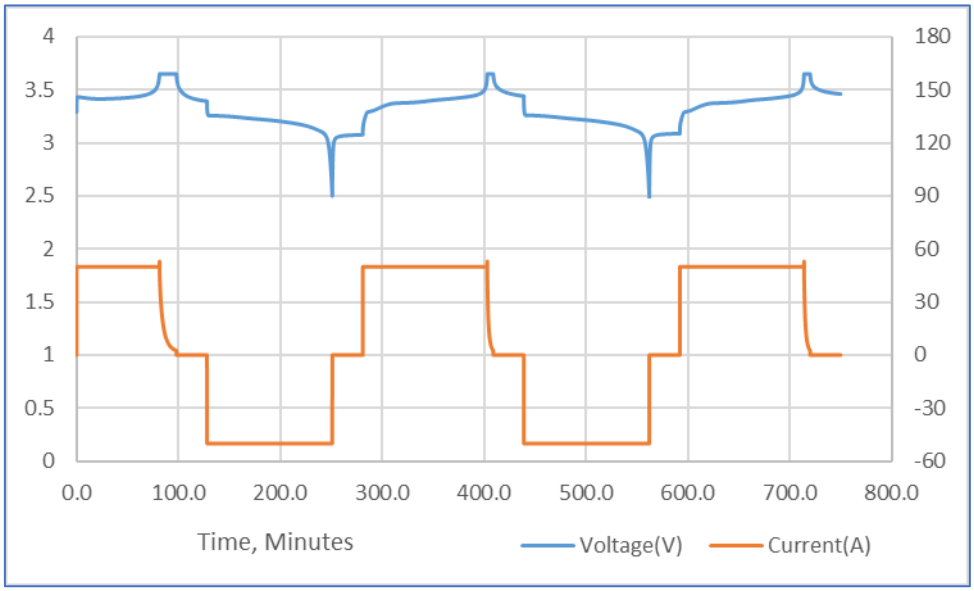


Figure 3: Cell 3 Conditioning (Charge/discharge) Profiles

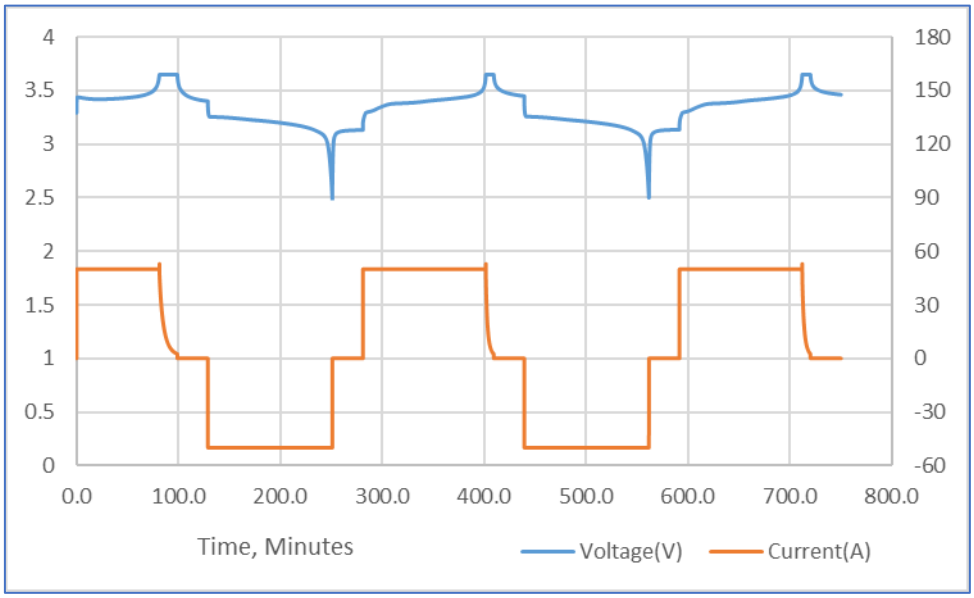


Figure 4: Cell 4 Conditioning (Charge/discharge) Profiles

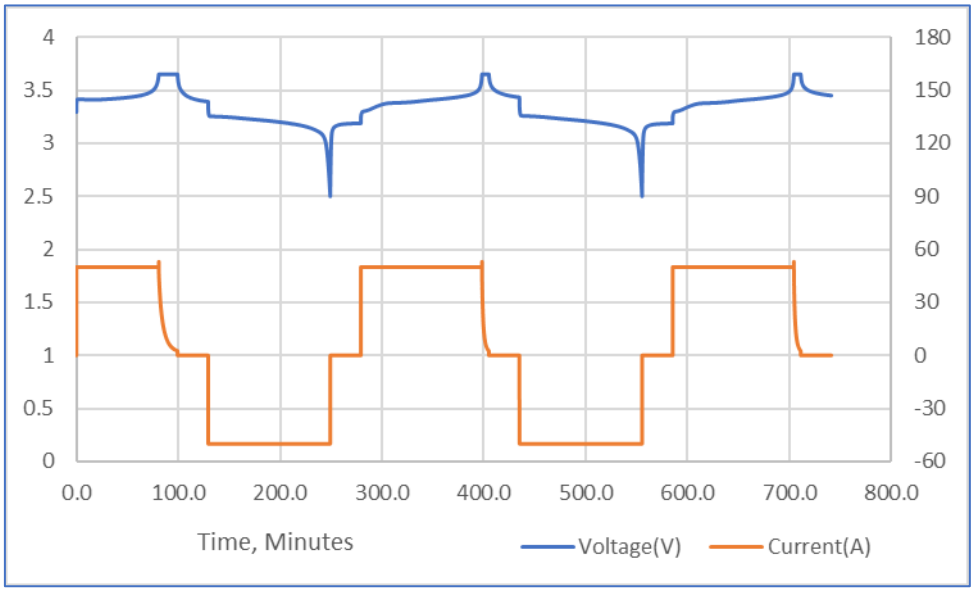
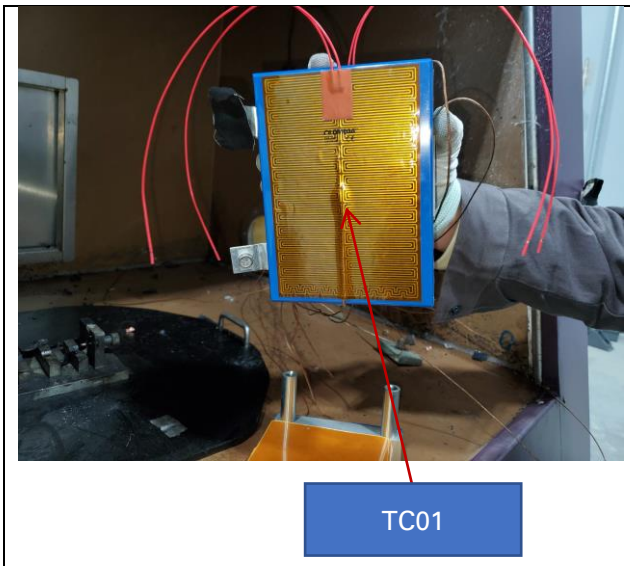
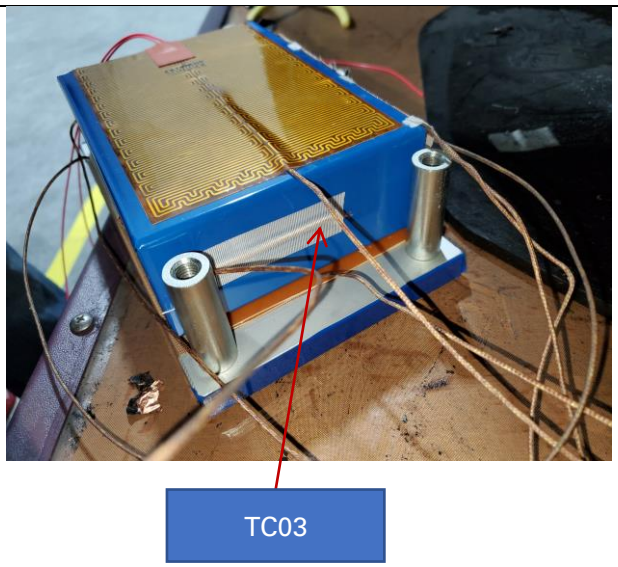


Figure 5: Cell 5 Conditioning (Charge/discharge) Profiles

Attachment B: Cell Instrumentation Photos - (*Page **21***)





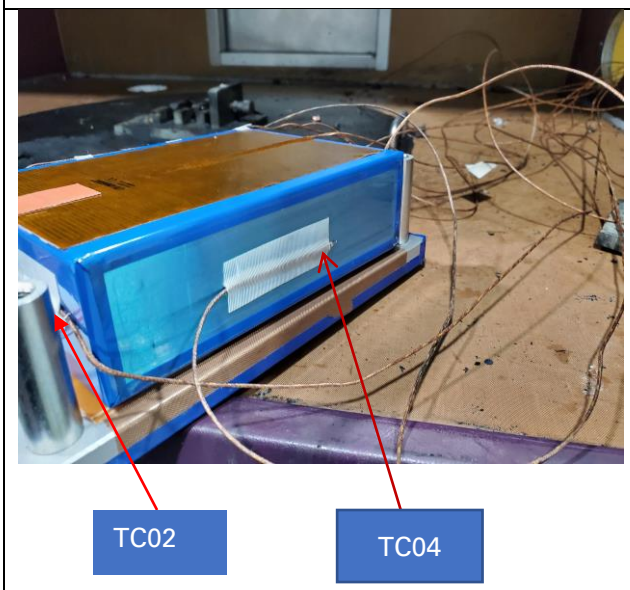


Figure 6: Sample Instrumentation Prior to Test

Note 1: heaters were placed on two sides of cell after thermocouple adhered.

Note 2: Cell was positioned between non-combustible test surfaces and fixed by jig so as to prevent outward movement from the jig, but without applying initial pressure to the cell.

Note 3: TC01 under heater; TC02 on the cell positive; TC03 at the cell bottom; TC04 on the cell body not cover by heater;

Attachment C: Cell Temperature Profiles during testing - (*Pages **22** through **24***)

Note: TC01 under heater; TC02 on the cell positive; TC03 at the cell bottom; TC04 on the cell body not cover by heater; TC05 Ambient temperature; V1 cell voltage

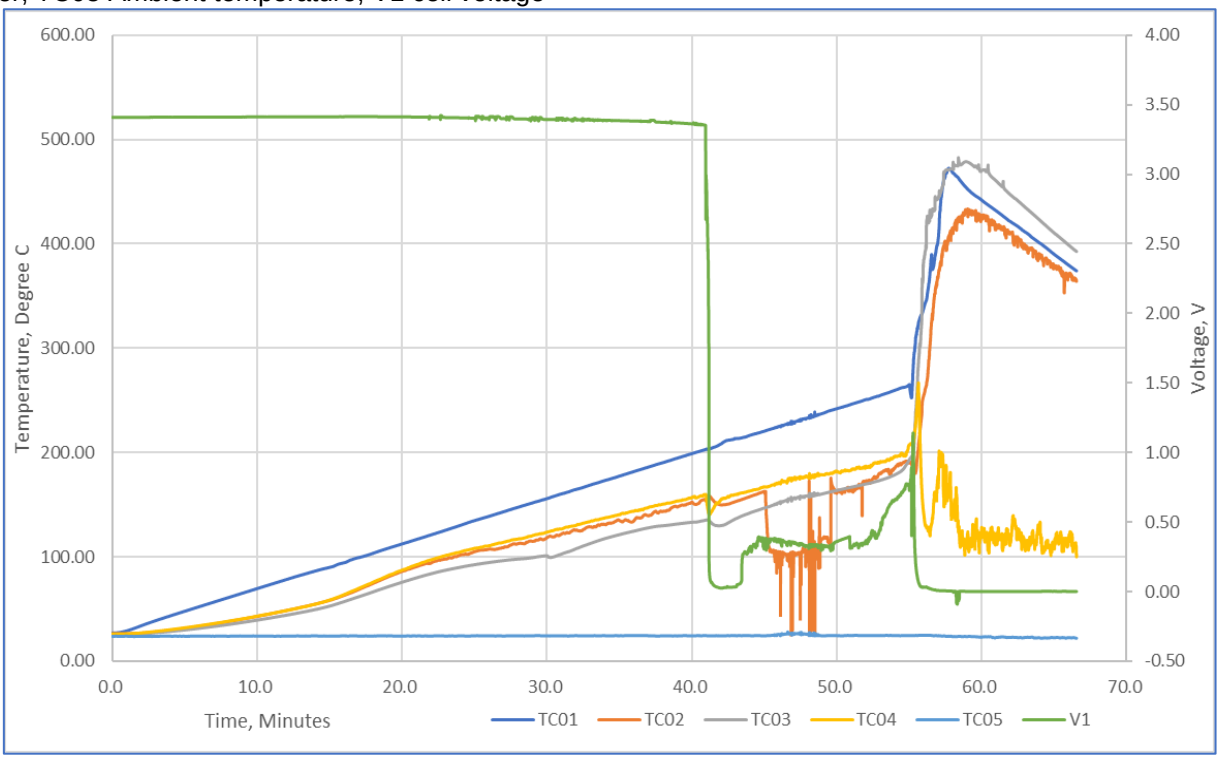


Figure 7: Cell 1 Temperature and Voltage Profile

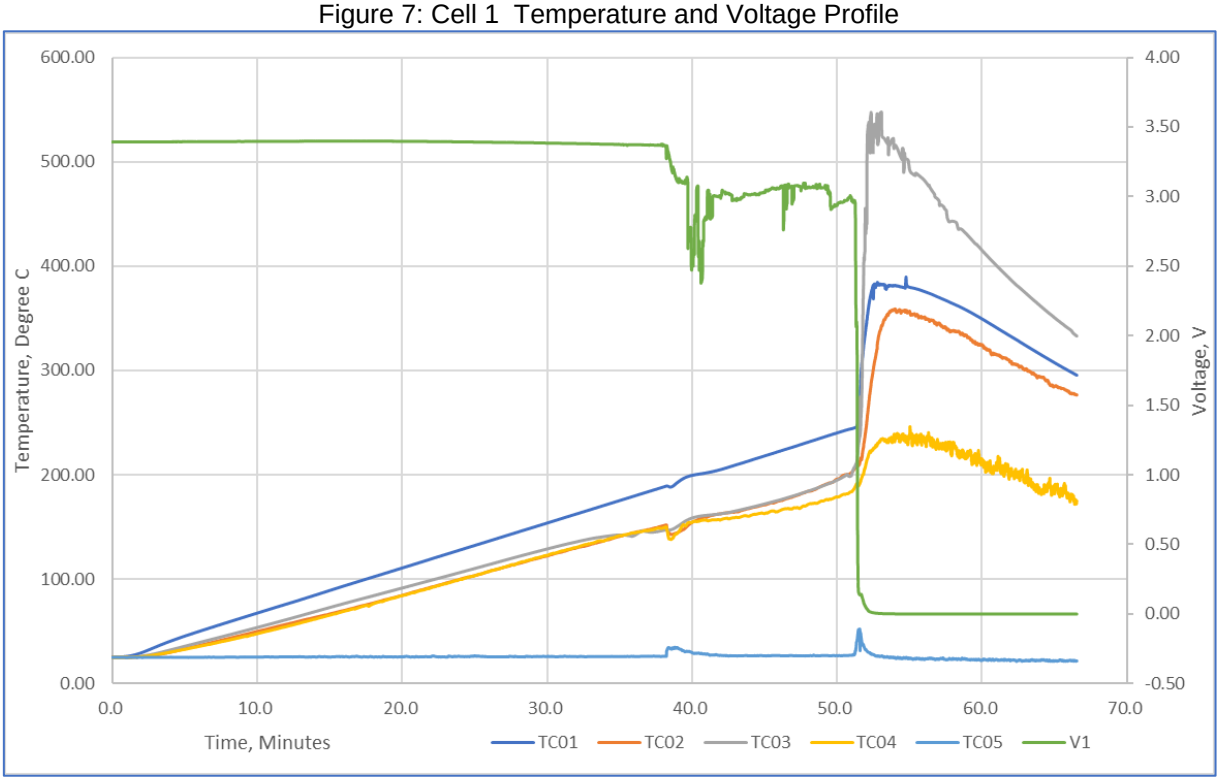


Figure 8: Cell 2 Temperature and Voltage Profile

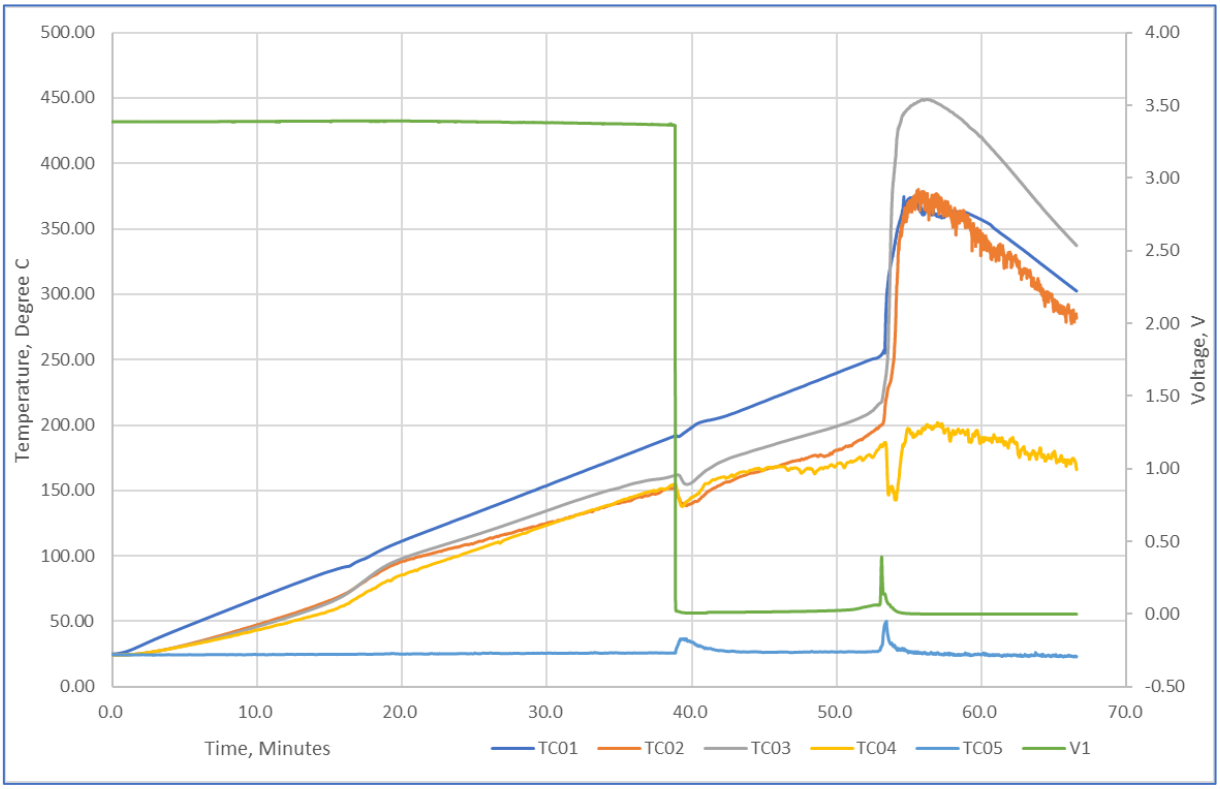


Figure 9: Cell 3 Temperature and Voltage Profile

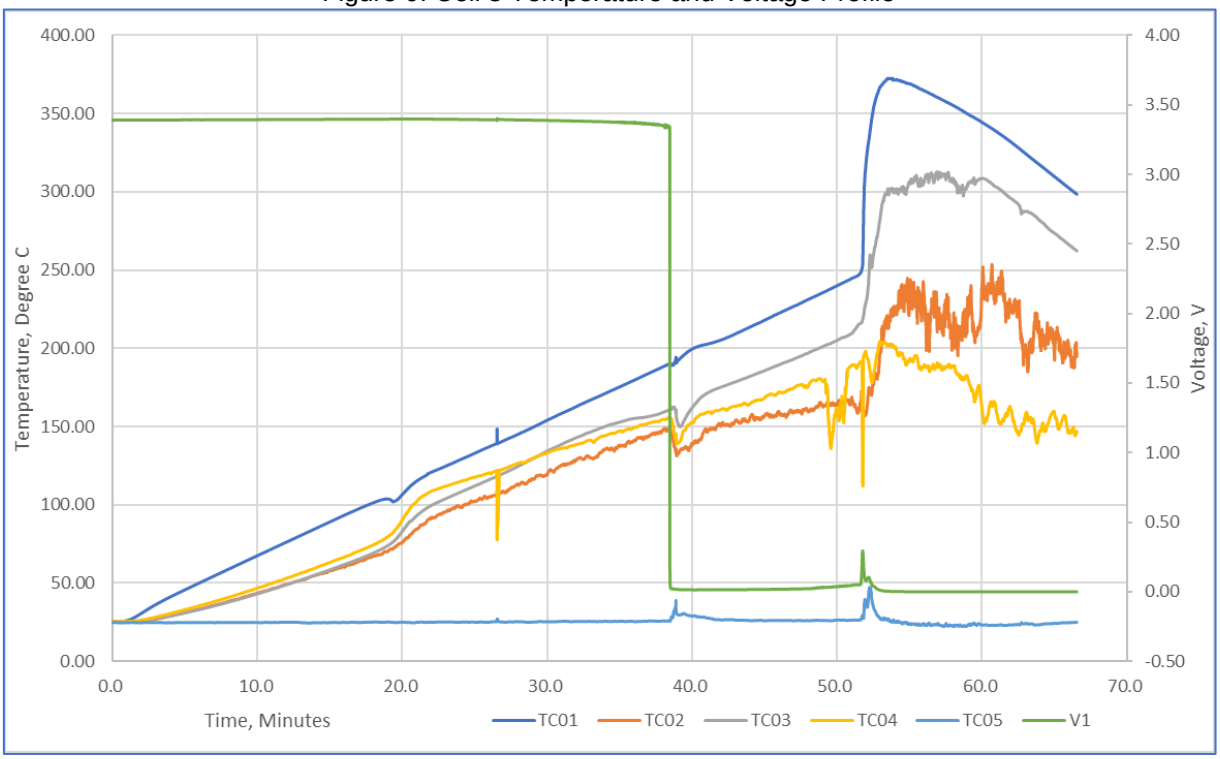


Figure 10: Cell 4 Temperature and Voltage Profile

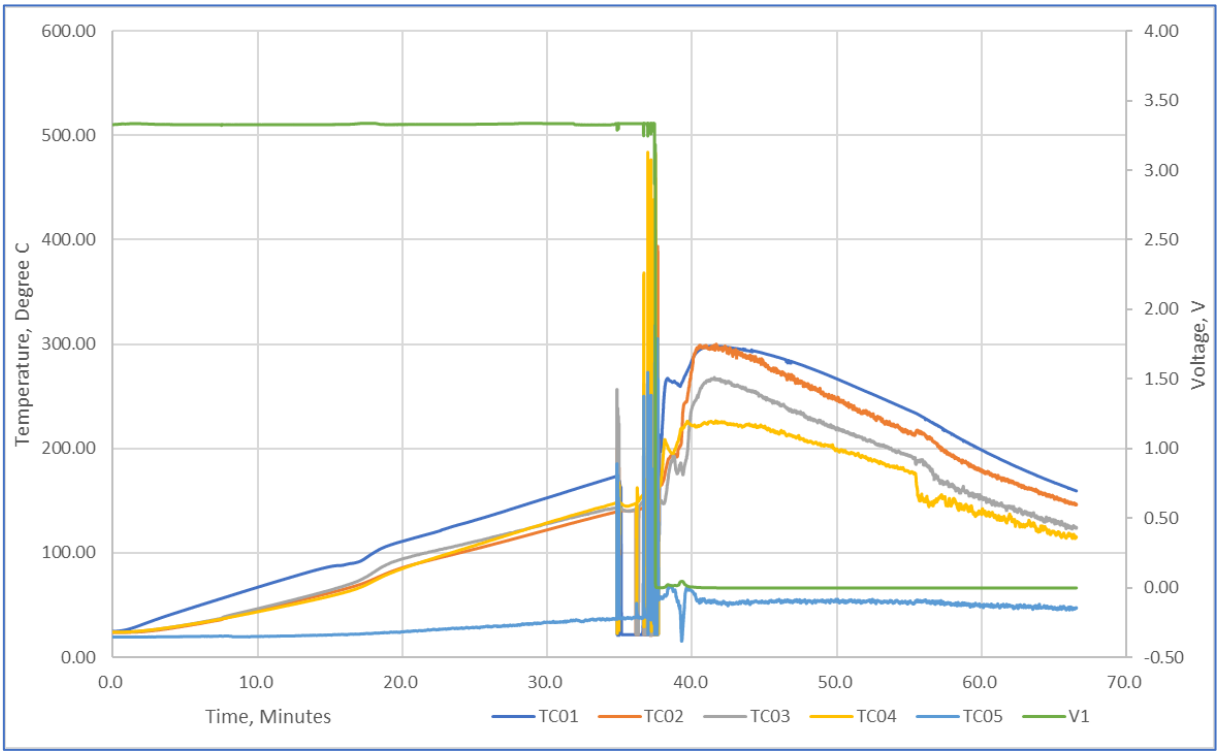
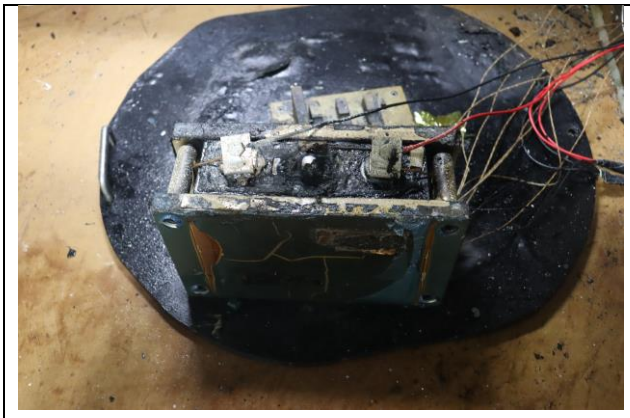


Figure 11: Cell 5 Temperature and Voltage Profile

Attachment D: Cell Testing Photos - (*Pages **25** through **33***)

Cell Sample 1 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>(a) Test Start
[00:00]</td><td>(b) Cell Venting
[41:45]</td></tr>
<tr><td>  </td><td></td></tr>
<tr><td>(c) Thermal runaway behavior
[54:48]</td><td></td></tr>
<tr><td colspan="2">Figure 12: Highlights of Cell 1 Testing</td></tr>
</table>



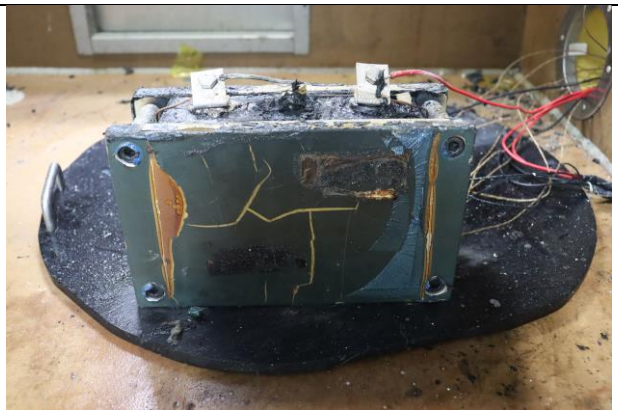
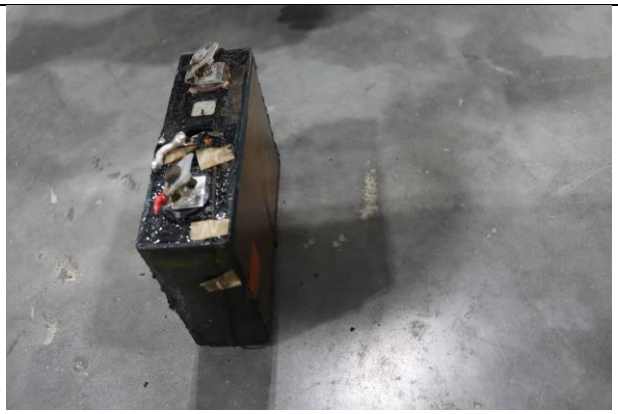


Figure 13: Sample 1 Post Test Photos

Cell Sample 2 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>(a) Test Start
[00:00]</td><td>(b) Cell Venting
[43:15]</td></tr>
<tr><td>  </td><td></td></tr>
<tr><td>(c) Thermal runaway behavior
[56:40]</td><td></td></tr>
<tr><td colspan="2">Figure 14: Highlights of Cell 2 Testing</td></tr>
</table>



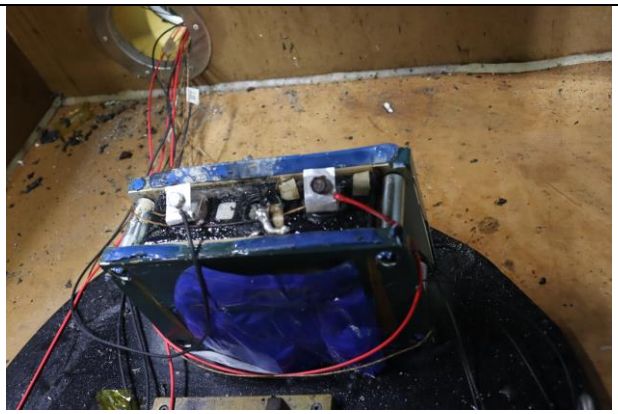


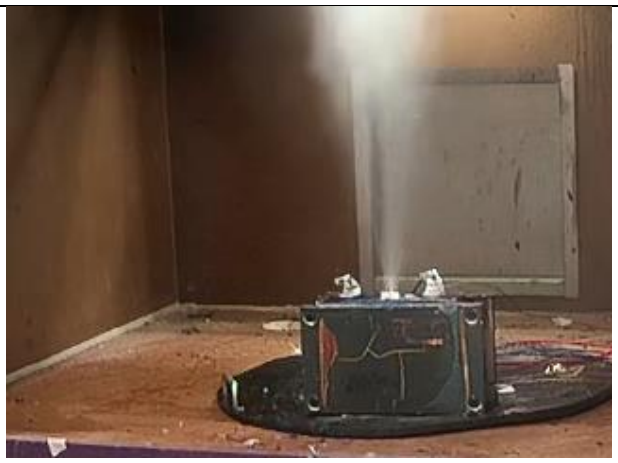
Figure 15: Sample 2 Post Test Photos

Cell Sample 3 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>(a) Test Start
[00:00]</td><td>(b) Cell Venting
[43:32]</td></tr>
<tr><td>  </td><td></td></tr>
<tr><td>(c) Thermal runaway behavior
[57:10]</td><td></td></tr>
<tr><td colspan="2">Figure 16: Highlights of Cell 3 Testing</td></tr>
</table>

Figure 17: Sample 3 Post Test Photos

Cell Sample 4 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.

<table>
<tr><td>  </td><td>  </td></tr>
<tr><td>(a) Test Start
[00:00]</td><td>(b) Cell Venting
[43:36]</td></tr>
<tr><td>  </td><td></td></tr>
<tr><td>(c) Thermal runaway behavior
[57:04]</td><td></td></tr>
<tr><td colspan="2">Figure 18: Highlights of Cell 4 Testing</td></tr>
</table>

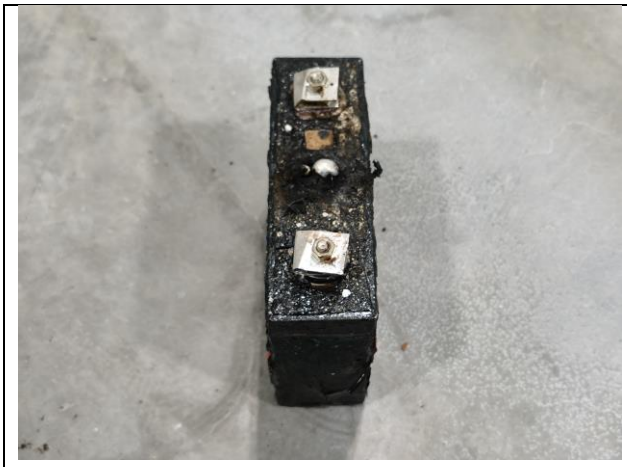


Figure 19: Sample 4 Post Test Photos

Cell Sample 5 – Cell venting and thermal runaway were observed.

The camera cannot record properly during test due to cell reaction inside test chamber, no photo provided.

Figure 20: Highlights of Cell 5 Testing

Attachment E: Cell vent gas test chamber photo and profile of chamber gas analysis (O_2 and Pressure) - *(Page **34**)*

The gas composition test was conducted with the battery inserted into the battery gas composition test chamber and the chamber was sealed. The battery gas composition test chamber is a 100 L pressure vessel and is shown in figure below.

Prior to initiating thermal runaway, the chamber's atmosphere was purged until a condition of less than 1% oxygen by volume (actual 0.023%, with initial pressure 0.138 psig).

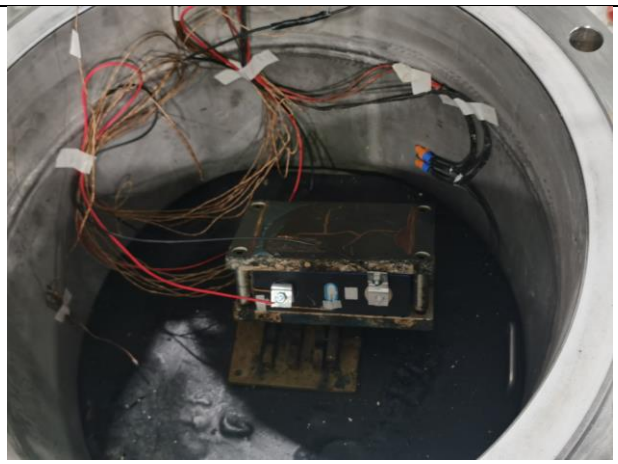


Figure 21: Sample 5 instrumented and inside gas test chamber

$\phi_{O2,\ chamber}$=	0.023	%	$P_{initial,chamber}$=	0.138	psig

Figure 22: Profile of gas test chamber (O2 and Pressure)

Attachment F: Cell Gas Analysis Report - (*Pages **35** through **36***)

Table Re-normalized Gas Quantification, excluding N_2 and O_2, and unknown compounds.

Item	Measure	Chemical formula	Conc.(%)
1	Carbon Monoxide	CO	7.475
2	Carbon Dioxide	CO_2	28.598
3	Hydrogen	H_2	49.513
4	Methane	CH_4	6.654
5	Acetylene	C_2H_2	0.156
6	Ethylene	C_2H_4	3.685
7	Ethane	C_2H_6	1.111
8	Propadiene (Allene)	C_3H_4	0.000
9	Propyne	C_3H_4	0.000
10	Propene	C_3H_6	0.581
11	Propane	C_3H_8	0.179
12	C4 (Total)	-	0.363
13	C5 (Total)	-	0.071
14	C6 (Total)	-	0.038
15	C7 (Total)	-	0.003
16	C8 (Total)	-	0.000
17	Benzene	C_6H_6	0.017
18	Toluene	C_7H_8	0.000
19	Dimethyl Carbonate	$C_3H_6O_3$	1.152
20	Ethyl Methyl Carbonate	$C_4H_8O_3$	0.406
21	Diethyl Carbonate	$C_5H_{10}O_3$	0.000
	Total	Measurement result	100.000

Figure 23: Gas composition analysis result

The lower flammability limit testing was performed using ASTM E918, *Standard Practice for Determining Limits of Flammability of Chemicals at Elevated Temperature and Pressure*. The explosion severity testing and calculations were performed using EN 15967, *Determination of Maximum Explosion Pressure and the Maximum Rate of Pressure Rise of Gases and Vapours*. The results from these tests and calculations are summarized in Tables 1-3 and 1-4.

Table 1-3: Executive Summary of Lower Flammability Limit Test Results

Sample Name	LFL at Ambient Temp (vol.%)	LFL at 153°C (vol.%)
Custom Gas Mix Ref #4789764706	7.05	6.35

Table 1-4: Executive Summary of Explosion Severity Tests Results

Sample Name	P_{max} (psig)	dP/dt_{max} (psi/s)	K_G (bar-m/s)	Max Temp (°C)
Custom Gas Mix Ref #4789764706	96.19	8060	96.73	288.3

Figure 24: Flammability characteristics test result – Lower flammability level (LFL) and Maximum pressure (Pmax)

Burning Velocity Summary

UL Project	4789764706
Sample	SG HY ULMX29-150A
Maximum Average Burning Velocity (cm/s)	106.7
Sample Concentration at maximum average burning velocity (%)	27.0

Figure 25: Flammability characteristics test result – Burning velocity (Su)