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

Project Number.....:	**4790342745**
Date of issue.....:	**2022.10.27**
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UL Report Office .....:	**UL(Changzhou) Quality Technical Service Co,. LTD**
Applicant's name.....:	**REPT BATTERO Energy Co., Ltd.**
Address .....:	**No.205, Binhai 6th Road, Konggang New District, Longwan District, Wenzhou Zhejiang, 325000 China.**
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

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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 .....:	CB56
Ratings (Vdc, Ah) .....:	3.2V, 100Ah
Chemistry of test item……:	Lithium Iron Phosphate /Graphite
Original Equipment Manufacturer (OEM):	REPT BATTERO Energy Co., Ltd.
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(MH64238)
Average cell surface temperature at gas venting, °C:	166
Average surface temperature at thermal runaway, °C:	210
Gas Volume:	58.9L
Lower flammability limit (LFL), % volume in air at the ambient temperature	6.95
Lower flammability limit (LFL), % volume in air at the venting temperature	5.95
Burning velocity (S_u) cm/s:	125
Maximum pressure (P_{max}) psig:	98.7

Cell Gas composition

Gas		Measured %
Carbon Monoxide	CO	9.302
Carbon Dioxide	CO_2	24.429
Hydrogen	H_2	57.227
Methane	CH_4	4.576
Acetylene	C_2H_2	0.164
Ethylene	C_2H_4	2.699
Ethane	C_2H_6	0.858
Propadiene (Allene)	C_3H_4	0.000
Propene	C_3H_6	0.264
Propane	C_3H_8	0.081
-	C4 (Total)	0.186
-	C5 (Total)	0.024
-	C6 (Total)	0.008
1-Heptene	C_7H_{14}	0.000
Benzene	C_6H_6	N.D
Toluene	C_7H_8	0.004
Dimethyl Carbonate	$C_3H_6O_3$	0.001
Ethyl Methyl Carbonate	$C_4H_8O_3$	0.148
Total	-	100.0

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)..... :	Lance Peng	
Witnessed by (for 3rd Party Lab Test Location) (name, signature) ..... :	N/A	N/A
Project Handler (name, signature)..... :	Gavin Chen (T) Benjamin Liu	Gavin chen Benjamin Liu
Reviewer (name, signature) ……:	Rebecca Le	Rebecca Le
Gas Analysis Testing Laboratory:		
Testing location/ address..... :	DEKRA Services, Inc.	
Project Handler (name, signature)..... :	9180 W. White Eagle Road	

	Forreston, Illinois
Reviewer (name, signature) …….:	Abdollah Kashani
Reviewer (name, signature) …….:	Andrew Kusmierz
Gas Analysis Testing Laboratory: (Lower Flammability Limit & Explosion Pressure)	Fauske & Associates LLC.
Testing location/ address..... :	16W070 83RD STREET, BURR RIDGE, ILLINOIS, 60527
Project Handler (name, signature)..... :	Adolfo Monarrez
Reviewer (name, signature) …….:	Patrick Wojcik

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

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages 1**7** through **19***)

Attachment B: Cell Instrumentation Photos - (*Pages **20***)

Attachment C: Cell Temperature Profiles during testing - (*Pages **21** through **23***)

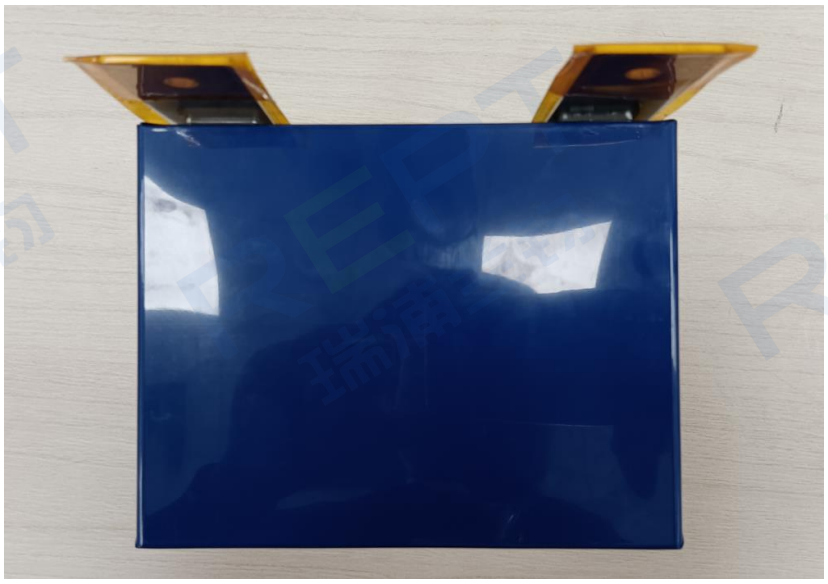
Attachment D: Cell Testing Photos - (*Pages **24** through **33***)

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

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

Photo of cell/Stack:





Test Item Charge/Discharge Specifications:	
• **Charge current, A:**	52
• **Standard full charge voltage, Vdc:**	3.65
• **Charge temperature range, °C:**	-10~ 60
• **End of charge power, A:**	5.2
• **Discharge current, A:**	52
• **End of discharge voltage, Vdc:**	2.5
• **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 CB56
Date of receipt of test item .....:	2022.04.19
Date (s) of performance of tests.....:	2022.04.25 to 2022.07.01

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) .....:	REPT BATTERO Energy Co., Ltd. No.205, Binhai 6th Road, Konggang New District, Longwan District, Wenzhou Zhejiang, 325000 China.

General product information and other remarks:

The tested cell is a Lithium-ion battery cell, Model CB56. Each cell has a capacity of 100Ah and nominal voltage 3.2 Vdc.

The overall dimensions of cell are 52.3±1 mm by 148.4±1 mm by 119.0±1 mm.

The weight of cell is 1.93±0.15kg.

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 / Graphite	—
	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 in test.	—
	Format: Cylindrical /Prismatic /Pouch Flow Battery Stack	Prismatic	—
	Overall Dimensions, mm	T*W*H: 52.3±1mm by 148.4±1mm by 119.0±1mm	—
	Cell Weight, g	1.93±0.15 kg	—
5.1.2	Cell Certification:	Certificated cell	—
	Standard Used for Cell Certification:	UL 1973	—
	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	—
6.0	**PERFORMANCE**		**Verdict**
6.1	**General**		C
7.2	**Samples**		C
7.2.1	Samples conditioned through charge discharge cycling a minimum of 2 cycles.	See Attachment A for profiles See Table 1 for specifications	C

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
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**		C
7.3.1	**General**		C
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 101.6 mm by 127 mm heaters on two largest sides of 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**		N/A
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
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

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Clause	Requirement + Test	Result - Remark	Verdict
	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**		C
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: 70L 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 E Atmospheric pressure (psig): 0.09	C
		Oxygen concentration measured (% volume): 0.12%	
		Inert gas used: Nitrogen	
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 E	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
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**		N/A

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
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**		C
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	F
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.		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
	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

UL 9540A, Edition 4,			
Clause	Requirement + Test	Result - Remark	Verdict
	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	52	**Current (CC), A**	52
Standard full charge voltage, Vdc	3.65	**Voltage at start of discharge, Vdc**	3.65
End of charge current, A	5.2	**End of discharge voltage, Vdc**	2.5
Charging Test Ambient, °C	-10 ~ 60	**Discharging Test Ambient, °C**	-20 ~ 60
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	4784574-S002	2022/04/25 11:54 AM	2022/04/25 05:28 PM
2	4784574-S003	2022/04/26 11:44 AM	2022/04/26 04:14 PM
3	4784574-S004	2022/04/27 11:00 AM	2022/04/27 04:13 PM
4	4784574-S005	2022/04/28 10:47 AM	2022/04/28 03:25 PM
5	4784574-S006	2022/07/01 01:01 PM	2022/07/01 06:13 PM

Table 3 - Test Initiation Details					
	Cell Test 1	**Cell Test 2**	**Cell Test 3**	**Cell Test 4**	**Cell Test 5**
Test Date	2022/04/25	2022/04/26	2022/04/27	2022/04/28	2022/07/01
Test Start Time	05:28 PM	04:14 PM	04:13 PM	03:25 PM	06:13 PM
Initial Lab Temperature	23.1	22.7	22.9	22.2	21.6
Initial Relative Humidity	73.5%	67.0%	68.7%	72.1%	55.5%

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	3.48	3.48	3.49	3.48	3.49
Average Heating Rate, °C/min	4.5	4.5	4.5	4.5	4.5
Venting Time after the test start, secs	2246	2366	2386	2293	2349
Venting Temperature, °C	163	167	165	167	167
Thermal Runaway Time after the test start, secs	3016	3173	3133	3052	3040
Thermal Runaway Temperature, °C	208	210	204	218	209
Refer to Attachment C for surface temperature profiles during testing Temperature indicated above were taken from TC03.					

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

Table 5 – Average Vent and Thermal Runaway Temperatures#	
Average of Cell Vent Temperatures, °C	166
Average of Cell Thermal Runaway Temperatures, °C	210
#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

Table 8 – Results of Gas Analysis (Excluding O_2 and N_2)			
Gas		Measured %	Component LFL[1]
Carbon Monoxide	**CO**	9.302	10.9
Carbon Dioxide	**CO_2**	24.429	N/A
Hydrogen	**H_2**	57.227	4.0
Methane	**CH_4**	4.576	4.4
Acetylene	**C_2H_2**	0.164	2.3
Ethylene	**C_2H_4**	2.699	2.4
Ethane	**C_2H_6**	0.858	2.4
Propadiene (Allene)	**C_3H_4**	0.000	1.9
Propene (Propylene)	**C_3H_6**	0.264	1.8
Propane	**C_3H_8**	0.081	1.7
-	**C4 (Total)**	0.186	N/A
-	**C5 (Total)**	0.024	N/A
-	**C6 (Total)**	0.008	N/A
1-Heptene	**C_7H_{14}**	0.000	N/A
Styrene	**C_8H_8**	N.D	1.1
Benzene	**C_6H_6**	0.004	1.2
Toluene	**C_7H_8**	0.001	1.0
Dimethyl Carbonate	**$C_3H_6O_3$**	0.148	N/A
Ethyl Methyl Carbonate	**$C_4H_8O_3$**	0.029	N/A
Total	-	100	-

[1] Extracted LFL values from ISO 10156-2017

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

Table 9 – Gas composition excluding the constituents with boiling points higher than 60°C[2]			
Gas		**Measured %**	**Component LFL**
Carbon Monoxi	**CO**	9.320	10.9
Carbon Dioxide	**CO_2**	24.476	N/A
Hydrogen	**H_2**	57.336	4.0
Methane	**CH_4**	4.584	4.4
Acetylene	**C_2H_2**	0.165	2.3
Ethylene	**C_2H_4**	2.705	2.4
Ethane	**C_2H_6**	0.859	2.4
Propadiene (Allene)	**C_3H_4**	0.000	1.9
Propene (Propylene)	**C_3H_6**	0.265	1.8
Propane	**C_3H_8**	0.081	1.7
-	**C_4 (Total)**	0.186	N/A
-	**C_5 (Total)**	0.024	N/A
Total	**-**	100.0	-

Table 10 – Properties of Vent Gas Analysis	
Lower Flammability limit at Ambient Temperature, 25°C (% vol in air)	6.95
Lower Flammability limit at Vent Temperature, [166°C] (% vol in air)	5.95
Burning Velocity Measurement, S_u cm/sec	125
Maximum Pressure P_{max}, psig	98.7

[2] The constituents with a higher boiling point were excluded for the flammability characteristic analysis as these components will turn into a liquid state at room temperature and will not release from the gas bottle as a homogenous mixture.

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	REPT BATTERO Energy Co., Ltd.	CB56	100Ah, 3.2V, Prismatic, LiFePO4, Carbon	UL 1973	MH64238
Separator	Shanghai Energy New Materials Technology Co., Ltd.	CH-6	PE+Al_2O_3, 12±3um thickness, melting temperature >140°C	UL1973	MH63784
Electrolyte	-	-	$LiPF_6$, EC, EMC, DMC	-	-
Case	-	-	Aluminium, Two-part construction consisting of casing and cell lid secured by laser welding, - Case Thickness: 0.5±0.2mm	-	-
Insulators/ location in cell	-	-	PP, located between jolly roll and Al shell	-	-
Vent	-	-	Aluminium, 0.6± 0.2MPa	-	-

Attachment A: Cell Conditioning (Charge/discharge) Profiles - (*Pages **17** through **19***)

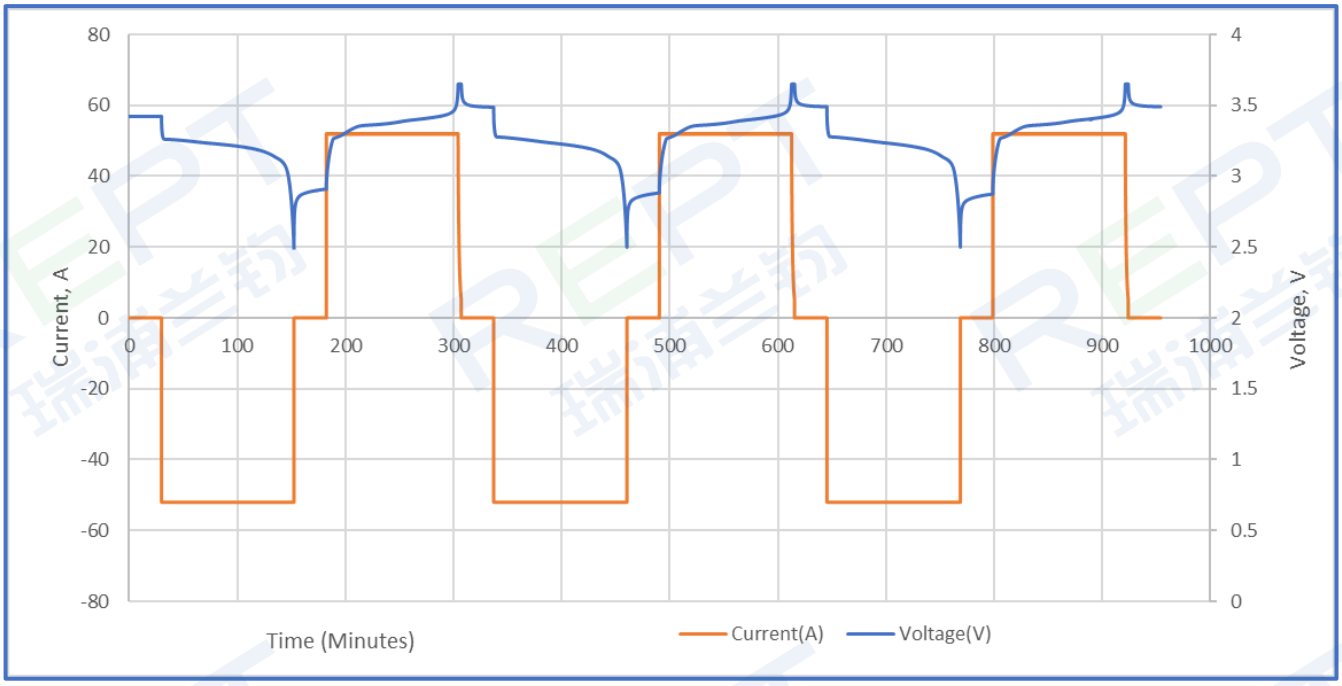


Figure 1: Cell 1 Conditioning (Charge/discharge) Profiles

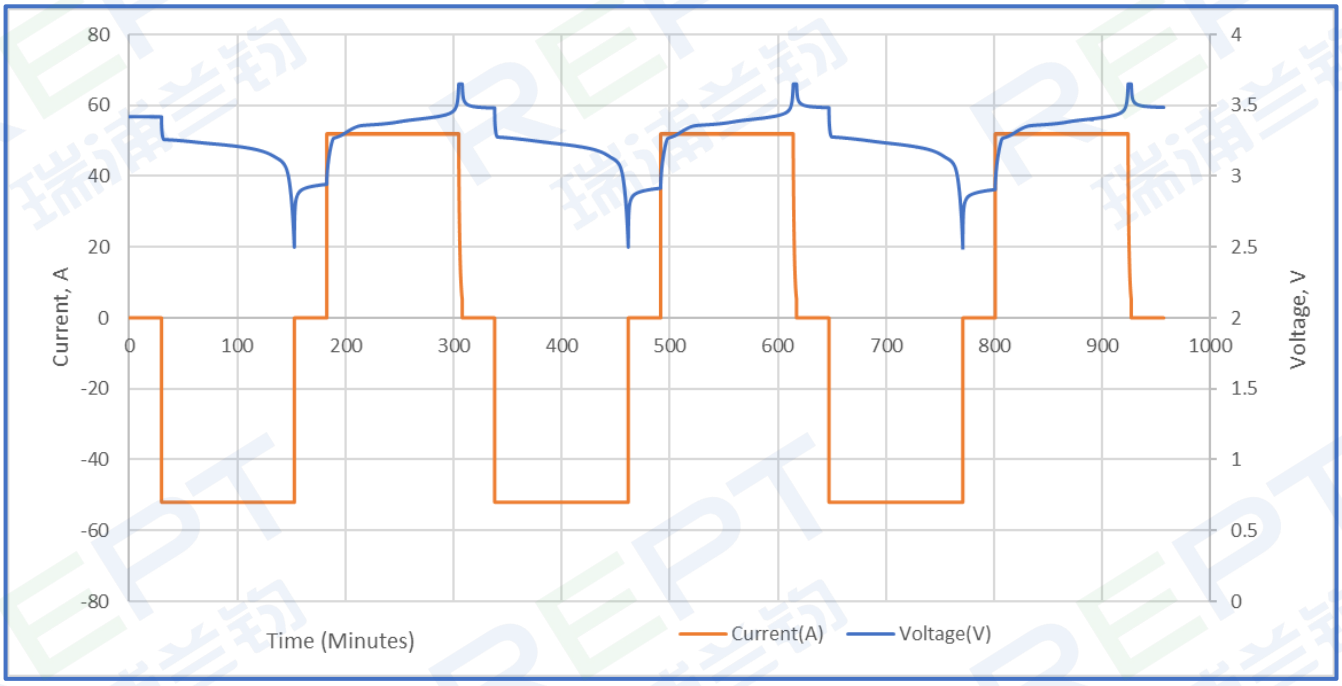


Figure 2: Cell 2 Conditioning (Charge/discharge) Profiles

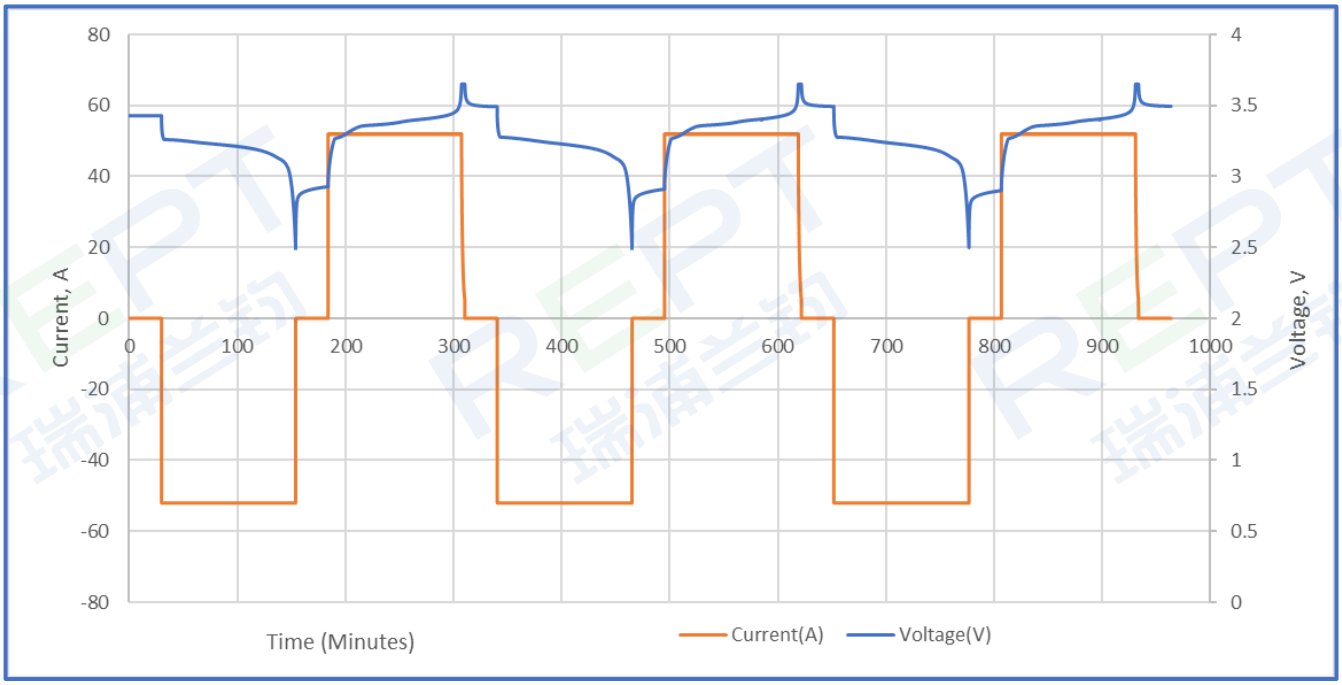


Figure 3: Cell 3 Conditioning (Charge/discharge) Profiles

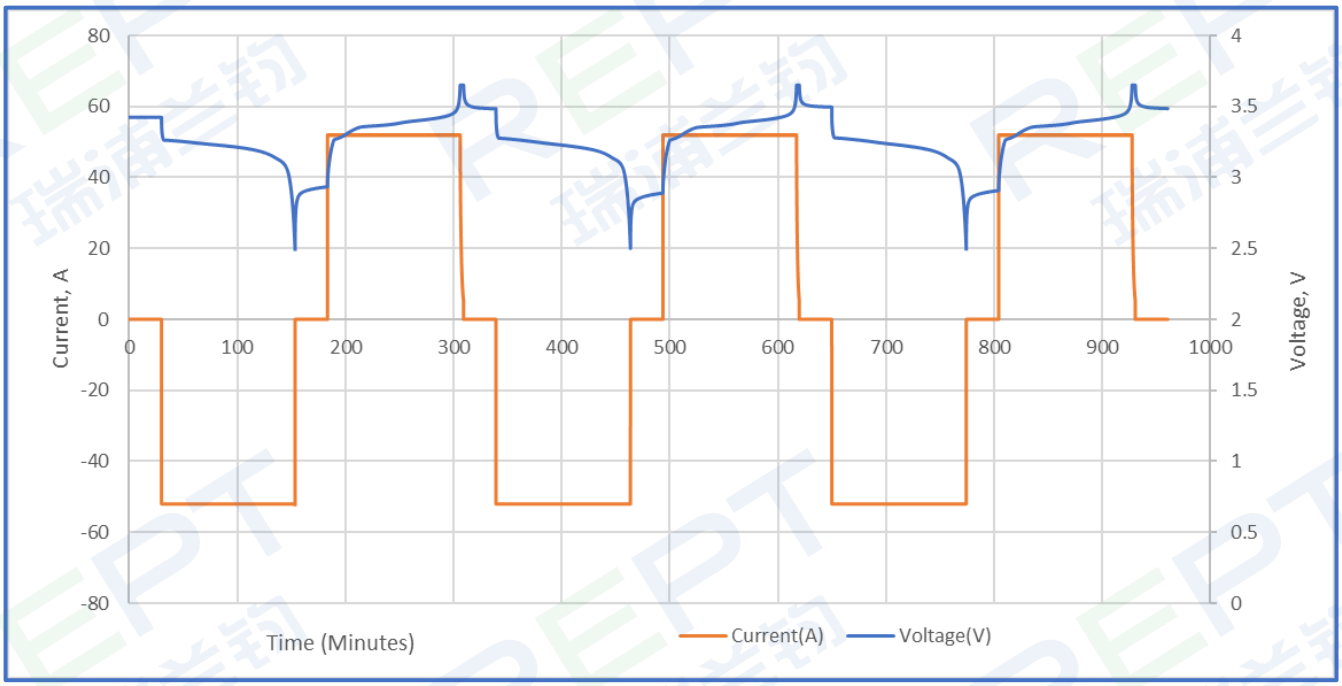


Figure 4: Cell 4 Conditioning (Charge/discharge) Profiles

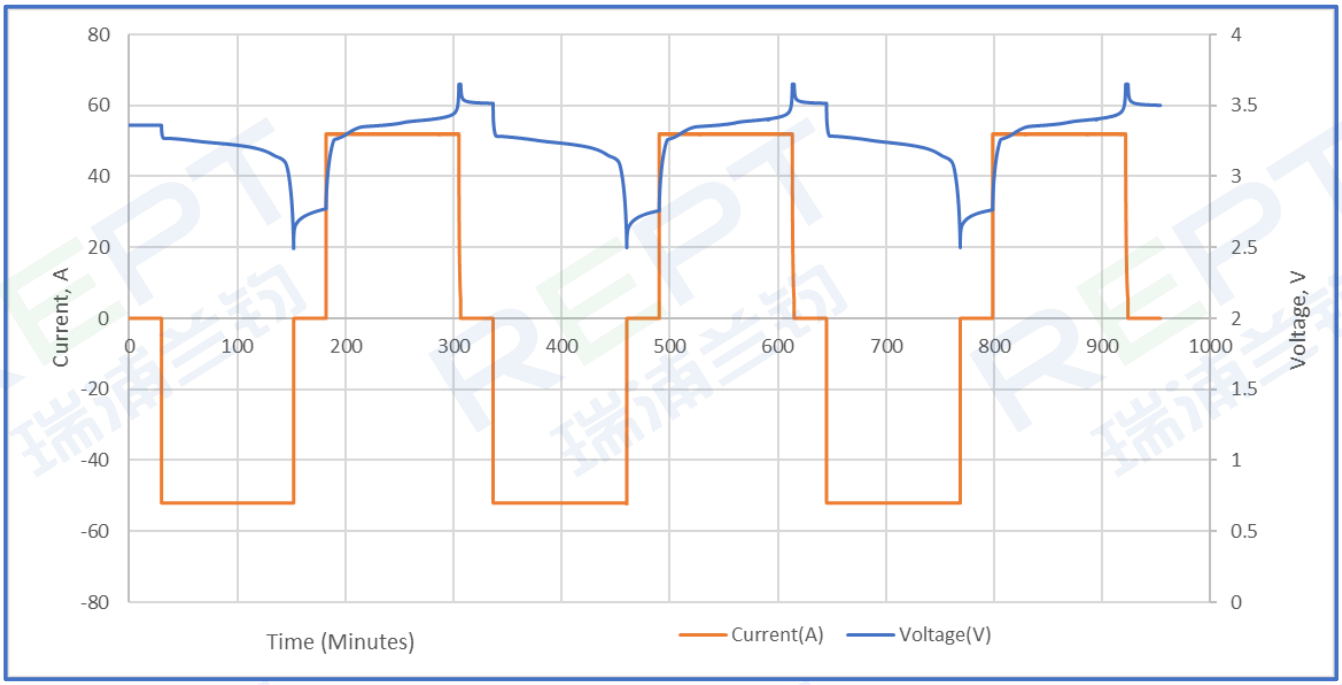
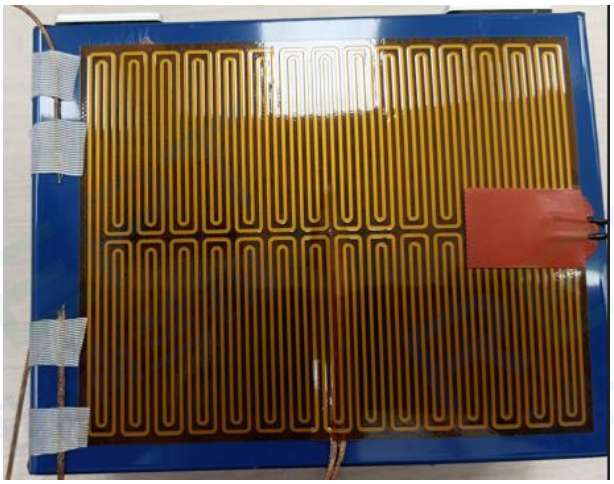


Figure 5: Cell 5 Conditioning (Charge/discharge) Profiles

Attachment B: Cell Instrumentation Photos - (*Pages **20***)







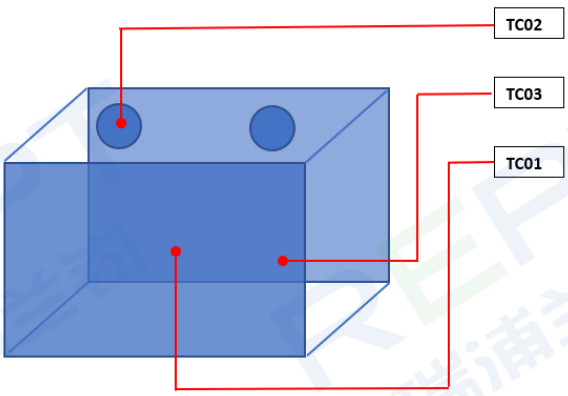


Figure 6: Sample Instrumentation Prior to Test

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

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

Attachment C: Cell Temperature Profiles during testing - (*Pages **21** through **23***)
Note: TC01 under heater; TC02 on the cell positive; TC03 on the cell body not covered by heater; TC04 Ambient temperature; V1 cell voltage
TC01 was used to control the temperature at 4 to 7°C/min and TC03 temperatures were reported herein for the surface temperature at the onset of vent and thermal runaway.

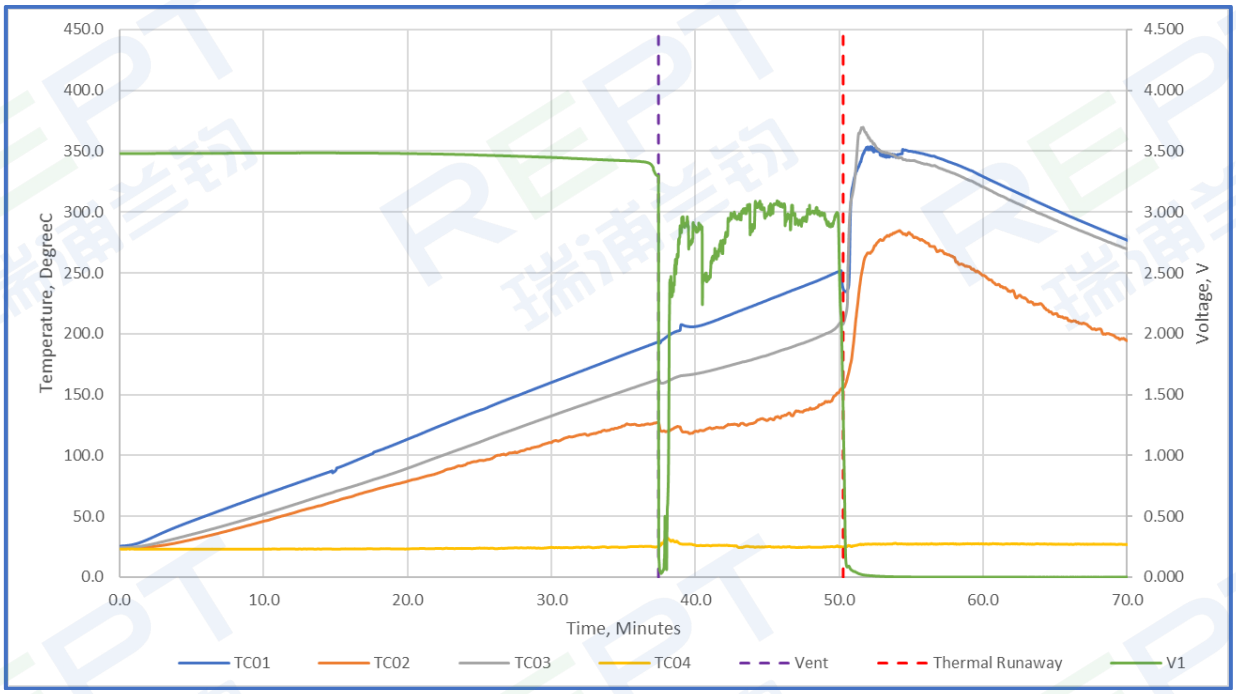


Figure 7: Cell 1 – External Heating 4.5**°C** per minute

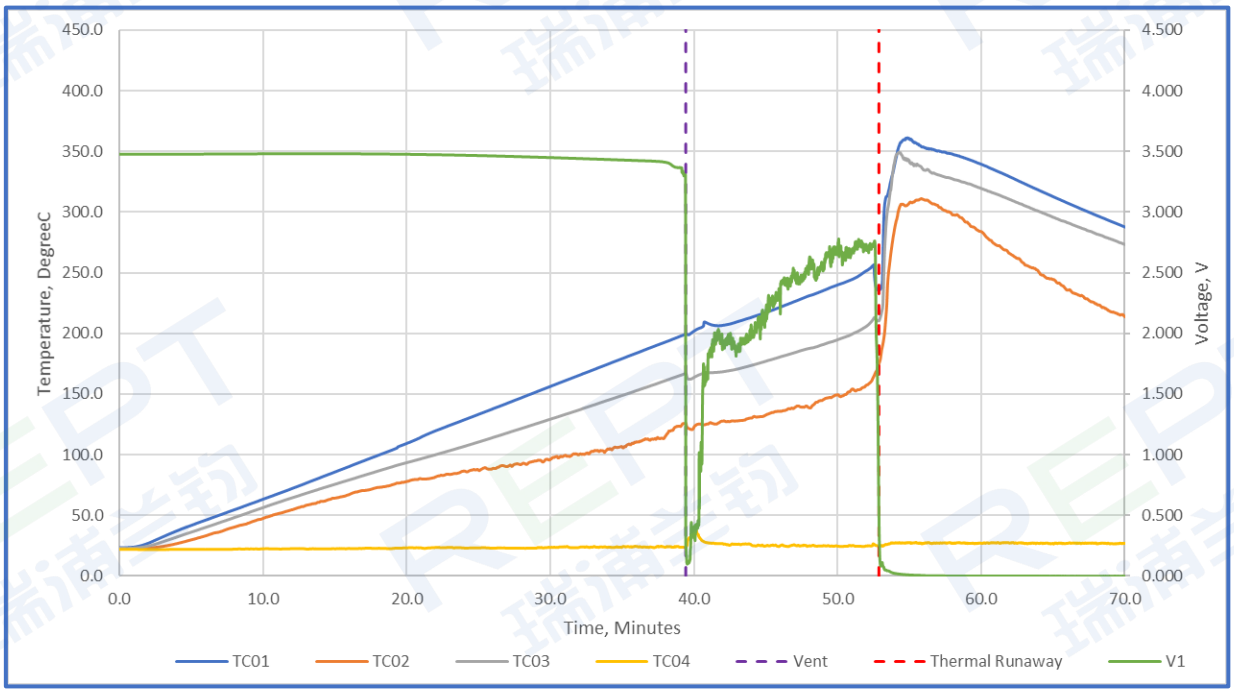


Figure 8: Cell 2 – External Heating 4.5**°C** per minute

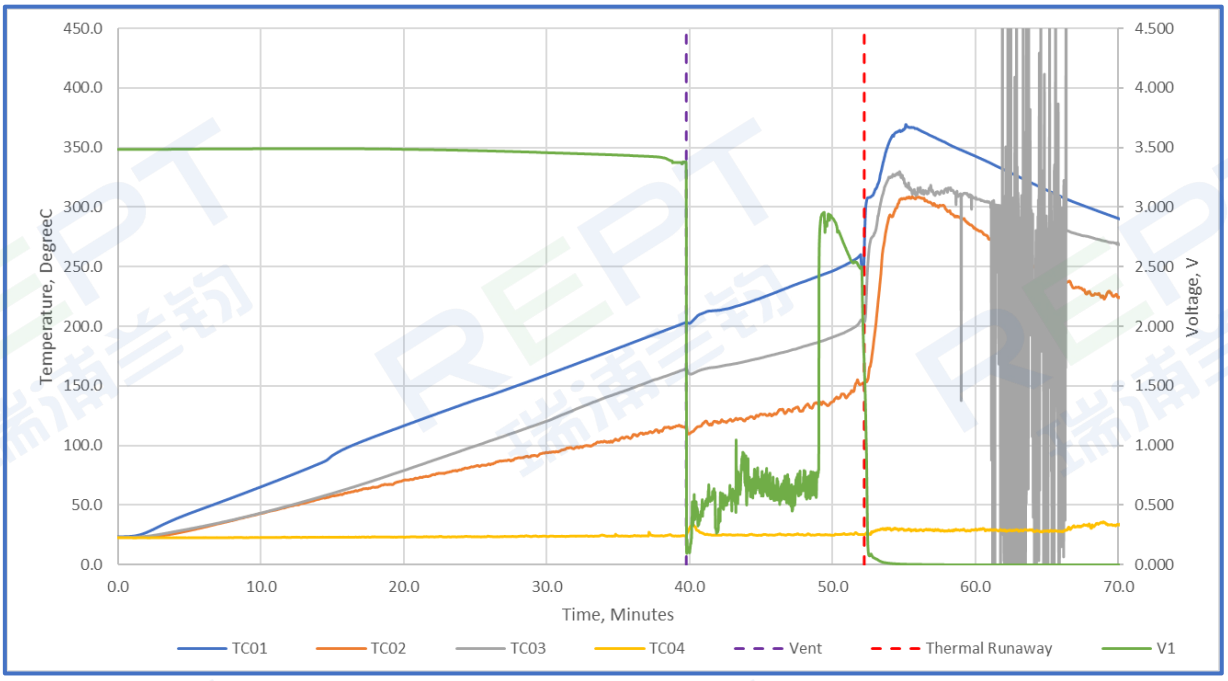


Figure 9: Cell 3 – External Heating 4.5**°C** per minute

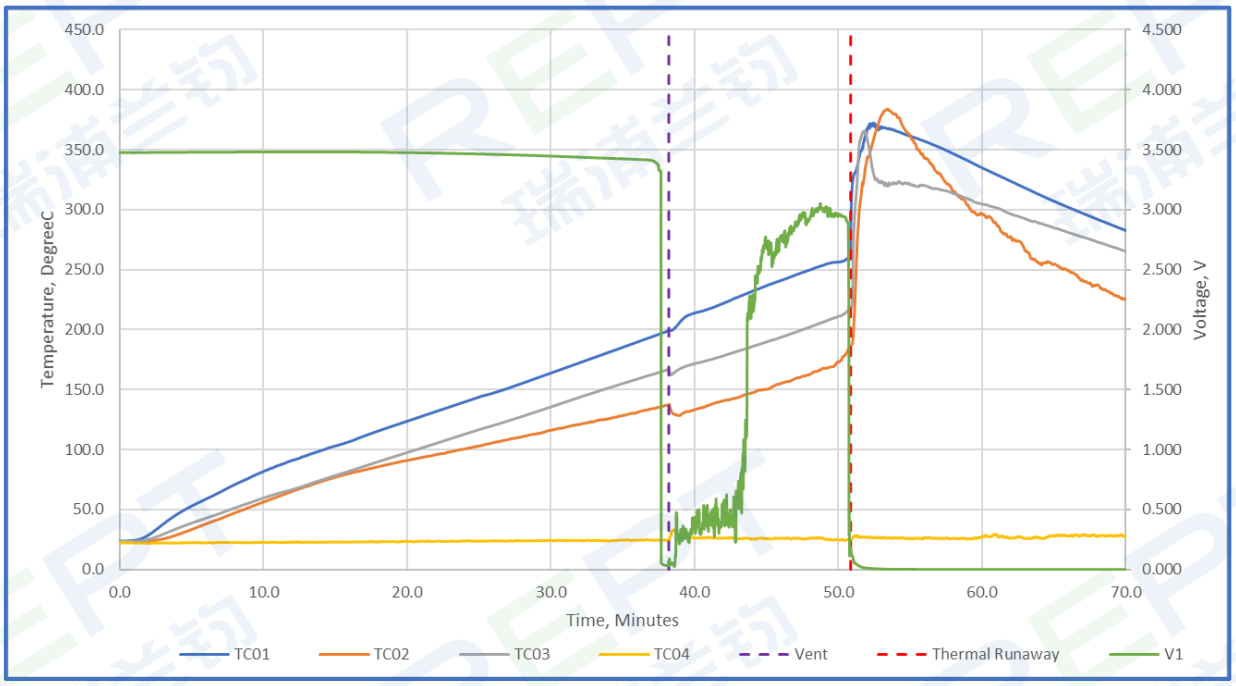


Figure 10: Cell 4 – External Heating 4.5**°C** per minute

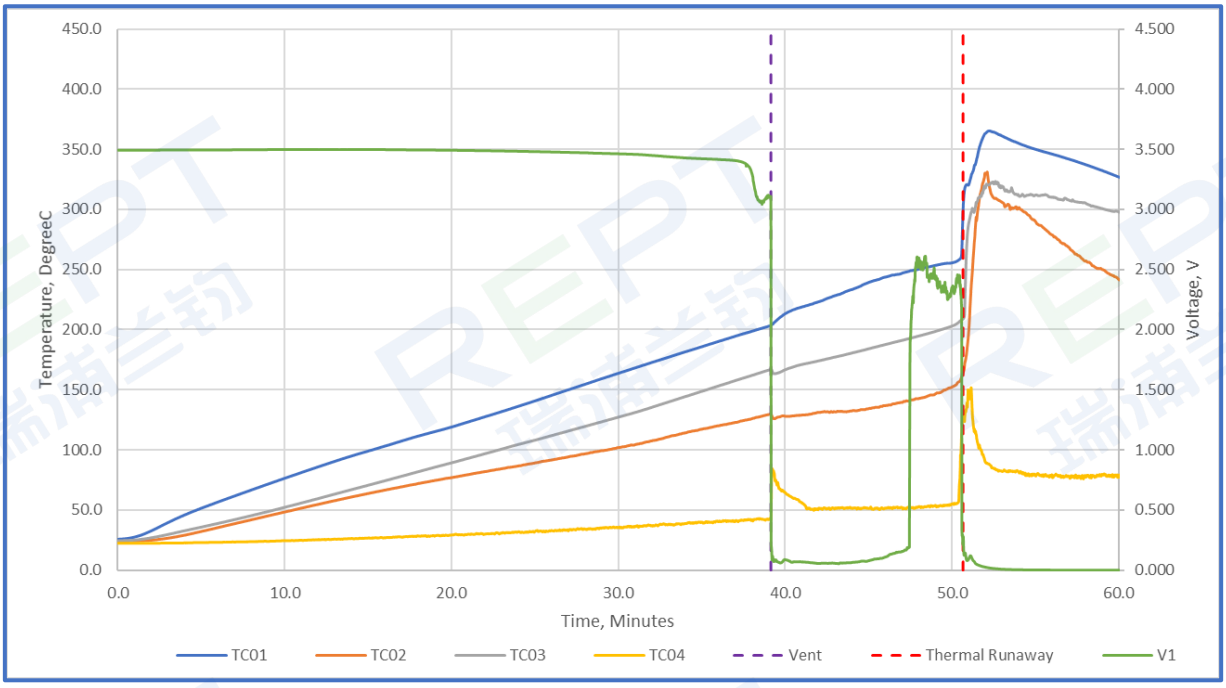


Figure 11: Cell 5 – External Heating 4.5**°C** per minute

Attachment D: Cell Testing Photos - (*Pages **24** 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.



(a) Test Start
[00:00]



(b) Cell Venting
[37:26]



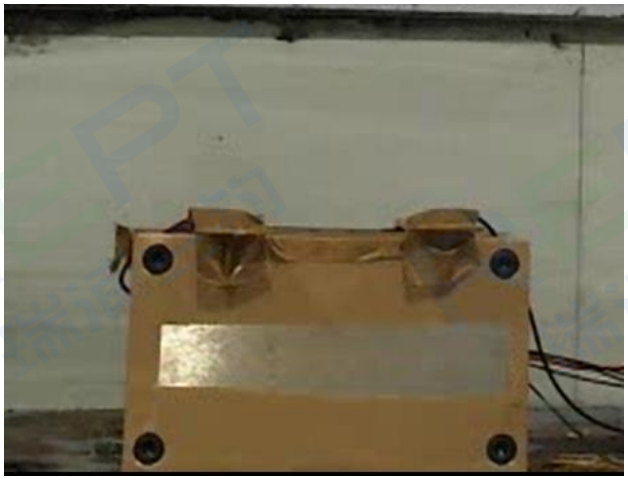
(c) Thermal runaway behavior
[50:16]

Figure 12: Highlights of Cell 1 Testing

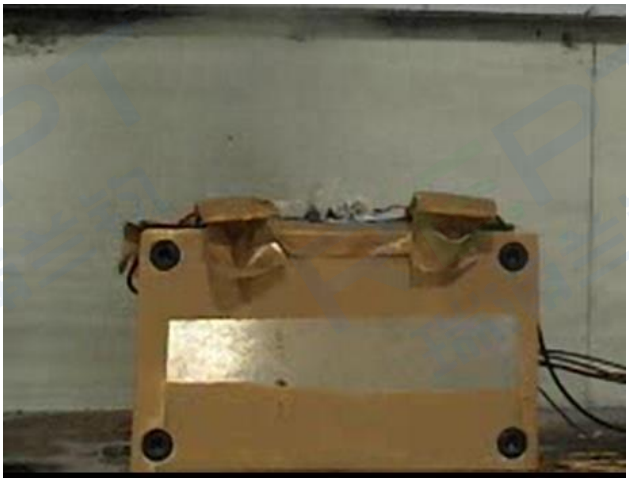


Figure 13: Sample 1 Post Test Photos

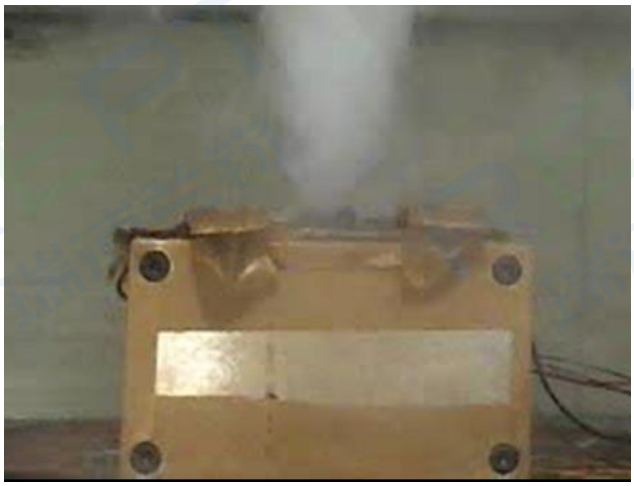
Cell Sample 2 – below figure shows highlights of cell testing. Cell venting and thermal runaway were observed, however no evidence of fire. Figure on next page shows photos of cell after testing.



(a) Test Start
[00:00]



(b) Cell Venting
[39:26]



(c) Thermal runaway behavior
[52:53]

Figure 14: Highlights of Cell 2 Testing

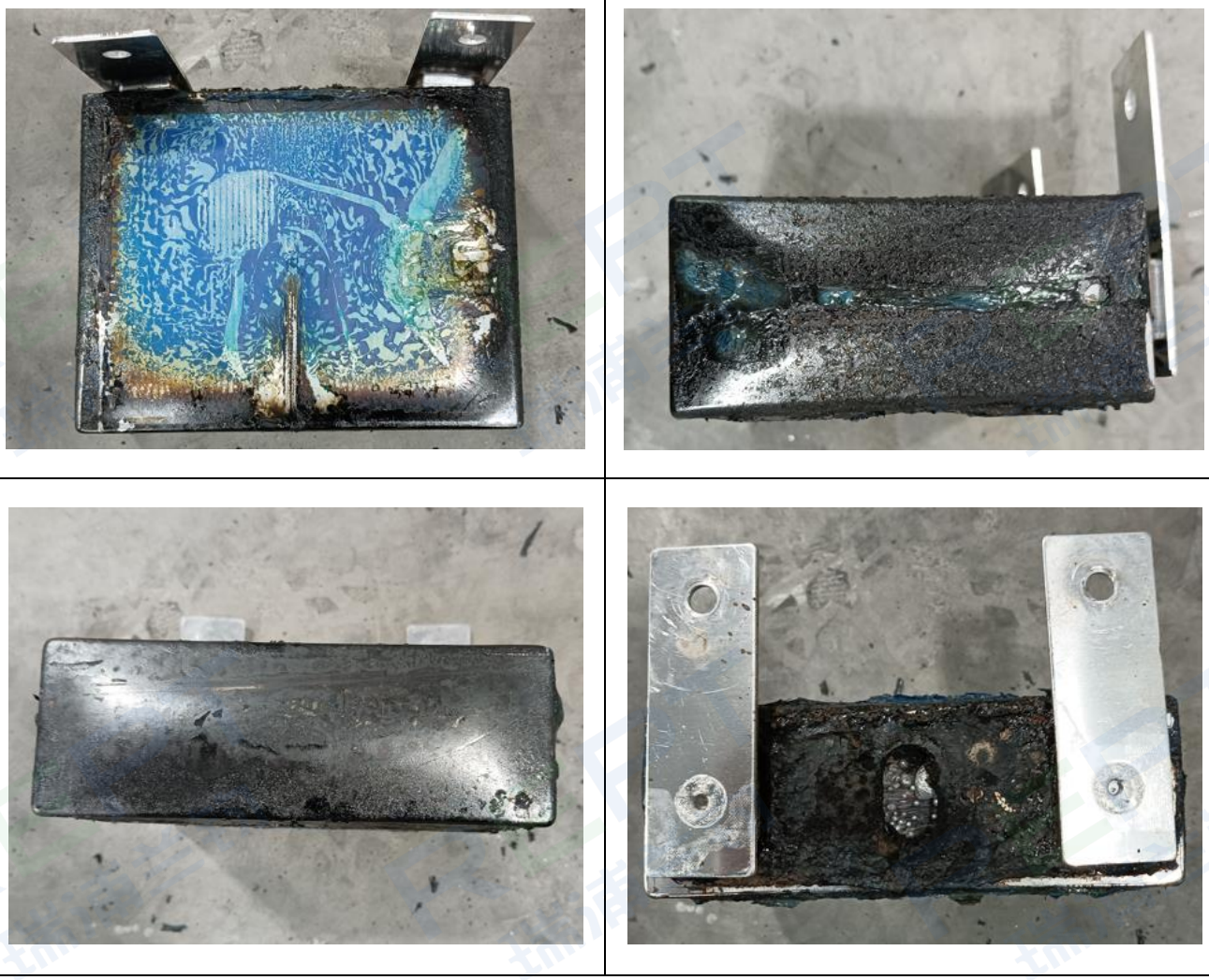
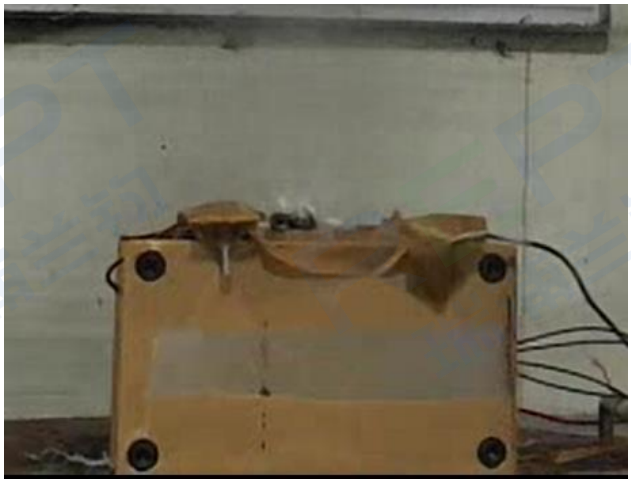
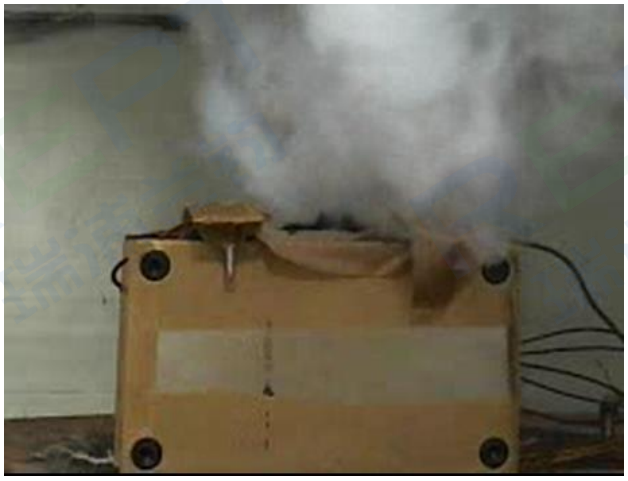


Figure 15: Sample 2 Post Test Photos

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
[39:46]</td></tr>
<tr><td></td><td></td></tr>
<tr><td>(c) Thermal runaway behavior
[52:13]</td><td></td></tr>
<tr><td colspan="2">Figure 16: Highlights of Cell 3 Testing</td></tr>
</table>

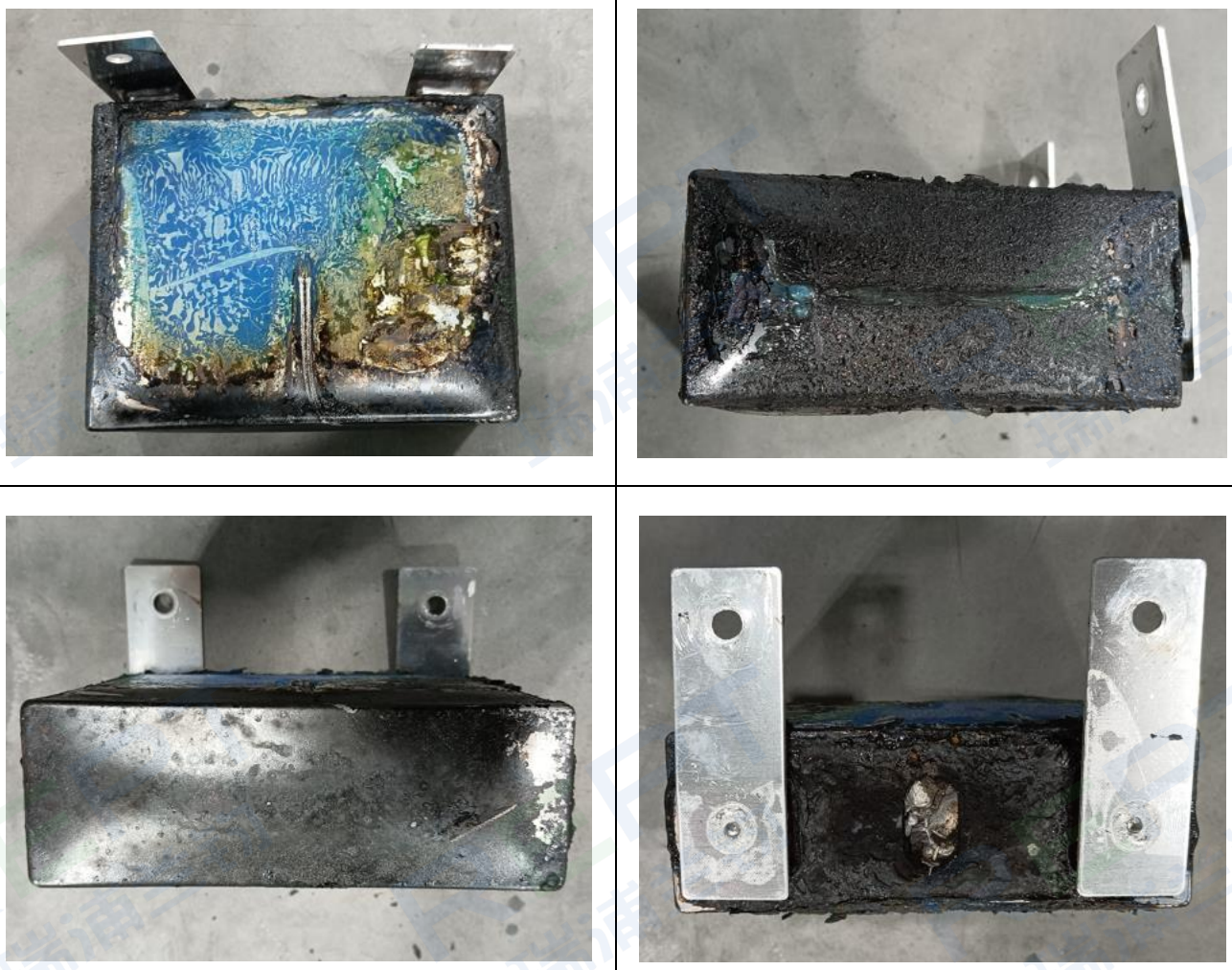


Figure 17: Sample 3 Post Test Photos

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.



(a) Test Start
[00:00]



(b) Cell Venting
[38:13]



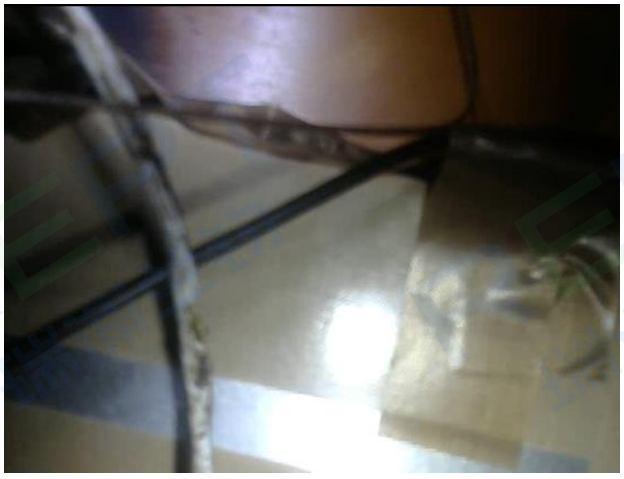
(c) Thermal runaway behavior
[50:52]

Figure 18: Highlights of Cell 4 Testing



Figure 19: Sample 4 Post Test Photos

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



(a) Test Start
[00:00]



(b) Cell Venting
[39:09]



(c) Thermal runaway behavior
[50:40]

Figure 20: Highlights of Cell 5 Testing

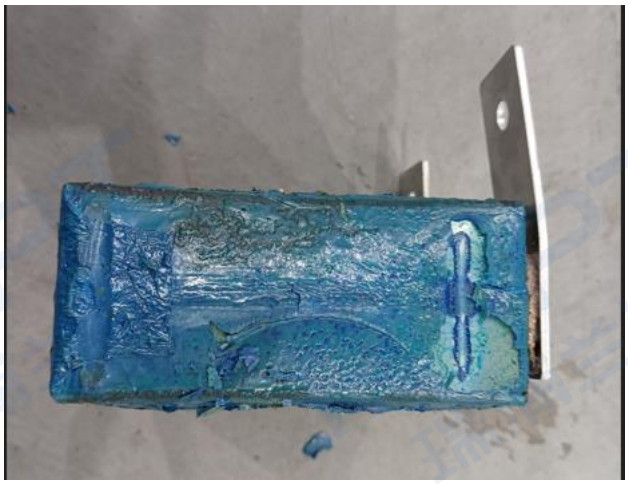
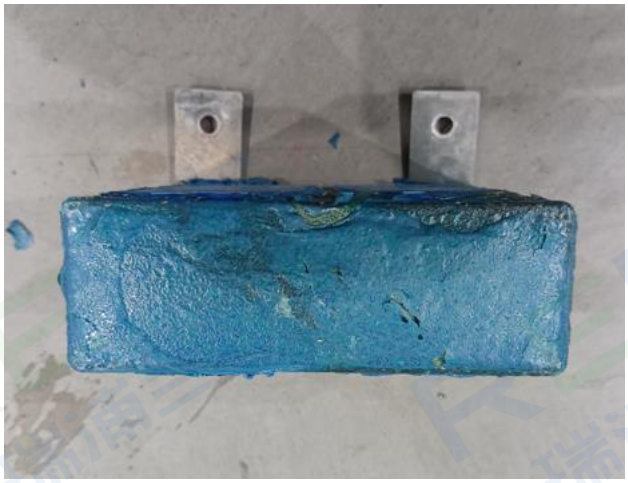





Figure 21: Sample 5 Post Test Photos

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 70 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 0.12%, with initial pressure 0.09 psig).

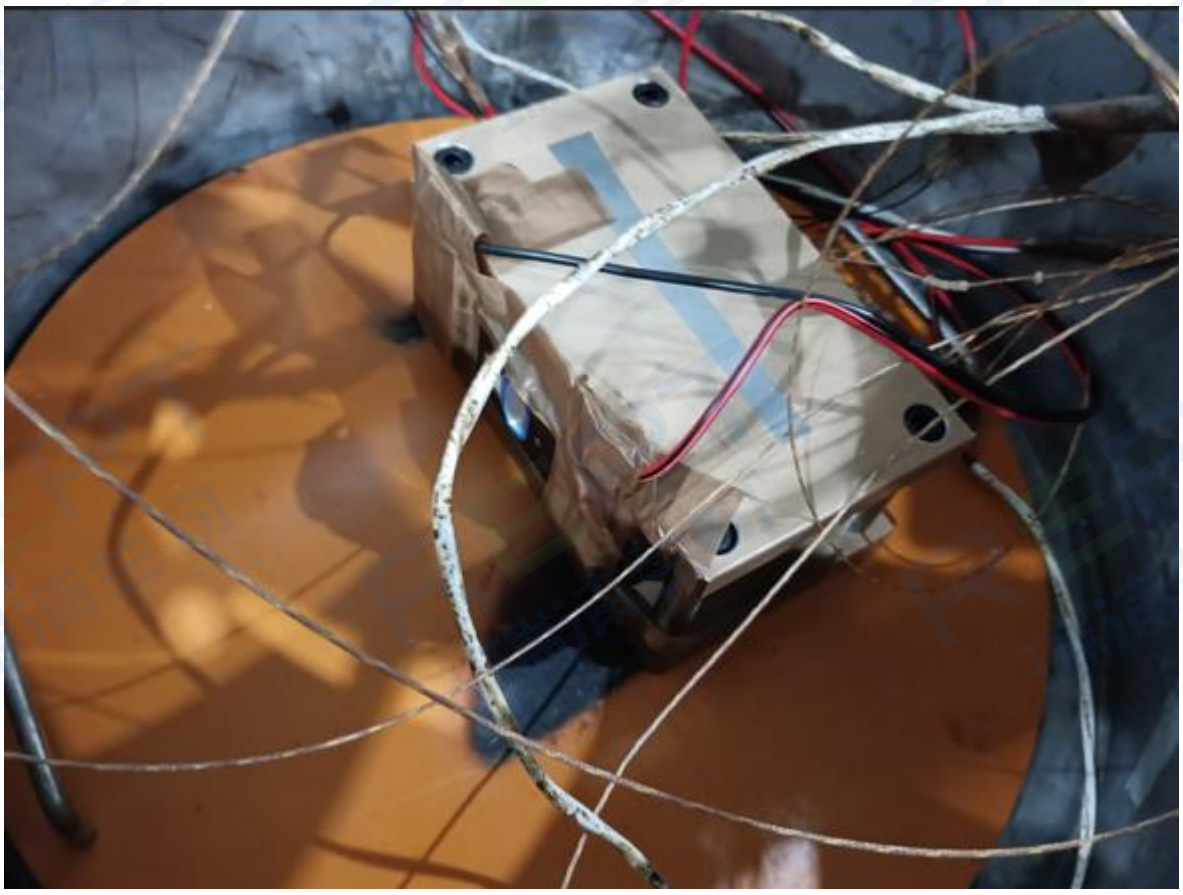


Figure 22: Sample 5 instrumented and inside gas test chamber

$\phi_{O2,\ chamber}$=	0.12	%	Pinitial,chamber=	0.09	psig

Figure 23: Profile of gas test chamber (O2 and Pressure)

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

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

Item	Measure	Chemical formula	Conc.(%)
1	Carbon Monoxide	CO	9.302
2	Carbon Dioxide	CO_2	24.429
3	Hydrogen	H_2	57.227
4	Methane	CH_4	4.576
5	Ethylene	C_2H_4	2.699
6	Acetylene	C_2H_2	0.164
7	Ethane	C_2H_6	0.858
8	Propane	$CH_3CH_2CH_3$	0.081
9	Propylene	C_3H_6	0.264
10	Propadiene (Allene)	C_3H_4	0.000
11	Isobutane	$CH_3CH(CH_3)CH_3$	0.004
12	Butane	C_4H_{10}	0.025
13	Isobutylene	C_4H_8	0.081
14	1-Butene	C_4H_8	0.023
15	trans-2-Butene	C_4H_8	0.030
16	cis-2-Butene	C_4H_8	0.023
17	Pentane	C_5H_{12}	0.020
18	trans-2-Pentene	C_5H_{10}	0.003
19	cis-2-Pentene	C_5H_{10}	0.001
20	1,4-Pentadiene	C_5H_8	0.000
21	Hexane	C_6H_{14}	0.001
22	1-Hexene	C_6H_{12}	0.006
23	Benzene	C_6H_6	0.004
24	1-Heptene	C_7H_{14}	0.000
25	Toluene	C_7H_8	0.001
26	Styrene	C_8H_8	0.000
27	Dimethyl Carbonate	$C_3H_6O_3$	0.148
28	Ethyl Methyl Carbonate	$C_4H_8O_3$	0.029
29	Diethyl Carbonate	$C_5H_{10}O_3$	0.000
	Total	Measurement result	100.000

Figure 24: Gas composition analysis result