UN Informal Meeting on Lithium Batteries – 2019-2020

7-9 October 2019– Arlington, Texas

Day 1 – 7 October 2019

Introduction

1. Claude Pfauvadel (France) and Robby Kinsala (Fulcrum Labs) welcomed participants to the latest session of the Informal Working Group on Lithium Batteries (IWG) and presented the tentative agenda for the meeting. The Chairman explained the purpose of the meeting was to share test results from cell/battery testing conducted by various laboratories. Once the tests results have been shared, the group discussed common observations and considered if any changes were needed be made to the current test conditions.
2. Concept proposals and test data presented at the meeting are available from the RECHARGE Website
3. In addition, all historical documents related to the current Informal Working Group are also posted on the RECHARGE Website.

Presentation of Test Results

4. All laboratories utilized identical cylindrical and pouch cells that originated from the same manufacturers and same lots.
    a) Capacities
        i. Cylindrical – 2.45 Ah/3.7V
        ii. Pouch - 4.8 Ah/3.7V

Test Lab 1 Test Results

5. The following observations were noted:
6. Cylindrical tests
    a. The cells were placed in the fiber cement box surrounded by kaowool.
    b. Using the test method, all cells propagated once the initiation cell entered thermal runaway.
    c. Trigger cell venting and voltage drop occurred at 120 ^{o}C. Trigger cell entered thermal runaway at 174 ^{o}C.
    d. Thermal camera indicated that the 3rd cell was not significantly impacted by heating of the initiation cell. Temperature of 3rd cell was less than 50 ^{o}C before TR in initiation cell.
    e. Test Lab 1 analyzed the gas in a normal oxygen atmosphere.
    f. They also measured the amount of energy released. Maximum amount released during any one recorded thermal event was 4.5 MJ.
    g. Similar propagation times were observed across the 3 tests.
    h. Heating of the initiation cell appeared to heat up the 2nd cell in Test 2. The two cell thermocouples provided different information; the thermocouple furthest from the trigger cell was utilized to determine internal temperature of the witness cell.
7. Pouch Cells

    a. Test Lab 1 increased the heater to 200 ^{o}C and maintained it at 200 ^{o}C for 1 hour before continuing to increase the heat until the trigger cell entered thermal runaway.
    b. Cells 2-6s were affected by heating of the initiation cell, and that may have created thermal instability with all test cells before thermal reaction occurred in the initiation cell.
    c. All cells entered thermal runaway within 30 seconds of initiation of thermal runaway of the trigger cell.
    d. Test Lab 1 analyzed the gas in a normal oxygen atmosphere.
    e. Gas and total energy were measured in the tests.
    f. The onset temperature was approximately 200 ^{o}C.
    g. Results of all three tests were similar.

Test Lab 2 Test Results

8. Test Lab 2 used the same testing design as Test Lab 1 including use of the kaowool as insulation.
9. Pouch Cells
    a. Test Lab 2 heated the trigger cell at rate close to the prescribed 20 ^{o}C. They also observed that the pouch cells propagated very quickly (within 30 sec).
    b. Onset temperature of Cell 1 was at 161 ^{o}C.
10. Cylindrical Cells
    a. Max temperature reached in the reactions was 985 ^{o}C.
    b. Onset temperature of other cells was much lower (as low as 60 ^{o}C). This may be due to location of the thermocouples and not representative of the actual internal temperature of the witness cell.
11. Both tests were conducted in a G-27 test chamber. The volume of smoke limited the visual observation of the tests and results.
12. The pouch cells appear to be damaged by fire from the first cell whereas on the cylindrical cells, the fire did less to damage the other cells. Instead the heat transfer led to heating of the other cylindrical cells.

Test Lab 3 Test Results

13. Cells were surrounded by fire bricks. Kaowool pad was placed next to Cell 6 for compression of cells. Kaowool did not surround all cells.
14. Heater was attached with a thin adhesive strip. thermocouples were placed both outside and inside inner sleeves to see if there was a difference. They also used different kinds of thermocouples.
15. Cylindrical Cells
    a. Test 1: All cells propagated. Total propagation time was approximately 5 minutes. Cell 4 ejected the contents, but sufficient heat had already transferred to Cell 5 to lead to thermal runaway.
    b. Test 2: Core of trigger cell ejected, and it led to no propagation. Heating was the same. Thus, ejection of the core prevented sufficient heat from transferring to Cell 2 or 3.

16. Pouch Cells
    a. The pouch cells all propagated very quickly (5 to 7 seconds between cell propagation) of Cell 1 initiating. Damaged to sides of the pouches suggests heat transfer through the sidewalls of the pouch cells is very significant.

Test Lab 4 Results

17. Test Lab 4 placed the cells in a composite box with lid and no kaowool. The thermal insulation properties of the composite material were not known. The rest of the setup with thermocouples and heater strips were similar to other test labs.
18. Cylindrical cells
    a. Heat rate of 17 ^{o}C /min was used.
    b. Test 1 proceeded with propagation across all cells.
    c. However, Test 2 Cell 1 initiated, but the rest of the cells did not propagate. The maximum exterior temperature of Cell 2 was in excess of 200 ^{o}C but no thermal event occurred. It is unclear why the cells in Test 2 did not propagate. The spike in temperature may be the thermocouple picking up the heat from Cell 1 venting. It was also noted that space between cells could result during venting or thermal event. This space could dissipate the heat and reduce the transfer between cells.
19. Pouch cells
    a. Propagation of cells proceeded as in other tests.
    b. Heat rate was slower (7 ^{o}C /min) but multiple heater strips were used.

Test Lab 5

20. Test Lab 5 used rigid kaowool board as the containment on 5 sides and a wooden top was placed over the box.
21. Cylindrical cells
    a. All 3 trials showed propagation of all cells.
    b. In Trial 1 and Trial 3, Cell 1 experienced an internal short circuit that possibly added to heat.
    c. Heating rate was approximately 20 ^{o}C /min.
    d. Mass loss was also calculated. Cell 1 results showed large mass loss, possibly due to a more complete thermal event.
22. Pouch cells
    a. Steel container with rigid kaowool board lining was used.
    b. All cells propagated very quickly and completely.
    c. Mass loss trend was the same as for the cylindrical cells.
23. Gas Data
    a. Gas analysis was also done to evaluate certain gas productions. Measurements were taken before combustion.
    b. Data is still being reviewed and will be forwarded at a later date.

Test Lab 6

24. Test Lab 6 tested the cells in a 208L capacity space.
25. Cylindrical cells

a. Cells were surrounded by rigid kaowool board.
b. Heating rate was 10 °C /min
c. All cells propagated.
d. The thermocouples on the side of the reacting cell appeared to be reacting to the temperature of the adjacent cell rather than the temperature the cell to which they are attached. This suggests that the thermocouple should be located on the opposite side of the cell from the adjacent reacting cell.
e. Trial 2 resulted in a violent destruction of the test box.

26. Pouch Cells
    a. Cells were surrounded by rigid kaowool board but then placed in a steel casing to keep cells together.
    b. Heating rate was 5 °C /min.
    c. All cells propagated completely.
    d. The difference in the 2 trials may have been due to compaction. Trial 2 did not propagate as fast from cell to cell.
27. Test Lab 6 conducted additional tests on single cells using different heating rates and measuring gas production.
    a. Gas measurements were taken after combustion. Therefore, the gas analysis can be compared between Test Lab 1 and Test Lab 5.

Early Conclusions

27. Heating rate of Cell 1 (trigger cell) has an impact on its propagation time. Higher heating rates seem to reduce "preheating" of other cells. Also, power of heating pad must be increased to have a consistent heating rate.
28. Ejection of core on trigger cell can lead to insufficient heat for test to complete. Prevention of core ejection (mechanical) may be necessary, or state that core ejection of trigger cell requires a retest.
29. All data will need to be consolidated and compared. When comparing data, times/temperature/voltage scales must be kept the same.
30. Test methods need to be clearly defined to be reproducible.

End of Day 1

Day 2 – 8 October 2019

Test Lab 7 Test Results

31. Cylindrical cells
    a. Steel plates were used instead of rigid kaowool sides. No cover was used.
    b. All cells propagated in both trials.
    c. Mass loss across cells were generally 33%
    d. Cell propagation ranged from 5 to 60 seconds.
32. Pouch cells
    a. Propagation of cells occurred within 5 seconds of each other.
    b. All cells propagated in both trials.
    c. Mass loss for pouch cells was approximately 40%.

    d. The max temperature was reported at 1300 ^{o}C. But it was discussed that contact with flame will spike the temperature. In general, the non-flame temperatures measured were approximately 950 ^{o}C.

33. Additional suggestions on results
    a. Large and small cells should be considered
        i. Change number of samples
        ii. Change heating power
    b. SOC should vary
    c. Constant power heater is better

Preliminary Review of Data

34. RECHARGE tabulated the data provided and a few observations were made.
35. The tests were run with the expectation that ALL cells would propagate.
    a. For pouch cells, the propagation time between cells was approximately 5 seconds across all cells tested. Only a few exceptions were observed. The onset temperature appeared to be 180 ^{o}C but there was variability in the data set.
    b. For cylindrical cells, the propagation time was less consistent. Many cells experienced thermal runaway after 2-5 min but others were quicker or slower. This suggests the testing protocols may need to be further refined.
        i. Observations of the cells after the tests may identify if the heat transfer occurs due to direct contact or through jet flame (failure of the can and jet flame from the side of the cell).
        ii. Cell propagation rates were widely varied between tests. Some labs experienced longer propagation times for cells 4-6 while others observed shorter times.
        iii. It is difficult to tell whether propagation times were impacted by heating rates. Additional analysis of the data is required.
    c. Additional data would be valuable from laboratories.
    d. Some laboratories covered the cells during the tests, where others left the cells uncovered. The cover may prevent ejection of the core or retain heat but may also impact other aspects of testing. Different compression and insulation materials were used but appeared to lead to globally the same result in this round of tests (except potentially larger variations in propagation time of cylindrical cells). It is unclear whether these changes would impact tests for different chemistries and SOCs.
    e. Compression of the cells is also important. Gaps between cells may lead to a loss of heat transfer cell to cell and result in a less aggressive test. The test method may need to specify cell compression.
    f. Thermocouples were attached in different manners and the laboratories reported external temperatures during the tests. The average maximum temperature was 834 C. The group discussed whether this could be used to calculate total heat of combustion of the reaction.
    g. But it was also noted the onset temperatures were measured on the external surface of the cells and may not fully represent the internal temperature of the cells at initiation of thermal runaway.

36. The group discussed whether the test could be modified to reduce the number of cells tested. The test results have been relatively consistent. Although reducing the number of cells in the method (6 cells) is a possibility, it may be more appropriate to reduce the number of tests. No conclusions were made. Therefore, the next round of tests should be conducted using the same number of cells as in previous tests.

Thermal Propagation Test

37. LG provided a presentation discussing the thermal propagation test and possible methods for heating the trigger cell for test initiation. Two sets of pouch cells were tested.
    a. First, lower density pouch cells were tested at 100 %, 50% and 30% SOC. The result was that all cells entered thermal runaway at 100% and 50%, but the cells at 50% SOC took longer. However, at 30%, only the first two cells experience a thermal event. The witness cell swelled due to off gassing, but no venting or fire resulted.
    b. The same tests were conducted on higher density pouch cells. Similar results were observed for the higher density cells than the lower density cells. The reaction time for cells at 50% was lower than the cells at 100% SOC. And for cells at 30% SOC, the witness cell did not experience a thermal event.
    c. They concluded:
        i. That SOC should be tested based on real world conditions, not always at 100%.
        ii. Initiation method must not affect witness cell.
        iii. Increasing the number of cells from 3 to 5 may result in a different result at 50% SOC for pouch cells.
38. The IWG discussed consideration of conducting the test in a closed containment vs. an open containment as heat release may affect heat transfer to other cells. Orientation of the cells was also discussed. The group concluded it is valid to consider transport conditions, but the test methods are not expected to simulate exact transport conditions. Thus, the test methodology could be refined to limit variability in test methods to those that are more likely to simulate conditions in transport (closed container, less than 100% SOC, etc.).
39. Other data is also available from G-27 testing. Participants in the IWG were invited to share those results with the rest of the group.

Toyota Presentation on Assessment of Batteries

40. Toyota presented initial ideas of how to transfer the testing of cells to the testing of batteries. Cell propagation outside of a battery does not necessarily equate to cell propagation within a battery, module or battery assembly because heat transfer mechanisms within the battery may preclude damage or high heat transfer to adjacent cells or adjacent modules.
    a. To open discussion on this issue, they proposed adding definitions to the discussion:
        i. Propagation of a cell
        ii. Propagation in a battery
        iii. Propagation of a battery
    b. These definitions would be considered as part of the classification and testing scheme.

c. They suggested that batteries composed of cells that do not propagate may be considered as to not propagate. Therefore, it may be that such a battery would not require additional testing. If a battery is composed of cells that propagate, then additional battery testing would be required and would be the basis of battery classification.
d. They proposed modification of the existing flowchart to include the battery classification idea. Classification could also be given for similar design/type without retesting. Initiation of the battery testing is not clear as to whether it should be the same as cell initiation or something different.
e. "Similar battery" is introduced. Similar batteries are ones using the same cells, parts and the same method of connection such as series and/or parallel and using the different number of the cell and parts. The test result could be referred to a similar battery because outcome is assumed to be equivalent between similar batteries.

41. The IWG considered whether SOC would need to be considered as part of the classification testing. The Chairman noted that while SOC is important in the development of the tests for classification, SOC cannot be guaranteed to remain the same during transport. Stated another way, if a battery is tested and classified at 30% SOC, one cannot assume the battery will only be transported at 30% during the life of the battery. Thus, SOC during testing can provide insight to as to how reactive the cells and batteries are, but SOC could only be considered as a condition of transport, not a condition of classification.
42. Some participants opined that the larger the battery, the larger the potential gas hazard. While the current flow chart addresses gas hazard for cells that do not propagate, the group noted that gas hazards associated with batteries with cells that do not propagate need to be considered. It may be that the eventual transportation conditions or classification may be impacted by the number of cells in the battery. Provisions or conditions by mode may also be based on number of cells contained in a battery.
43. Others voiced concern that just because a cell does not propagate, that does not mean that a battery composed of non-propagating cells will not propagate. Cell to cell connections within a battery may transfer heat more effectively. Thus, it may be that some level of battery testing is required even for batteries composed of non-propagating cells.
44. The discussion led to consideration of how a cell fire can be assessed and whether the issue is the volume of flammable gases is less of a concern as that of toxic gases. The group may need to consider toxic or flammable gas hazards if the production of vented gas reaches certain quantity thresholds. In the air mode, it was suggested that gas production that leads to a flammable atmosphere is more of a concern than production of toxic gases.
45. Participants also discussed the apparent level of danger identified in the flowchart "exits". The group confirmed that no inference can be taken yet regarding the answers out of the flowchart. The flowchart, at this point, is only to categorize hazards. Future work would be needed to refine the flowchart to provide a logical progression from low hazard/risk to high hazard/risk.

France/RECHARGE presentation of Assessment of Batteries

46. France and RECHARGE suggested modifications to the flow chart to introduce a bonfire test, replacing when a cell does not initiate, as determining the total energy of combustion. A bonfire test would also be used when cells/batteries experience rapid disassembly and

additional parameters cannot be properly measured. Again, the total energy of combustion may be measured. "Rate of heat release" may also be considered a key measurement. The bonfire test would be considered as a "worst case" situation. The total power could then be used to determine relative danger. Concerns were voiced about the bonfire test and the need to clarify how the data from the bonfire test would be used.

47. As in previous discussions, the presentation mentions gas hazard and further defines gas hazard as emitting flammable, toxic, non-flammable or non-toxic gases. But it remains to be decided how the measurement is made for gas hazard and what concentration/volume would be trigger levels for flammability and toxicity.

End of Day 2

Day 3 – 9 October 2019

Next Round of testing

48. The IWG discussed what changes might be needed for the next round of tests.
    a. Generally, the test results were consistent between laboratories even though there were some differences in the methods. However, only Test Series 1 was completed in the first round. It is possible to refine the test method before conducting the next round of tests.
    b. Heating rate does not appear to significantly impact the test results. Rates of 5-20 ^{o}C all led to reactions of the cells. Therefore, heating rate may continue to have some variability (in the range noted above).
    c. Regarding state of charge, the objective is to study how reproducible the results of the tests are when the cells are at a lower state of charge (for example, 30%). It was noted that there will inherently be significant variability between cells at the lower SOC. Tests would capture specific cell responses versus reproducibility of the test method. Although the 30% SOC would be valuable data, it may be more important to examine gas emissions before conducting lower SOC tests.
    d. Several participants felt that it would be important for the laboratories to continue testing the original cells at 30% and perhaps at 20% 40% or 50% SOC, paying particular attention to the previously collected parameters but also taking a close note to how many cells propagated in the stack. But others noted that the intention of the test development was to test cells under conditions that will lead to propagation (Test Series 1) and conditions where normally propagating cells are not likely to propagate (expected 30% SOC, Test Series 2), and then assess whether the test results from different laboratories were reproducible.
49. Participants considered varying the cell size and chemistry for the next round of testing. For cell testing the key parameters that should be collected would be
        i. Type of cell (prismatic, pouch, cylindrical, etc.)
        ii. General Chemistry (lithium manganese, lithium cobalt, etc.)
        iii. Use of cell (automotive application, consumer electronics, etc.)
    b. Laboratories may conduct testing on their own cells, acknowledging there will be significant variability from other test rests. Each lab would need to repeat the test 3

times because each laboratory would be collecting all the data for that particular cell (other laboratories would hypothetically be using different cells).

50. After significant discussion, the IWG concluded the next round of testing would be:
    a. Conducted with the same cells used in Round 1.
    b. The test should be enclosed on all sides but the shroud/cover should NOT be airtight. Gaps in the cover should not exceed 2-4 mm in thickness. However, if a laboratory would like to also test cells outside of a box (closed cover), the laboratory may do this test in addition to the proposed test.
    c. Cells must be properly compressed to maintain contact between the sides of the cells.
    d. Based on the original Test Series 2, heating rate should vary (3 different rates). But it is recognized that laboratories may not be able to vary heating rate. Therefore, heating of trigger cell should remain at 20 ^{o}C/min, but variations due to differences in heating pads/mechanisms between 5-20 ^{o}C/min are acceptable.
    e. Rigid thermal insulation should be consistent in all tests at all laboratories.
    f. State of Charge is intended to be at 20% and 50%. However, preliminary testing may be necessary to determine if 20% or 30% is appropriate.
    g. Details of the test parameters that need to be specified will be further discussed by laboratories in separate technical group (via telephone).
    h. The laboratories will conduct 8 tests:
        i. 2 tests using cylindrical cells at 20% SOC
        ii. 2 tests using cylindrical cells at 50% SOC
        iii. 2 tests using pouch cells at 20 % SOC
        iv. 2 test using pouch cells at 50% SOC
        v. Key parameters to monitor
            1. Heating rate
            2. Time of propagation from each cell
            3. Number of witness cells (cells 3-6) that experience thermal event
            4. Gases emitted (if laboratory is able to collect).
            5. Temperature of cells during the test.
            6. Other data needed to complete data spreadsheet.
    i. Laboratories may test additional cell types at their discretion. Additional data would be reviewed on the final day of the next meeting.
    j. All tests must be completed by mid-April 2020. Data should be submitted to RECHARGE by 30 April 2020 to be presented at the next meeting in May 2020.

Schedule of next meetings

51. The following timeline is suggested for future actions:
    a. 30 October 2019 - Laboratory technical group will conduct a telephone conversation to finalize the details of testing specifications. Exact date to be determined at a later date.
    b. Mid-April 2020 - Laboratories complete testing.
    c. 30 April 2020 – Deadline for data submission to RECHARGE for tabulation.
    d. May 18-20, 2020 – To be held in Europe (France or Belgium)

Outstanding points/Action Items

52. The group should consider whether:
    e. The test is reproducible?
        i. Is there variability in the methods used that impact results?
        ii. Is there any data that does not conform to expected outcome? What can be done to limit exceptions (e.g. ejection of core prevented heat transfer to continue test)?
    f. Does test prejudice the results to failure/success?
    g. Is this test discriminating enough or does it need more granularity?
        iii. Different states of charge (SOC) still needs to be considered.
        iv. Testing could demonstrate that lower state of charge affects propagation.
        v. .
    h. What additional improvements can be made to the test method?
        vi. Cover or no cover
        vii. Kaowool or no kaowool
        viii. Does the outer "casing" need to be defined?
    i. Is test appropriate for different battery chemistries?
    j. How should additional hazards be addressed?
    k. What impact does this have for modal transport?
53. Next steps would be:
    a. The laboratories to reconvene to discuss additional steps to refine the test methodology and review the data provided. A new test plan will be finalized during a telephone call with laboratories. Call to be conducted on 30 October 2019.
    b. Laboratories were encouraged to conduct additional testing on other cell chemistries and SOCs to share with the group.
    c. RECHARGE will also present a revised testing concept (flowchart) that includes batteries based on input from Toyota, France, INERIS and RECHARGE.
54. Progress of the work will be provided to the Subcommittee in December 2019.

Annex 1

Table of test reports *[to be supplied by RECHARGE]*

Name	Organization	Email Address
Tom Ferguson	COSTHA	tom@costha.com
Arnaud Bordes	INERIS/France	Arnaud.bordes@ineris.fr
Claude Pfauvadel	France	Claude.pfauvadel@developpment-gurable.gouv.fr.
Claude Chanson	RECHARGE/France	cchanson@rechargebatteries.org
Dick Hill	US FAA	Richard.hill@faa.gov
Michael Givens	US FAA	Michael.givens@faa.gov
Thomas Maloney	US FAA	Thomas.maloney@faa.gov
GANG JI	Medtronic	Gang.ji@medtronic.com
Masato Kamiya	Toyota	Masato_kamiya@mail.toyota.co.jp
Manabu Tsushima	Toyota	Manabu_tsushima@mail.toyota.co.jp
Katsuhiro Nakano	BAJ	Nakano.k@jp.panasonic.com
George Kerchner	PRBA	gkerchner@wileyrein.com
Amy Herrmann	Motorola Solutions	Amy.herrmann@motorolasolutions.com
Lisa Runde	Apple	lrunde@apple.com
Bob Richard	HSC	brichard@hazmatsafety.com
Todd Mackintosh	GM	Todd.mackintosh@gm.com
Stephane Rossetti	Medtronic	Stephane.rossetti@medtronic.com
Mike Wentz	American Airlines	Mike.wentz@aa.com
Bill Wojtas	United Airlines	Bill.wojtas@united.com
Kristin Cooney	Ford	Kcooney1@ford.com
Wayne Pitt	Saft	Wayne.pitt@saftbatteries.com
Katherine Rooney	ICAO	krooney@ICAO.INT
Judy Jeevarajan	UL	Judy.jeevarajan@ul.org
John Redman	Toyota Motor North America	John.redman@toyota.com
Chris Egloff	Americase	Chris.egloff@americase.com
Mike Pagel	HSC	mpagel@hazmatsafety.com
Kevin Gallatin	CDW	kevigal@cdw.com
Philippe Bermis	SAFT	Philippe.bermis@saftbatteries.com
Keith White	VCA	Keith.white@vca.gov.uk
Remko Dardenne	Belgian CAA	Remko.dardenne@mobilit.fgov.be
Michael Hoff	NEC	mhoff@neces.com
Maruisz Walkowiak	INFM (Poland)	Mariusz.walkowiak@claio.poznan.pl
Jianfeng Lu	SRICI Testing Co. LTD.	jianfenglumsds@ib3.com
Don Zhang	CATL	zhanghongb@catlbattery.com
Cho Minyoung	KBIA	mycho@k-bia.or.kr
Lee Jaeseung	LG Chem	paradiso@lgchem.com
Yun Yong Hee	Samsung SDI	Yonghee.yun@samsung.com
James Russell	Boeing	James.c.russell2@boeing.com
Robby Kinsala	Americase	Robby@americase.com
Jonna Morean	Americase	Jonna.morean@americase.com