EUROPEAN SYNCHROTRON RADIATION FACILITY

INSTALLATION EUROPEENNE DE RAYONNEMENT SYNCHROTRON

ESRF

Experiment Report Form

The double page inside this form is to be filled in by all users or groups of users who have had access to beam time for measurements at the ESRF.

Once completed, the report should be submitted electronically to the User Office via the User Portal:

https://wwws.esrf.fr/misapps/SMISWebClient/protected/welcome.do

Reports supporting requests for additional beam time

Reports can be submitted independently of new proposals – it is necessary simply to indicate the number of the report(s) supporting a new proposal on the proposal form.

The Review Committees reserve the right to reject new proposals from groups who have not reported on the use of beam time allocated previously.

Reports on experiments relating to long term projects

Proposers awarded beam time for a long term project are required to submit an interim report at the end of each year, irrespective of the number of shifts of beam time they have used.

Published papers

All users must give proper credit to ESRF staff members and proper mention to ESRF facilities which were essential for the results described in any ensuing publication. Further, they are obliged to send to the Joint ESRF/ ILL library the complete reference and the abstract of all papers appearing in print, and resulting from the use of the ESRF.

Should you wish to make more general comments on the experiment, please note them on the User Evaluation Form, and send both the Report and the Evaluation Form to the User Office.

Deadlines for submission of Experimental Reports

- 1st March for experiments carried out up until June of the previous year;
- 1st September for experiments carried out up until January of the same year.

Instructions for preparing your Report

- fill in a separate form for each project or series of measurements.
- type your report, in English.
- include the reference number of the proposal to which the report refers.
- make sure that the text, tables and figures fit into the space available.
- if your work is published or is in press, you may prefer to paste in the abstract, and add full reference details. If the abstract is in a language other than English, please include an English translation.

ESRF

Experiment title:

Understanding the causation and extent of risks associated with Li-ion battery failure

Experiment number: ME1454

Beamline: ID19

Date of experiment:
from: 26 Sept 17 to: 30 sept 17

Date of report: 8 Mar 18

Shifts: 12

Local contact(s): Alexander Rack

Received at ESRF:

Names and affiliations of applicants (* indicates experimentalists):

*Donal Finegan (US National Renewable Energy Lab)

Paul Shearing (PI) (University College London)

Report:

Lithium ion batteries are becoming increasingly energy dense, and consequently there is more heat and gas produced per unit volume upon failure than ever before. This presents an extreme challenge in mitigating the risks of thermal runaway and improving the safety of commercial cell designs. The purpose of this experiment was to link internal phenomena to external risks for a broad range of cell designs and safe matials. Thereafter, we aim to identify and resolve weaknesses in the designs of cells.

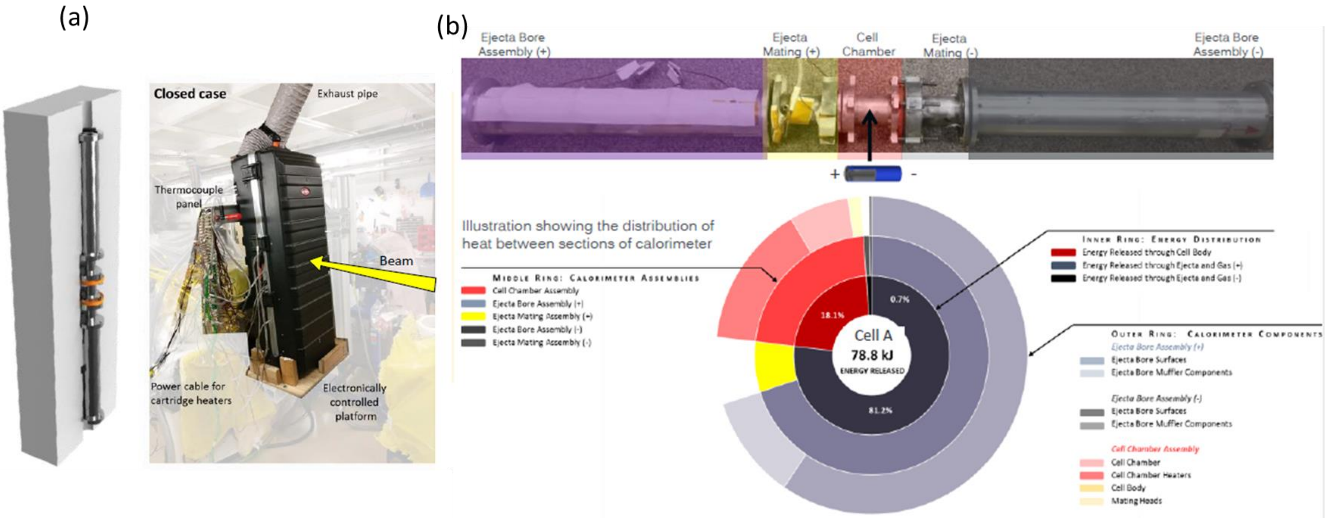

Figure 1: (a) (Right) Illustration of the in-situ calorimeter, and (left) photograph of the insulation case holding the calorimeter in ID19. (b) Distribution of heat between ejected material (Blue and yellow) and from the casing (red).

In this experiment, an in-situ calorimeter was designed to contain the blast of battery failure and measure the total heat emitted as well as the distribution of heat between ejected and non-ejected (from the cell casing) material. The calorimeter consisted of aluminium for X-ray transparancy and was encased in X-ray transparant insulation moulded inside a rigid case (Figure 1a). The ends of the calorimter were directly connected to the beamline ventilation to exhaust the smoke and fumes arising from thermal runaway of the cells.

From the calorimetry measurements we have determined that the majority of heat stems from ejected material (Figure 1b) – a previously unforeseen result, and one that is not considered in modelling and during the design of modules. We also observed that cells that incur sidewall breaches, on average, produce more heat than cells that don't.

During a sidewall breach, the steel casing melts or splits, releasing a dangerous flare (Figure 2a) that can lead to propagation of thermal runaway from cell to cell inside a module. Figure 2b shows an example of a melt-hole that formed on the header of an 18650 cell – one of many observed during our testing. This is a highly unfavourable event and one that manufactures are keen to prevent.

From the high-speed radiographs, the cause of sidewall breaches could be determined. It was found that the breaches mostly occurred where molten ejecting material deflected off a surface. For example, at the spin-groove and on the base plate of commercial 18650 cells.

The unique high-speed imaging capability of the ESRF, specifically ID19 which has a highly coherent beam, allows such clear images as seen in Figure 2b to be captured at >2000 frames per second. Since, during thermal runaway, lithium ion batteries change from being entirely intact to entirely destroyed in about 1 second, such high-speed radiography is essential to characterise the fleeting stages that lead to catestrophic failure mechanisms.

We thank the ESRF and in particular, Alexander Rack, for allowing us to use their facilities and obtain such high impact results. We expect publications to arise from this work in the near future.

(a) (b) (c)

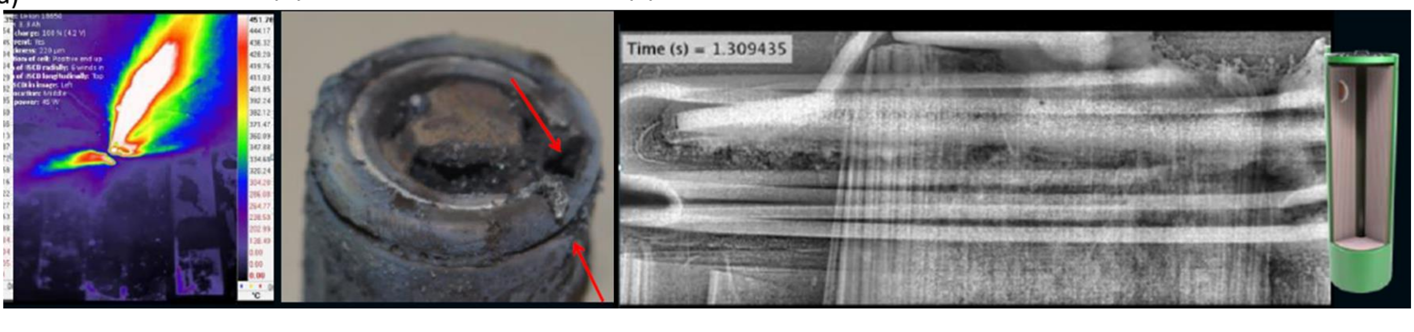

Figure 2. (a) Thermal image during a side wall breach. (b) photograph showing a breach on the header of a cell. (c) Radiograph showing the displacement of the electrode assembly in the direction of the side-wall breach.