BAM
Bundesanstalt für Materialforschung und -prüfung

Annex 2 to BAM-GGR 024

Requirements for the fire test

1.1 Test preparation

The state of charge (SoC) of a cell/module/battery has a significant influence on the result of the fire test. Therefore, the SoC of all elements of the test sample (cells/modules/battery) must be determined before the test begins.
The lowest measured SoC of a cell/module/battery specifies the maximum permissible SoC for transport. It is therefore recommended to test with the highest possible SoC. For tests carried out with at least 98 % SoC, fully charged batteries may also be transported.
The entire packaging, including cells/modules/batteries, must have a temperature of at least 0 °C at the start of the test. This must be ensured by suitable measures.
The regulation for discharged cells/modules/batteries, as described in Annex 1, also applies.
BAM reserves the right to audit the performance of the fire test.

1.2 Measurement technology

Minimum scope of the measurement technology

- Temperature measurement on the outer surface of the packaging (evaluation of the maximum temperature on the surface)
- Temperature measurement on the cells/modules/batteries (assessment of the initiation and progression of thermal runaway (TR))
- Camera technology to assess the escape of flames and splinters from the packaging and the structural integrity of the packaging following the test.

1.2.1 Temperature measurement technology for the outer surface of the packaging

- The temperature sensors must be attached to the surface of the packaging in such way that the measuring point is in direct contact with the surface for the entire duration of the test.
- A sufficient number of sensors must be provided for each side of the packaging (including the top and bottom) so that:
  - temperature sensors are installed at a maximum distance of 50 cm from each edge and
  - the temperature sensors are at a maximum distance of 100 cm from each other (see Figure 1).
- When four or more temperature sensors per side are used, temperature measuring strips (stickers) can be used for the other measuring points on this side. For validation, one of these stickers must be positioned next to a thermocouple.
  If the measuring strips show an excess of 100 °C, this is to be assessed as a failure, as this method does not provide a time-based statement.

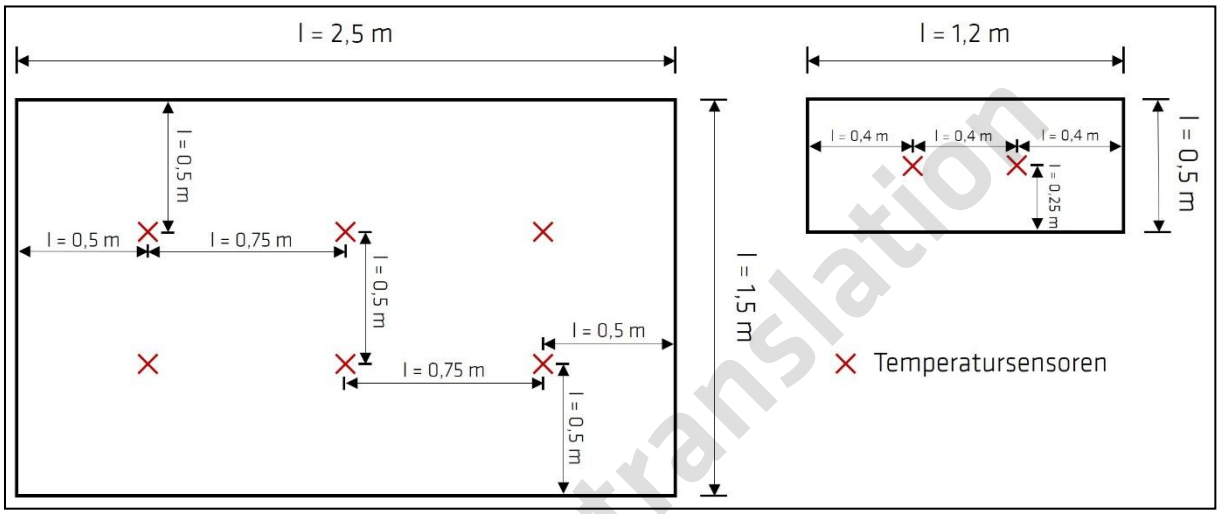

Figure1: Exemplary distribution of the temperature sensors for a side surface with the dimensions 2.5 m x 1.5 m (left) and a side surface with the dimensions 1.2 m x 0.5 m (right).

- Temperature measurements must be realised at gas outlets/valves at a maximum distance of 5 cm. Temperature measurements must also be taken at structural thermal bridges.
  No temperature measuring strips are permitted at these measuring points.
- A calibration or reference measurement must be carried out on each temperature sensor. Suitable methods are:
  - Comparison with a test standard (calibration),
  - Reference measurements at three temperature points (e.g. outside temperature, hand temperature, boiling water). The values determined in this way should be compared with a calibrated reference thermometer.

1.2.1 Temperature measurement technology on the cells/modules/batteries

The number and distribution of the temperature sensors must be selected in such a way that the propagation of the TR of the cells can be visualised based on the temperature curve.

1.2.2 Camera

- The camera must be positioned in such a way that the recording clearly documents the following points:
  - From/until when did gas leakage from the packaging occur?
  - Did this gas escape from the designated openings or from further/other openings?
  - Was there a discharge of flames?
  - Was there a discharge of splinters?
  - Was there a discharge of liquid?
  - Did other material (e.g. filling granulate) discharge?
- At least one camera must be provided, two cameras are recommended (see Figure 2).

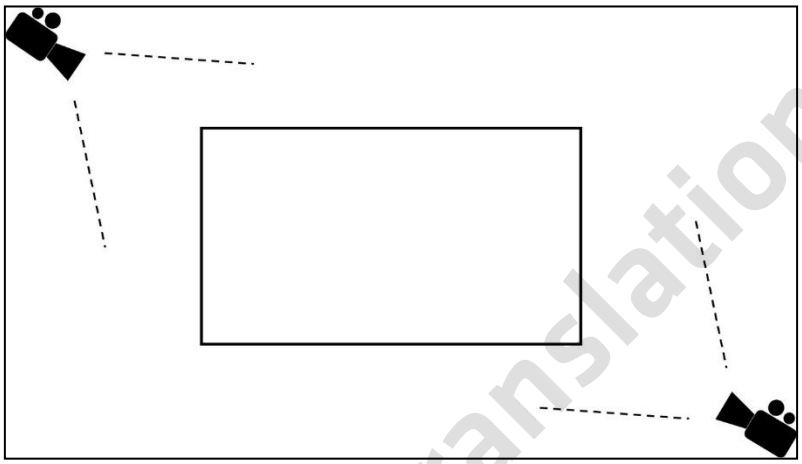

Figure2 : Number and positioning as a minimum for the camera documentation of the test.

2. Execution

- The method of initiation can be chosen freely. It must be ensured that the initiated cell(s)/module(s) enters the TR.
- The cells/modules/batteries initiated, and the method used to initiate the TR must be documented.
- The complete TR should not take longer than one hour for cells/modules/batteries up to max. 50 kWh and no longer than 2 hours for cells/modules/batteries greater ~~or equal~~ 50 kWh. Several points may be needed to be initiated for this. Two initiation points per 50 kWh are recommended.

2.1 Temperature recording on the cells/modules/batteries

The measurements must cover at least the following time periods:

- the time until the first thermal runaway (see Figure 3, left),
- the thermal runaway (see Figure 3, left: Δt_{TR})
- after completion of the last thermal runaway (see Figure 3, left: $t_{TR\,1}$) a period of at least 6 hours .

Figure 3, right, shows an example of the entire period.

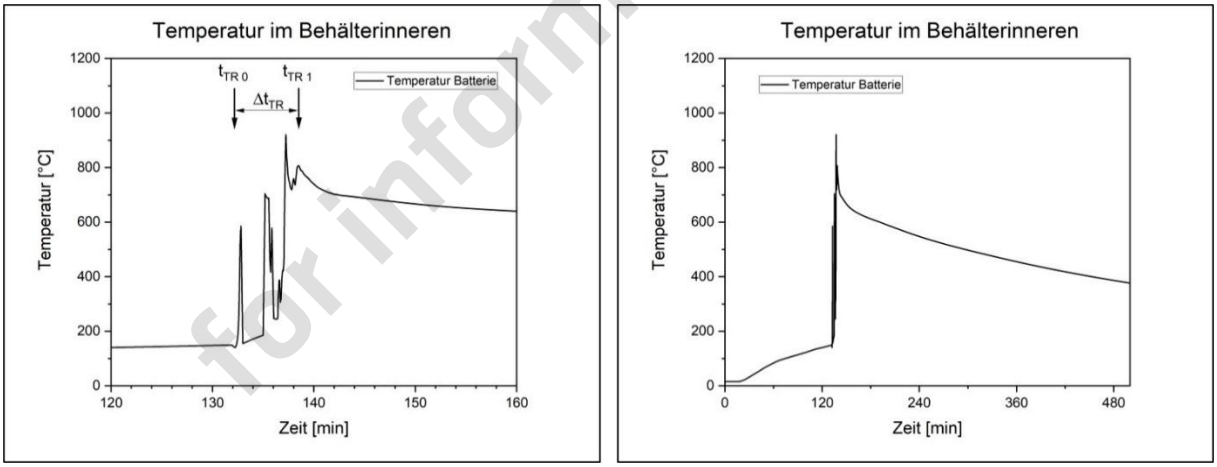

Figure3 : Exemplary temperature curve in a packaging for a module consisting of several round cells; left: Detailed representation of the thermal runaway with definition $t_{TR\,0}$ as the time of the start of the thermal runaway, $t_{TR\,1}$ as the time at which the thermal runaway is completed and Δt_{TR} as the duration of the thermal runaway; right: the overall process (start of heating, thermal runaway, 6 h cooling phase).

2.2 Temperature recording on the surface of the packaging

The measurements must include at least the following time periods:

- the time until the thermal runaway,
- the thermal runaway,
- the time until the temperature maxima are reached on all temperature channels on the surface of the packaging ($\Delta t_{T\,max}$),
- a period of at least 24 hours from the start of the first thermal runaway according to section 2.1, whereby in the last 6 hours all temperature measurement channels must no longer show a significant increase.

2.3 Camera recording

- It is recommended to keep the recording running for the entire test period.
- The camera recording (see section 1.2.3) must be ensured from the start of the initiation of the thermal runaway until the time at which no more gas can be visually detected escaping from the container.
- The recording must show when the initiation of the thermal runaway was started (e.g. displayed timer, visual signal, acoustic signal). It is recommended that the camera recordings are provided with a time stamp.

3. Evaluation criteria

3.1 Proof of thermal runaway

It must be ensured that all cells/modules/batteries have had thermal runaway.
This can be done, for example, by taking informative photos of the contents of the packaging after the test or by evaluating the temperature values inside the packaging (see Figure 3).

3.2 Surface temperature

- The maximum permitted temperature on the surface of the packaging is 100 °C. Proof must be provided for each measuring point.
- A short-term temperature peak of up to 200 °C is permissible (sum of all events: maximum 10 minutes). It must be determined at which time the limit of 100 °C was exceeded and when this limit has fallen below 100 °C again and whether the limit of 200 °C was exceeded.

3.3 Camera recordings

The recording must be used to analyse whether the points mentioned in section 2.3 have been complied with.

3.4 Photo documentation

At the end of the test, the internal and external condition of the packaging must be documented. In particular, it should be documented whether the structural integrity and transport safety of the packaging is still given. If possible, photos should also be taken to prove that all cells/modules/batteries have experienced a TR.

4. Test report

- For the procedure according to Part A of this BAM-GGR, it is recommended to prepare a test report in order to be able to prove the qualification and usability of the packaging.
- For the procedure according to Part B of this BAM-GGR, the test report must be submitted to BAM.

The forms in Annex 6 are available for evaluating the test and for documenting the cell/module/battery data.

4.1 Formal documentation of the test and the test stand

- Test date
- Unique number of the test/report
- Location and name of the executive body of the test
- Brief description of the test stand, e.g. closed (e.g. inside a building), open (e.g. open field), semi-open (e.g. container, shelter)
- Name of author

4.2 Documentation of the packaging

- Description and technical documentation of the packaging
- Specification of dimensions, tare mass and material
- If applicable, certificate of approval (UN-approval certificate ~~number,~~ incl. revision status and date of issue) or reference to technical drawings contained in the approval certificate (drawing number with date and, if available, revision status)
- Description and pictorial documentation of all internal components (e.g. cushioning material, absorption material, insulation material, additional stabilising elements), description with regard to quantity (e.g. number, mass, size), material and its properties (e.g. heat capacity, thermal conductivity, calorific value, melting temperature) and the arrangement of the individual components in the packaging.
- Description and pictorial documentation of the arrangement of the cells/modules/batteries in the transport packaging (e.g. distances of the batteries, cells, modules to each other and to the outer wall of the packaging)
- Description and pictorial documentation of the modifications made to the packaging for the fire test (e.g. additional cable bushings) and attached components (e.g. inserted heating elements to initiate thermal runaway)

4.3 Documentation of the battery specification

- Manufacturer, cell type, number of cells, cell chemistry, cell geometry, nominal voltage, nominal capacity, nominal energy, mass, dimensions, etc. (Battery data form in Annex 6)
- Visual documentation of the SoC, e.g. photo of the voltage measurement for each cell/module/battery with a specifically recognisable value and description, e.g. from the data sheet of the cell/module/battery, of which SoC the measured voltage corresponds to. For more than 10 cells/modules/batteries, the values can also be given in text form (e.g. table).
- Description and pictorial documentation of the components of the battery housing that were included in the transport packaging for the fire test (or other substantial fire load that was included)

4.4 Documentation of the overall structure at the time of the test

- Description and pictorial documentation of the test sample on/in the test stand
- Documentation of the ambient temperature at the start of the test
- Description of the measurement technology (individual components of the temperature measurement chain, cameras, thermal imaging camera, etc.) with regards to positioning in relation to the test sample (e.g. distances, height), e.g. with a sketch.
- Description of other components of the setup that are relevant for the test procedure and documentation (e.g. mechanical ventilation, UAV).
- Measuring point plan showing the distribution/arrangement of the temperature sensors on the container surface and inside the container (e.g. table, sketch, labelled image).

- Individual components of the entire temperature measuring chain (e.g. sensors (type), cable, measuring amplifier, recording of the measured values)
- Position of the cameras in relation to the transport packaging
- Description at which cells/modules/batteries the thermal runaway was initiated
- All temperature measuring points inside the packaging and on the surface of the packaging as a diagram including evaluation
- Overview (e.g. table) of the chronological sequence of the main events. These can be, for example: start of the measurement recording, start of the initiation of the TR, start/end of the TR (see Figure 3), incidents
- Documentation of the TR process of the cells/modules/batteries
- If necessary, video/photo recordings in a suitable form

The raw data must be kept for at least three years beyond the period of use of the packaging.