AMI EVENT | Fire Resistance in Plastics

Application Relevant Test Methods for Characterizing Materials in Thermal Runaway Conditions

Dec 2nd, 2025

10:10	<u>Introduction</u> Ravi Bhairi | AZL Aachen GmbH
10:15	Test Methods for Characterizing Materials for thermal runaway in BEVs Ravi Bhairi | AZL Aachen GmbH
10:35	Q&A Session
10:40	End

Ravi Bhairi
Head of Fire Testing E-Mobility @
AZL Aachen GmbH

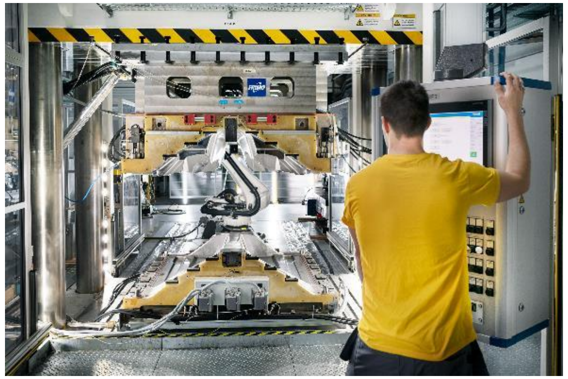
AZL Aachen GmbH
Excellence in Lightweight Production

AZL Know-how and Networks for Excellence in Lightweight Production

Our Assets for Business and Technology Development

Our technology know-how:

Composite-based multi-material technologies



Our high-tech ecosystem:

RWTH Aachen Campus

Our international cross-industry network:

80+ companies from 21 countries

Our systematics for combining

Market and technology intelligence

Joint Technology Development through Cost-Sharing

Efficiently drive your development!

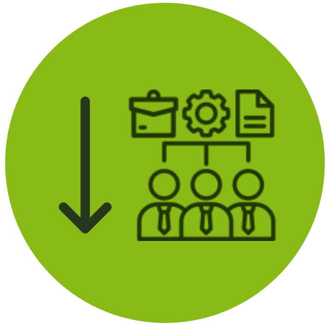
What it is

Within the AZL Joint Partner projects, international companies come together to improve their understanding of trend topics & their markets, to optimize technology and business development strategies and to develop approaches to solve future challenges.

How it works

1. Project proposal
2. Compilation of a project consortium
3. Kick-off with input from the consortium
4. Project work will be carried out by AZL
5. Validation of the results by the consortium
6. Direct access to all results

How you benefit



Joint Technology Development through Cost-Sharing

Previous Activities

Joint Partner Project
Trends & Design Factors for Hydrogen Pressure Vessels

Joint Partner Project
Thermal Propagation

Joint Partner Project
Rotor Sleeves for Electric Motors

Joint Partner Project
Emerging Battery Storage Technologies

Joint Partner Project
Propellers and Rotors

Joint Partner Project
Cost and CO2 Saving Lightweight Tailgate Concept Study

Joint Partner Project
Concept Study & Development of Cell-to-Pack Battery Casings

Joint Partner Project
Battery Casing Follow-Up: Bottom Impact Protection

Joint Partner Project
Battery Casing Follow-Up: Fire Protection

Joint Partner Project
Multi-Material Battery Casing

Joint Partner Project
Inductive Double Belt Press

Joint Partner Project
Ultra-Fast Manufacturing

Joint Market & Technology Study
New Potentials for Composite Technologies in Buildings & Infrastructure

Joint Market & Technology Study
Composites in the Furniture Industry

Joint Market & Technology Study
Potentials and Challenges of Thermoplastic Tapes for SME Injection Molders

Joint Market & Technology Study
Next Generation Mobility Solutions

Joint Market & Technology Study
Energy Storage Systems

Joint Market & Technology Study
High-Performance SMC

Joint Market & Technology Study
Bio-based Composites

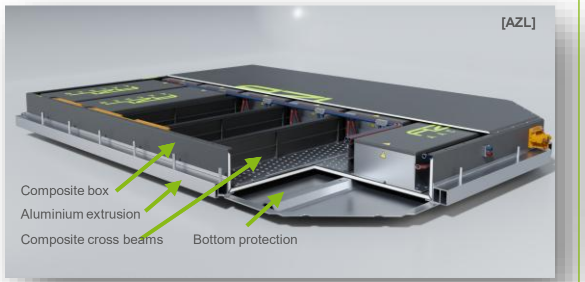
Get more details on completed activities!

AZL Background in EV Battery Box Structures

Overview Battery Casing Joint Partner Projects

2020 - 2021 | **2021 - 2022** | **2022 - 2023** | **2024 - 2025**

2020 - 2021



Multi-material battery casing (completed)

- 46 participating companies
- Trends, requirements
- 20 Different design concepts
- CAE optimisations

➔ Up to 20 [%] cost saving
➔ Up to 25 [%] weight saving

over aluminium reference

2021 - 2022

Fire test setup

Bottom impact test setup

Application relevant fire test set-up (Completed)

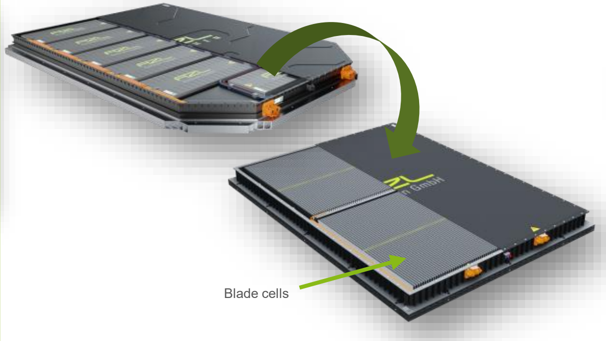
- Application relevant Instrumented test method developed
- 50 different materials tested

Oblique angle bottom impact protection (completed)

- Application relevant Instrumented test method developed
- 25 different materials tested

Test method is available on individual basis

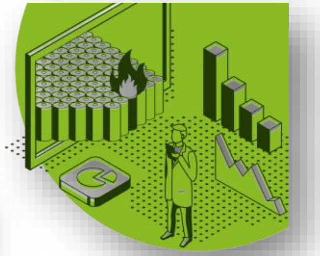
2022 - 2023



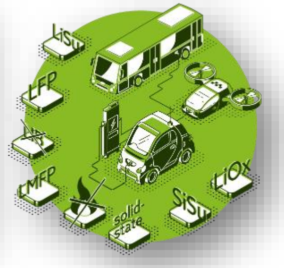
Cell to Pack (Completed)

- Alternative future design concepts
- Direct cell installation into pack
- Cells mechanical characterization (theoretical)
- Contribution of cells to structure

2024 - 2025



Thermal Propagation in BEV Battery Casings



Emerging Battery Storage Technologies

Thermal Propagation in BEV Battery Casings

- Techniques for prediction of cell and casing behaviour after the initial trigger event for thermal propagation

Emerging Battery Storage Technologies

- Insights into emerging battery storage technologies and their impact on design factors for battery casings

Joint Technology Development through Cost-Sharing

81 project partners in battery joint partner projects

3M | AIREX | AOC Trusted Solutions | aperam | ArcelorMittal | Arkal Automotive | ARKEMA | AsahiKASEI | ASCEND Performance Materials | Audi | autoneum

BASF We create chemistry | BOYSEN GROUP | BMW | carcoustics more than silence! | CASCADE engineering | Celanese The chemistry inside innovation | c.f.maier Firmengruppe | CLARIANT | covestro | DID DAIDO KOGYO CO., LTD. | DRÄXLMAIER

DSM | econcore | ENGEL | exel COMPOSITES | farplas | faurecia inspiring mobility | 台湾塑膠工業股份有限公司 FORMOSA PLASTICS CORPORATION | Frenzelit | F.tech R&D North America | H.B. Fuller | KÖMMERLING

Henkel | HANKUK COMPOSITE UK | HRC | HUNTSMAN Enriching lives through innovation | HUTCHINSON | IPTE Experts in Factory Automation | isovolta GROUP | JAGUAR LAND ROVER | Johns Manville A Berkshire Hathaway Company | KATCON GLOBAL

KAUTEX A Textron Company | LAMILUX | LG Chem | LYB LyondellBasell | MAGNA | MARELLI | MINTH | MITSUBISHI CHEMICAL EUROPE | Mitsui Chemicals | MOCOM

montaplast | GLASS FOR FUTURE Nippon Electric Glass | POLYTEC | porcherindustries | posco | profol Performs | Nemak Innovative Lightweighting | 联洋 | PUREM by Eberspächer

Rassini | REHAU | Röchling | سابك sabic | أرامكو السعودية saudi aramco | SEKISUI | SEKISUIKASEI | SCOTT BADER Making a positive difference | SCHULER Member of the ANDRITZ GROUP | sgl carbon

SSDT | SUMITOMO CHEMICAL | SYENSQO | TEIJIN | thyssenkrupp | TORAY | TOYOTA | TRINSEO | WKW. extrusion | YIZUMI伊之密

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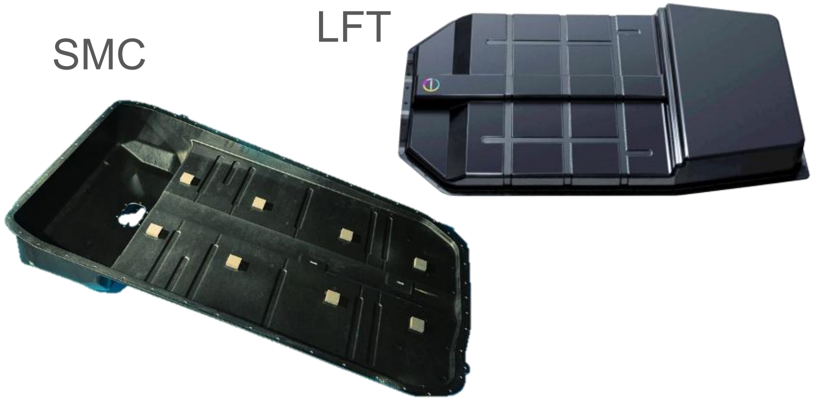
Excellence in Lightweight Production

Advanced Battery Casing Technologies: Application Relevant Testing

Fire testing for EV battery casing: Motivation

- OEMs are most familiar with metal production

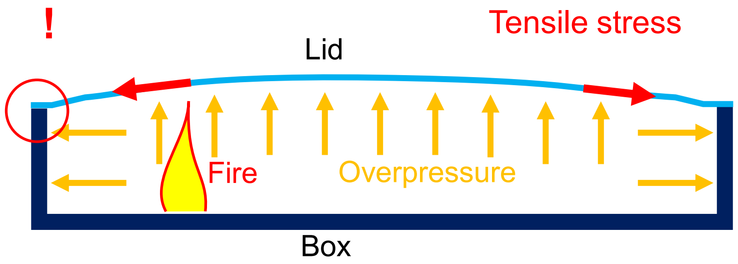
  When possible, they will prefer steel solutions. → Heavy!
  Composite solution introduction likely needed via suppliers.
  → Need to demonstrate safety & predictability.
  → Lid is an "easy" first part.



- Thermal runaway event duration 10 minutes,
  800-1200°C (at cell level up to 1200°C).

  1. Aluminium will melt! → requires protective layers,
  2. Heavy steel will need thermal insulation.

- **→ Opportunity for composites!**
  Resins can decompose, but no burn-through for fibres.



→ Designing a fire safe casing needs relevant testing and CAE.

https://plasticscar.blogspot.com/2018/03/battery-enclosure-cover.html
https://www.linkedin.com/feed/update/urn:li:activity:6788139693889347585

Advanced Battery Casing Technologies: Application Relevant Testing

Fire testing for EV battery casing: Overview

2021 - 2022

Fire test setup

- Application relevant fire test set-up (Completed)
- Application relevant Instrumented test method developed
- **55+ different materials tested**
- **Report of 350+ slides**

Consortium

Audi, AsahiKASEI, Ascend Performance Materials, BMW, carcoustics, Celanese, Clariant, Daido Kogyo Co., Ltd., Faurecia, Formosa Plastics Corporation, Frenzelit, Hutchinson, lyondellbasell, Magna, Marelli, Mitsui Chemicals, Rehau, Röchling, Scott Bader, Sekisui, Solvay, Teijin, Toray

+ anonymous

List of materials types tested:

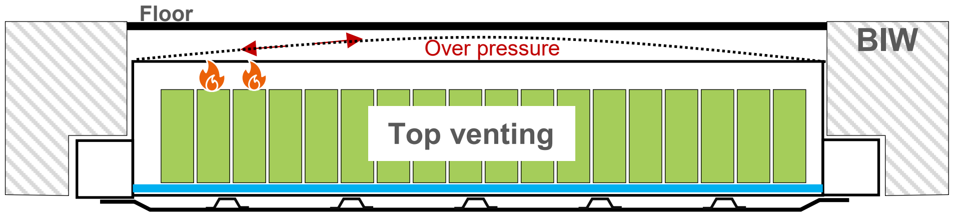
- Aluminium
- Steel
- Thermoplastics:
  - SGF
  - LGF / LCF
  - Hybrid
  - UD
  - Fabrics
  - Sandwich

  PP, PA, PE, PC, PPS, PK, CPVC, PMMA and Various FR formulations
- Thermosets
  - SMCs
  - Mats
  - UD
  - Fabrics

  Polyester, Epoxy, Phenolic, VE, PU and Various FR formulations
- Protection layers
  - Mica
  - Intumescent coatings
  - Blankets
  - Board
  - Foam

Advanced Battery Casing Technologies: Application Relevant Testing

Fire testing for EV battery casing: Test conditions and Schematic Test Set-up

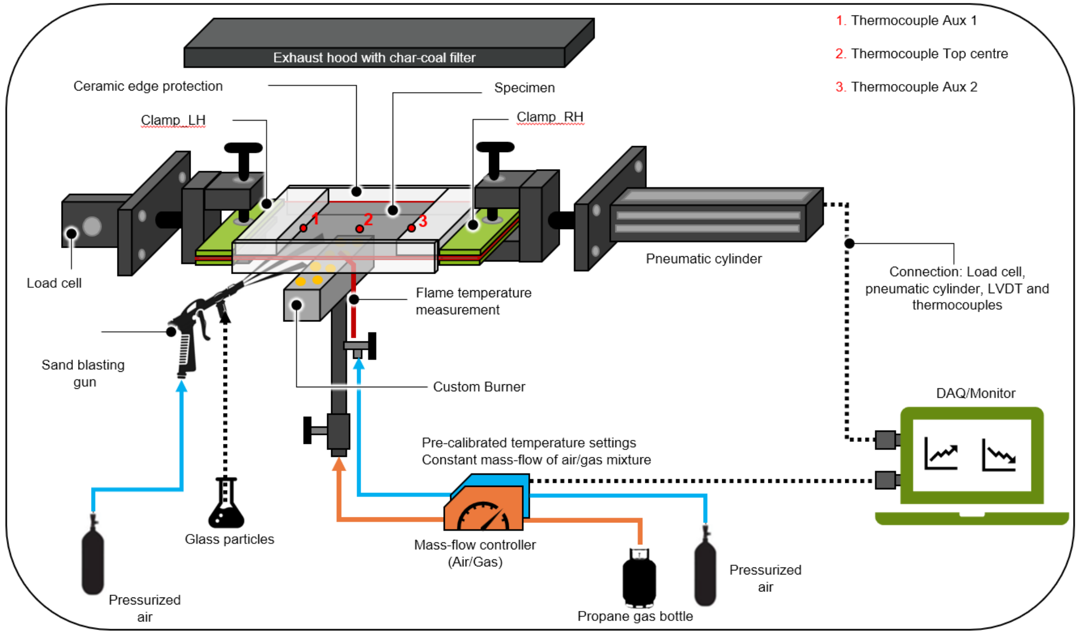


Material **Str**ength Test under **Fire**

- Heating source: 3 kW **Li**ne **F**lame (LiF) across the width of the specimen
- Temperatures representing various cell chemistries:
  - 800 °C, 1000 °C, 1200 °C
- Overpressure as tensile force:
  - 0.5 kN over 10 minutes under flame exposure
- Measurement of residual strength:
  - If no failure within 10 min, increase force up to 5 kN until failure

High Energy **F**lame and **Par**ticle **Blast**ing Test

- Heating source: 3 kW **Li**ne **F**lame (LiF) across the width of the specimen
- "The test profile has been calibrated to reproduce the damage equivalent to that observed in actual testing of an LFP 240 Ah cell."
- Temperature and duration
  - 1200 °C for 80 sec
- Particle blasting mass flow and duration
  - 20 g/sec for 10 sec



Advanced Battery Casing Technologies: Application Relevant Testing

Demonstrate safety & predictability: Comparison Composite Versus Aluminium

Composite

Hybrid Fabric / LFT FR-PP material

Aluminium

Epoxy G-Fabric FR-Intumescent

1200 [°C] Particle blast test

LFP Prismatic cells, capacity 214 [Wh]

AZL HiParBlast Test

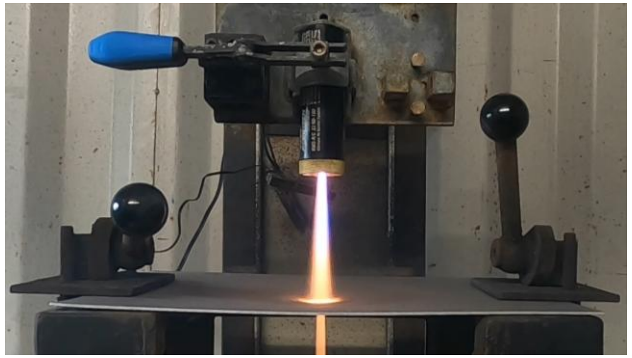
Key observations:

- Variation maximum measured flame temperatures: 740 – 920 [°C] (5 tests per material)
- Duration maximum temperature ~10 [s]
- Aluminum_2 mm: The high thermal conductivity, low melting point, and thinness made aluminum prone to rapid melting under concentrated, high-intensity heat, leading to a hole.
- LGF-FR_PP_4 mm: The composite's low thermal conductivity, greater thickness, and protective char layer allowed it to withstand heat without forming a hole, preventing rapid temperature rise and catastrophic failure.

Advanced Battery Casing Technologies: Application Relevant Testing

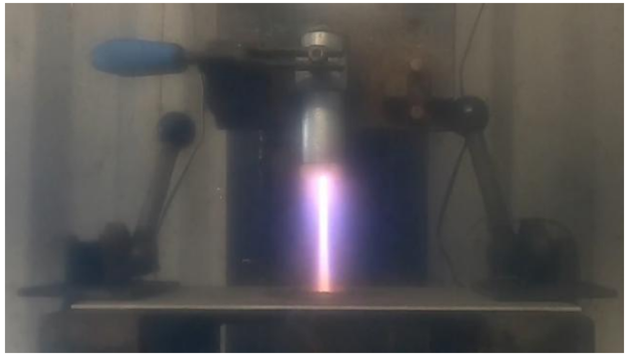
Demonstrate safety & predictability: Comparison Composite Versus Aluminium

Mitsubishi Chemical: Rocket test



Aluminium Material:

Penetration time: ~ 1 s



KyronTEX
Fiber Reinforced
Thermoplastic Woven

No penetration

- Peak Flame Force: 14-16 N
- Avg Flame Velocity: 1250m/s (calculated)
- Temperatures: > 1200 °C

AZL HiParBlast test: Particle blast test **1200 [°C]**

Back side | Flame side | Flame side | Back side

hole | No hole

Aluminium Material | FR-PP - SGF Material

- Many SGF and LGF materials survive the blast test

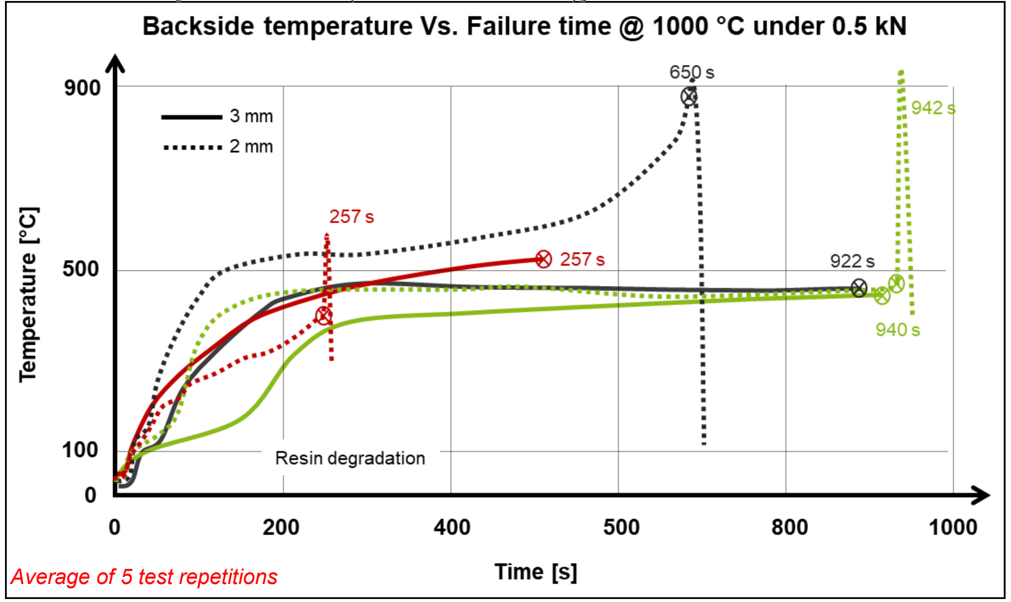
Test conditions:
- Max. temp: 1200 [°C]
- Duration: 80 s flame + 10 s blast
- Blast pressure: upto 5 [bars]
- Particle mass flow: > 20 g/s

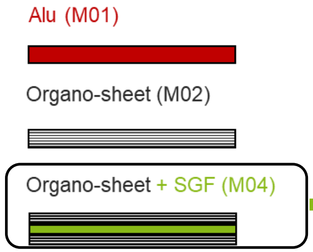
Advanced Battery Casing Technologies: Application Relevant Testing

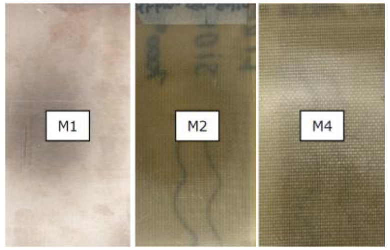
Demonstrate safety & predictability: Comparison Composite Versus Aluminium

- Composite solution introduction likely needed via suppliers.
  → Need to demonstrate safety & predictability.
    → **Best way to achieve that is with application relevant testing**

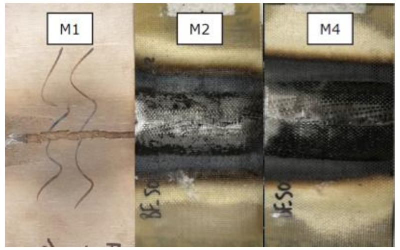
Master thesis [Julian Krichel (AZL & FH-Aachen)]





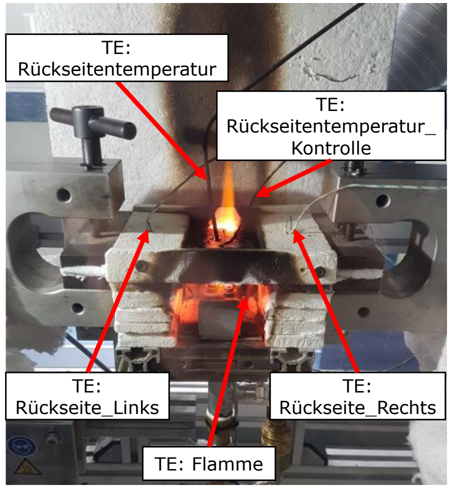


Before testing

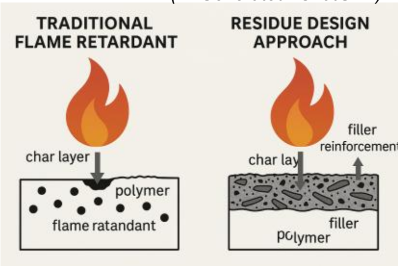


After testing

Bench-scale test rig for thermal runaway testing
(Material strength test under fire)



(AI Generated: ChatGPT)



"Residue Design" — Tailored Flame Retardancy Approach:

- Instead of simply adding FR chemicals, engineer the composite microstructure so that the residue itself (the char, foam, or inorganic scaffold left after combustion) has desired thermal and mechanical properties [Prof. Dr. Schartel's]

Why It Matters ?

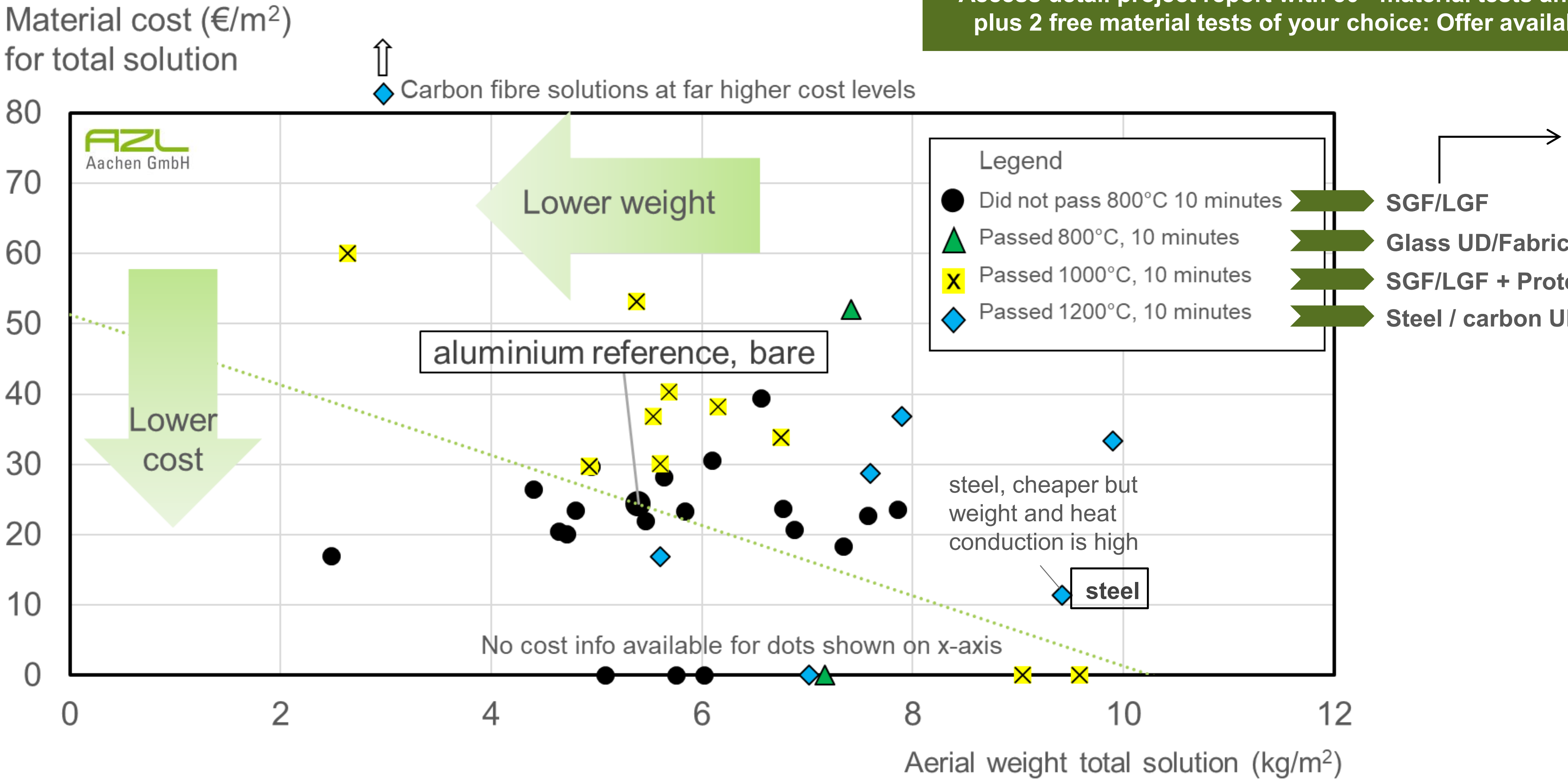
- In modern high-performance composites (for EV battery casings, aircraft interiors, etc.), we can't simply rely on chemical flame retardants — they may compromise mechanical, electrical, or thermal properties.

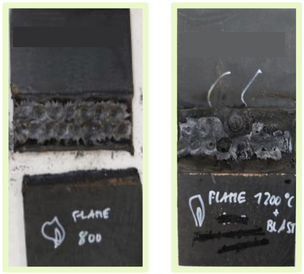
  Instead, residue-based design:
  - Enables synergistic mechanical + fire performance,
  - Avoids halogenated systems,
  - And fits sustainability & recyclability goals.

Advanced Battery Casing Technologies: Application Relevant Testing

Fire testing for EV battery casing: Cost Versus Weight for 50 Tested Materials

Access detail project report with 50+ material tests and cost analysis, plus 2 free material tests of your choice: Offer available on request





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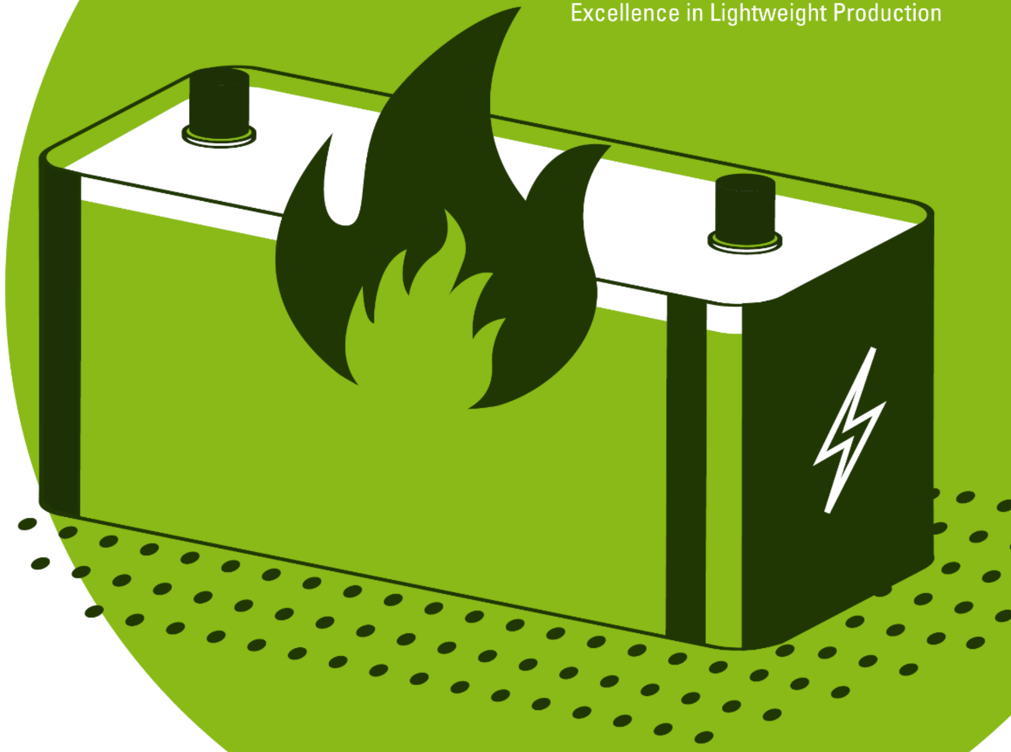


Participants:

German OEM | International OEM

aperam
autoneum
HUTCHINSON
MITSUBISHI CHEMICAL EUROPE
Nabaltec
posco
TRINSEO

AZL Joint Partner Project:
Thermal Runaway Testing for Battery Casings

Benchmarking systems for high-gradient heating and hot particle blasting for fire testing of housing and functional materials for EV battery casings

Project Started: July 15th 2025

In cooperation with:
AZL Aachen Center for Integrative Lightweight Production | RWTH AACHEN UNIVERSITY

Joint Partner Project: Thermal Runaway Testing for Battery Casings

Project Objectives

Objectives:

- Development and implementation of improved systems with high-gradient heating (flame temperature) and hot particle blasting without consider overpressure load
- Deriving application and cell chemistry specific testing protocols/profiles
- Evaluate candidate materials at the plaque or coupon level using these test protocols and reduce the resources and time required for prototyping and system-level testing.

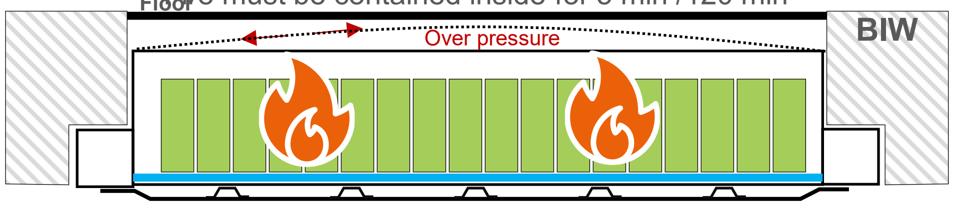
Results:

- Development and construction of test bench
- Tailored test profiles for relevant cell chemistries e.g. LFP or NMC cathode.
- Standard test profiles enabling screening of various materials for fire safe application in a battery casing.
- Comparison of relative performance of various materials and/or protection layers against tailored test profiles.
- Option to provide your materials for benchmarking
- Guidance to minimum material needs to survive battery fire testing according cell chemistry

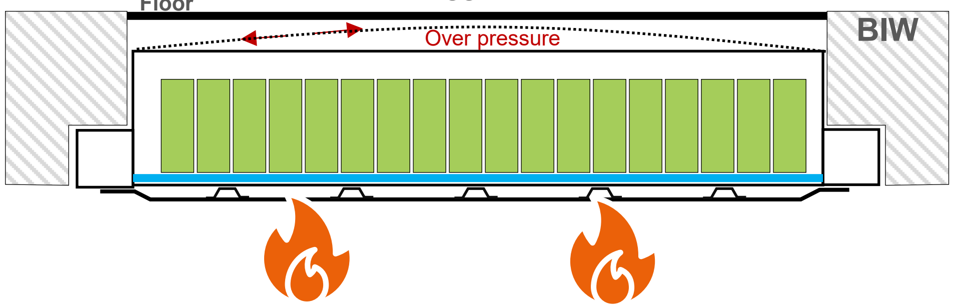
Background: Thermal Runaway Testing for Battery Casings
Motivation

- **GB 38031-2020: Needs a 5-minute warning before fire or explosion** for safe passenger exit. Applies to cells, modules, packs, and vehicles.
- **ECE R100 (Rev3):** After detection of a thermal runaway event, notified to the car driver, there should be a 5 minute safe escape time, without having a hazardous situation for the car passengers
- **ECE GTR 20 Addendum: Also requires a 5-minute warning before thermal hazards** that could harm vehicle occupants.
- **GB 38031-2025*:** Updated version requires **no fire or explosion for 2 hours after thermal runaway starts**.

Internal fire (caused by cell TR)
Fire must be contained inside for 5 min /120 min*



External fire (Bonfire)
Fire must not trigger TR or enter inside



1. **How these system-level standards translate to their own technical requirements on material level?**
2. **How to guide enclosure design and material configuration to meet these requirements?**

Background: Thermal Runaway Testing for Battery Casings

Available material screening test: Lack of harmonisation

UL 2596

- **Commonly used**
- **Biaxial load with real cells TR**

- Not tailored for all cell layouts and chemistries
- Relies on availability of real cells and repeatability of the TR event

UL 2596 TaG

- **Commonly used**
- High repeatability by adjusting temperature and blast sequence

- Strong interdependency between flame and blasting parameters
- Lower mass flow of particles
- Standard approach with fixed parameters

Rocket test

- **Excellent screening method** suitable for single cell event with high impact velocities
- **No real cells needed**
- **Highly customizable**

- Does not consider prolonged exposure of specimens under flame
- Does not consider mechanical tensile loads

AZL MaStFire

Material strength test under fire

- Developed in **collaboration** with international consortium **incl. two German OEMS**
- **Excellent screening method** for top **venting pack layouts** for different cell chemistries
- **Customizable and repeatable**
- Consider **prolonged exposure** of specimens under flame and tensile load
- **Simultaneous flame and blasting** under **tensile** load

- **Limited to cold particle blasting**
- Cannot simulate the initial impulse blast

AZL Torch and blast (1.0)

- **Developed in bilateral collaboration with an internation OEM**
- **Excellent screening method** for **alternative pack layouts** for different cell chemistries
- **Highly customizable and repeatable** for individual pack layout and cell chemistries
- Consider **prolonged exposure** of specimens under **flame and blasting**

- **Limited to cold particle blasting**
- Limited initial impulse

AZL Torch and blast (2.0) ★

- …………
- …………
- **Integration of hot particle blasting (recommended by OEMs)**

Increasing need for optimization of battery systems requires more realistic and adaptable test protocols and capable testing systems

Background: Thermal Runaway Testing for Battery Casings

What's the need for tailor-made test profiles for material screening?

Material degradation stages
above 2nd or 3rd cell

Stage 1: Thermal Pre-Damage

- The material's initial softening, resin decomposition, delamination onset, and loss of stiffness before the actual particle jet impact.

Key KPI: Thermo-mechanical stability under fast heat-up

Stage 2: Blast damage

- High-velocity particle jet creates craters, propagates delamination, melts or erodes the surface.

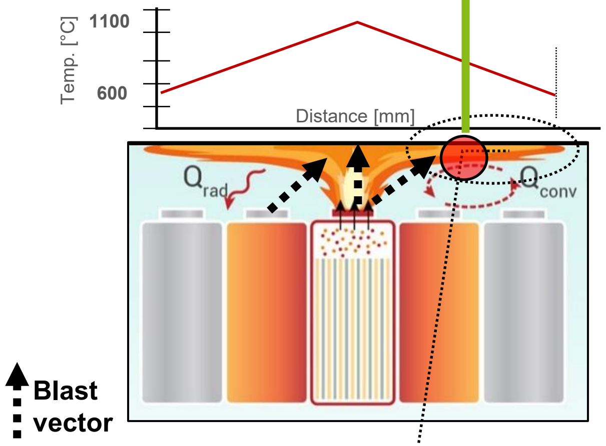
Key KPIs: Penetration time, backside temperature, residual tensile strength, mass loss, erosion depth.

Stage 3: Heat-soak failure

- The weakened zone experiences long-duration 500–900 °C exposure, causing oxidation, sagging, and insulation breakdown.

Key KPIs: Backside temp curve, insulation integrity, structural shape retention

Typical fire behaviours in standard cells
Thermal runaway does not load materials with a single uniform heat flux



Critical location
Adjacent material is pre-exposed to the flame between 500 to 900 °C before taking the particle blast (still within the 5 min escape time)

Ideal testing stages:

1. Pre-flame exposure
   - Short duration
   - High temperature
2. Particle blasting
   - Short duration
   - Ideally high temperature
   - High pressure blast
   - Multiple blast

   (Blast can be perpendicular or angular depends on vent opening)
3. Post-flame exposure
   - Long duration
   - Lower temperatures

≥ 5 min

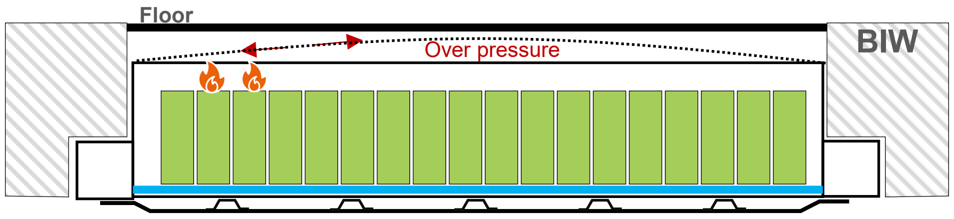
Fire behaviour and blast intensities might vary according to the cell chemistries and formats, but the exposure of protection materials remains more or less silimar

Background: Thermal Runaway Testing for Battery Casings

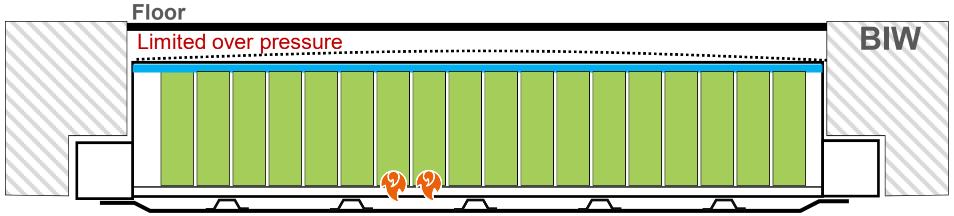
What's the need for tailor-made test profiles for material screening?

Pack layout and vent direction

Cross section view



Top venting

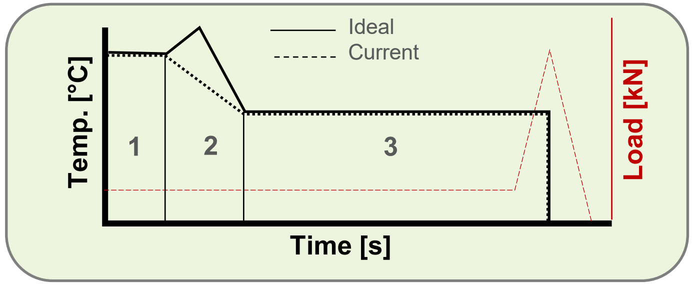


Bottom venting

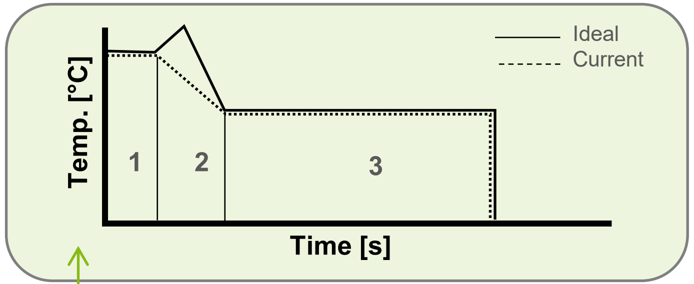
Load and boundary conditions

Valid for cylindrical, prismatic and pouch cells with varying flame and blast intensities

- Overpressure significant: 0.5 to 1 bar (incl. safety factor)
- Tensile or biaxial loading is relevant
- Pre-exposure of protection material to the flame
- Blast impact occurs once or twice per location



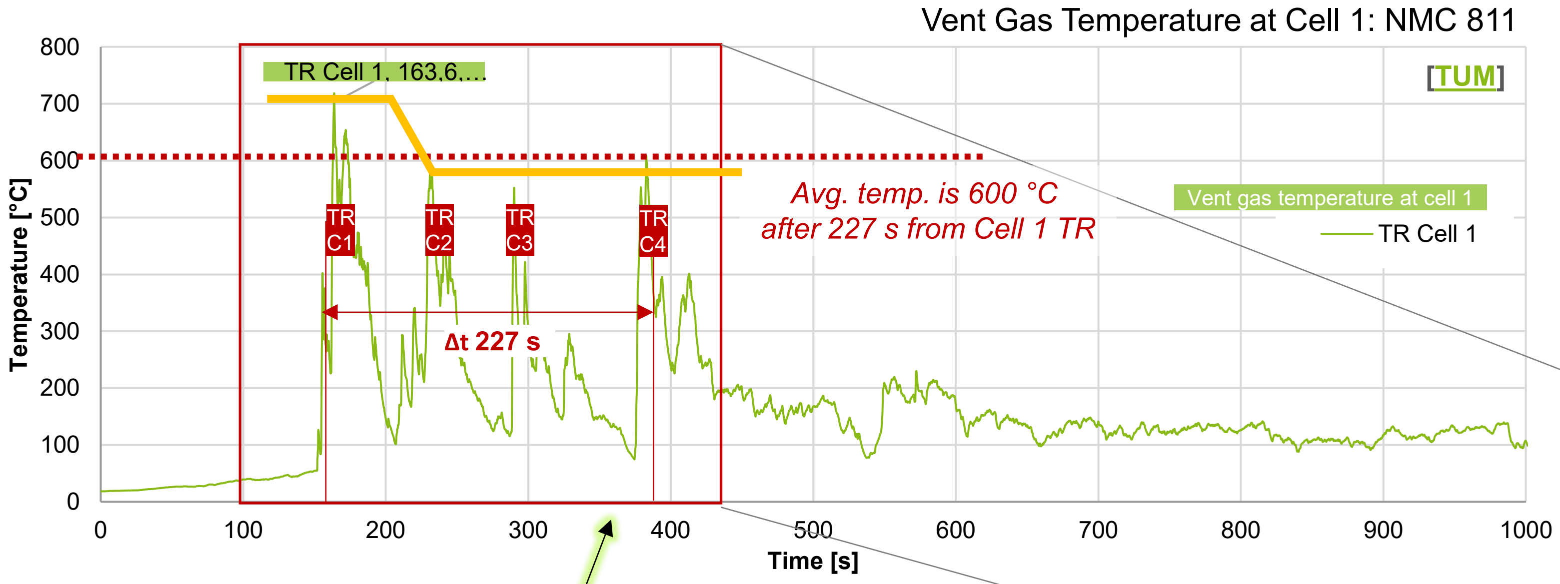
- Overpressure is not significant due to venting location and lid is reinforced with cooling plates
- Pre-exposure of protection material to the flame
- Blast impact occurs once or twice per location

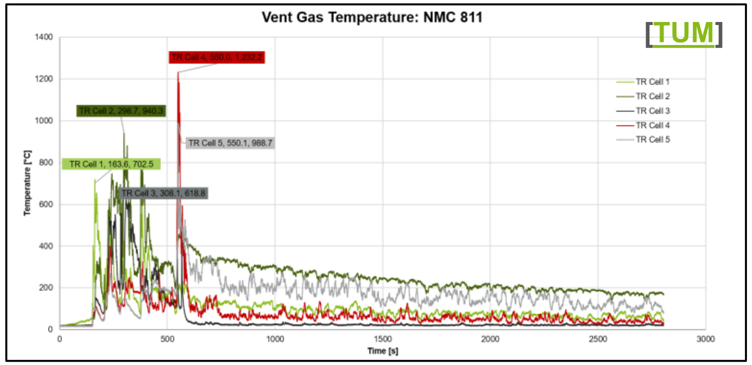


Cell chemistries and formats

Background: Thermal Runaway Testing for Battery Casings

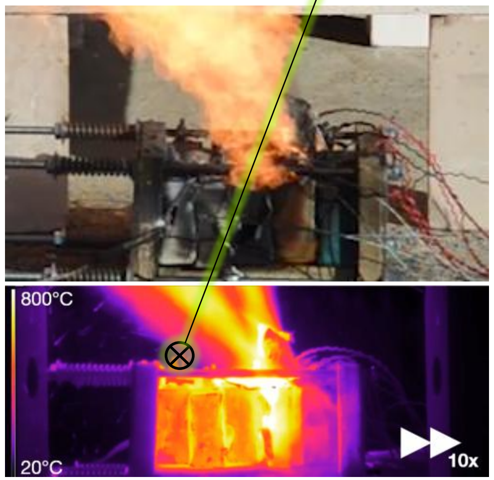
How to implement a tailored test profile from real cell module level testing





Vent gas temperature for all 5 cells

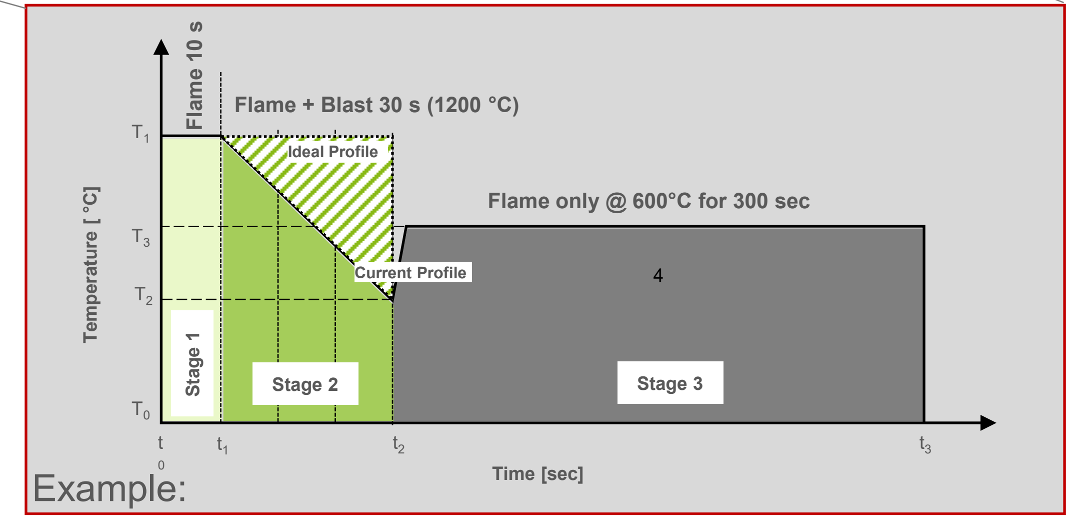
Example from literature experiment:



Screen shot @ t = 227 s

[TUM]

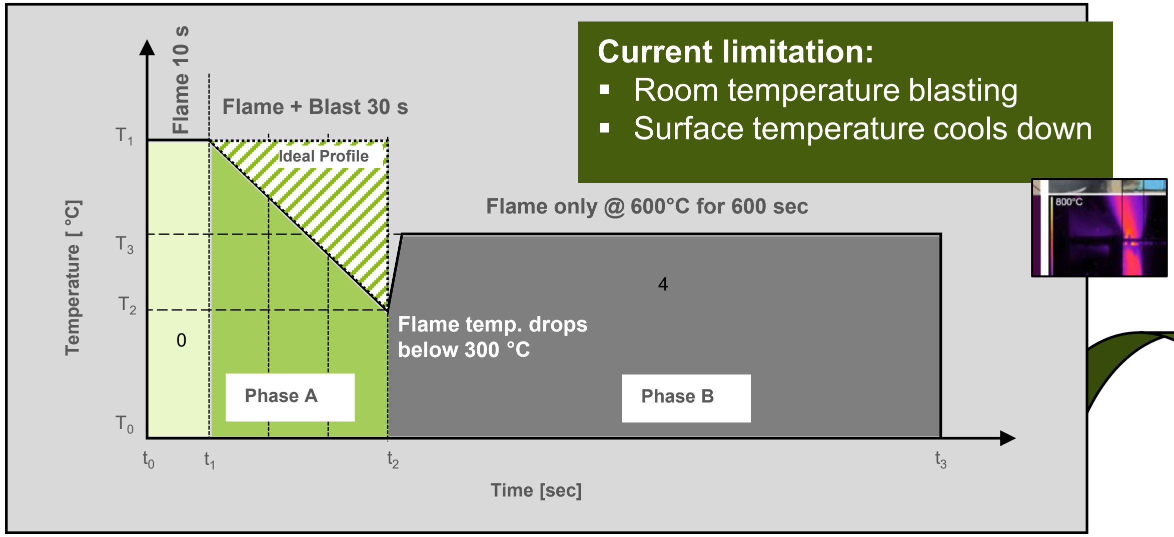
Extended test profile: Module Level

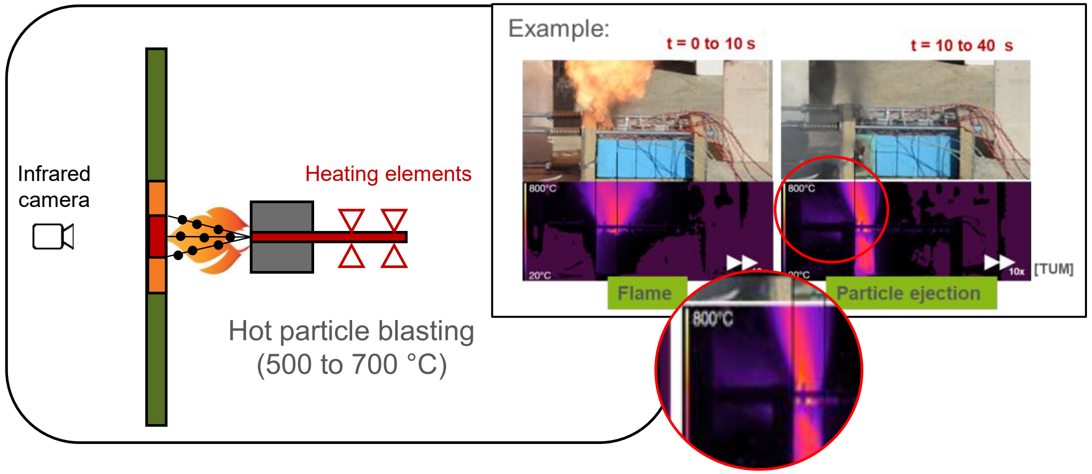


Joint Partner Project: Thermal Runaway Testing for Battery Casings

What do we want to achieve in this project

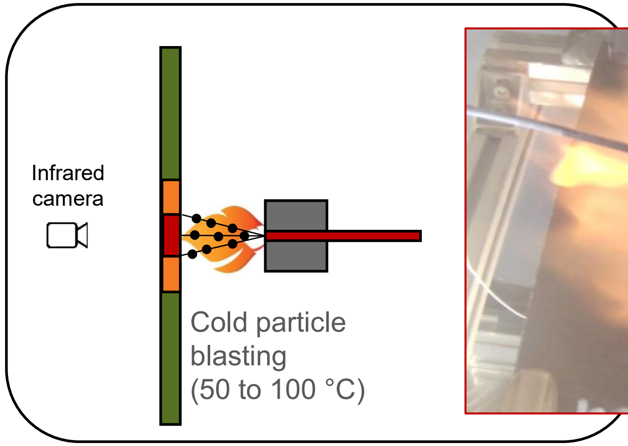
Example test profile: Module Level

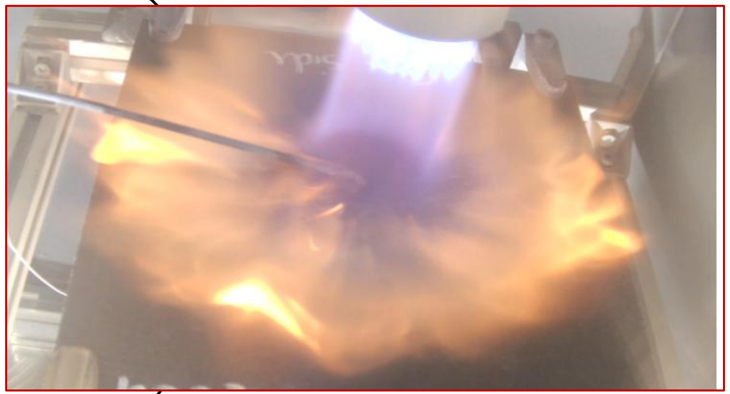


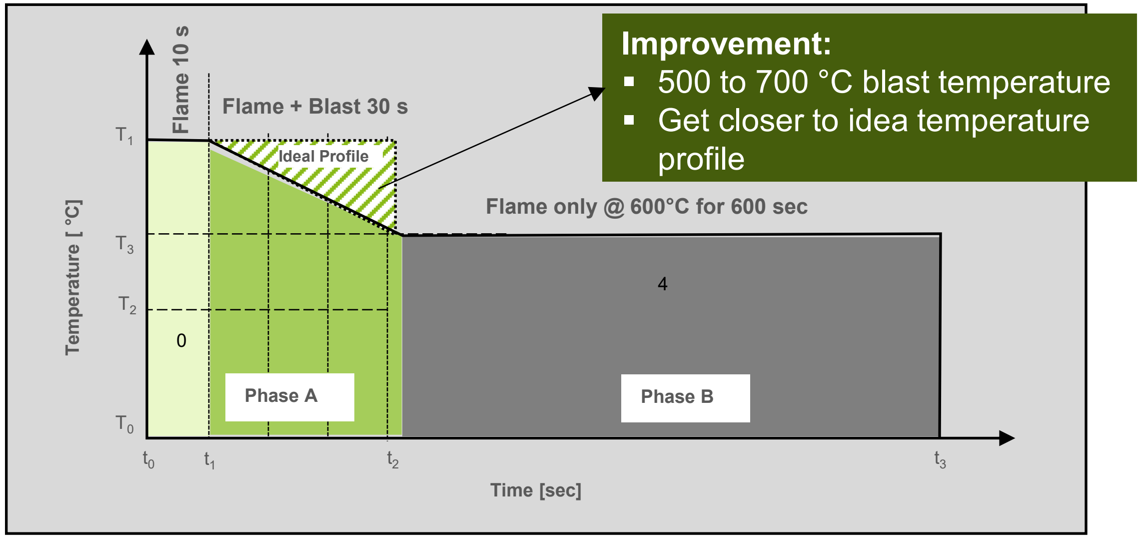


And what we propose to achieve in this project

Current test condition







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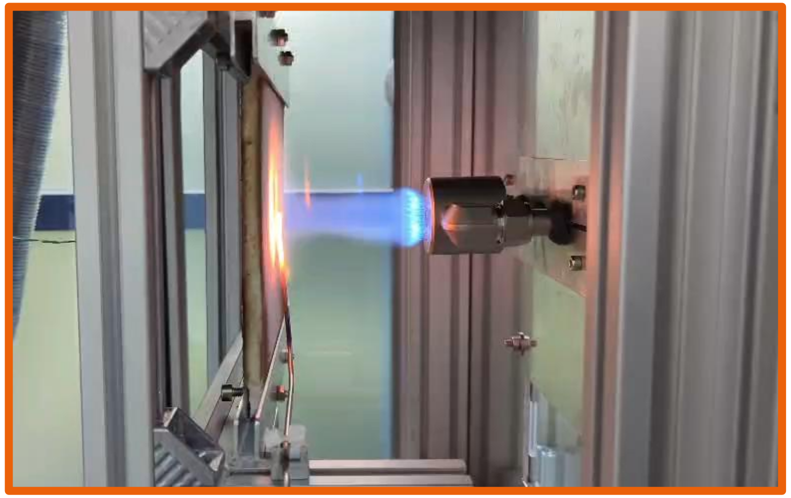
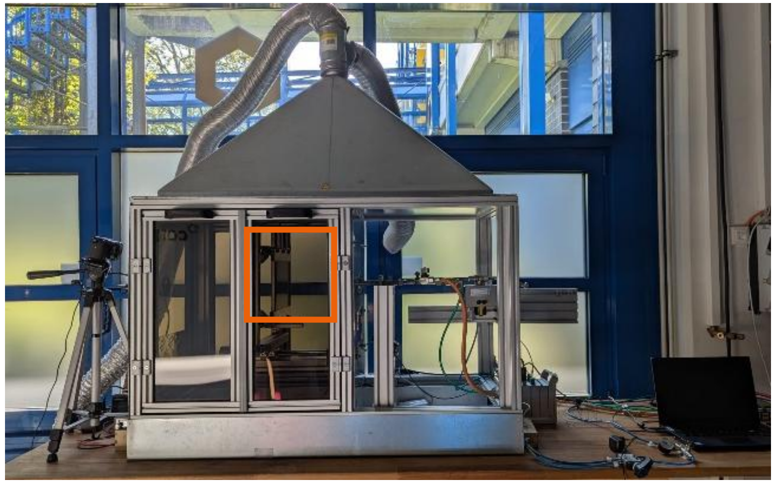
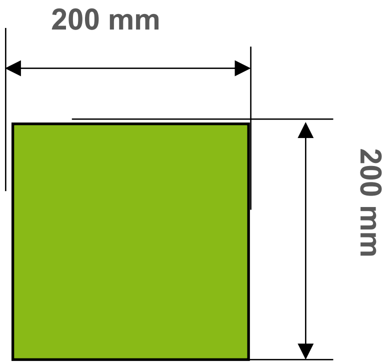
Test plan and specimen dimensions





No. of specimens’ and dimensions:



X 10 Specimens / Material

Test protocol 1 : Example
- NMC high energy density
- Temperature : ~1300 °C
- Blasting mass flow: tbd
- Duration: tbd

⇨ Mat. 1: 3 (repetitions) + 2 (spare) = 5
Mat. 2: 3 (repetitions) + 2 (spare) = 5

Test protocol 2 : Example
- LFP high energy density
- Temperature : ~800 °C
- Blasting mass flow: tbd
- Duration: tbd

⇨ Mat. 1: 3 (repetitions) + 2 (spare) = 5
Mat. 2: 3 (repetitions) + 2 (spare) = 5

Total no. of specimens for 2 materials = 20

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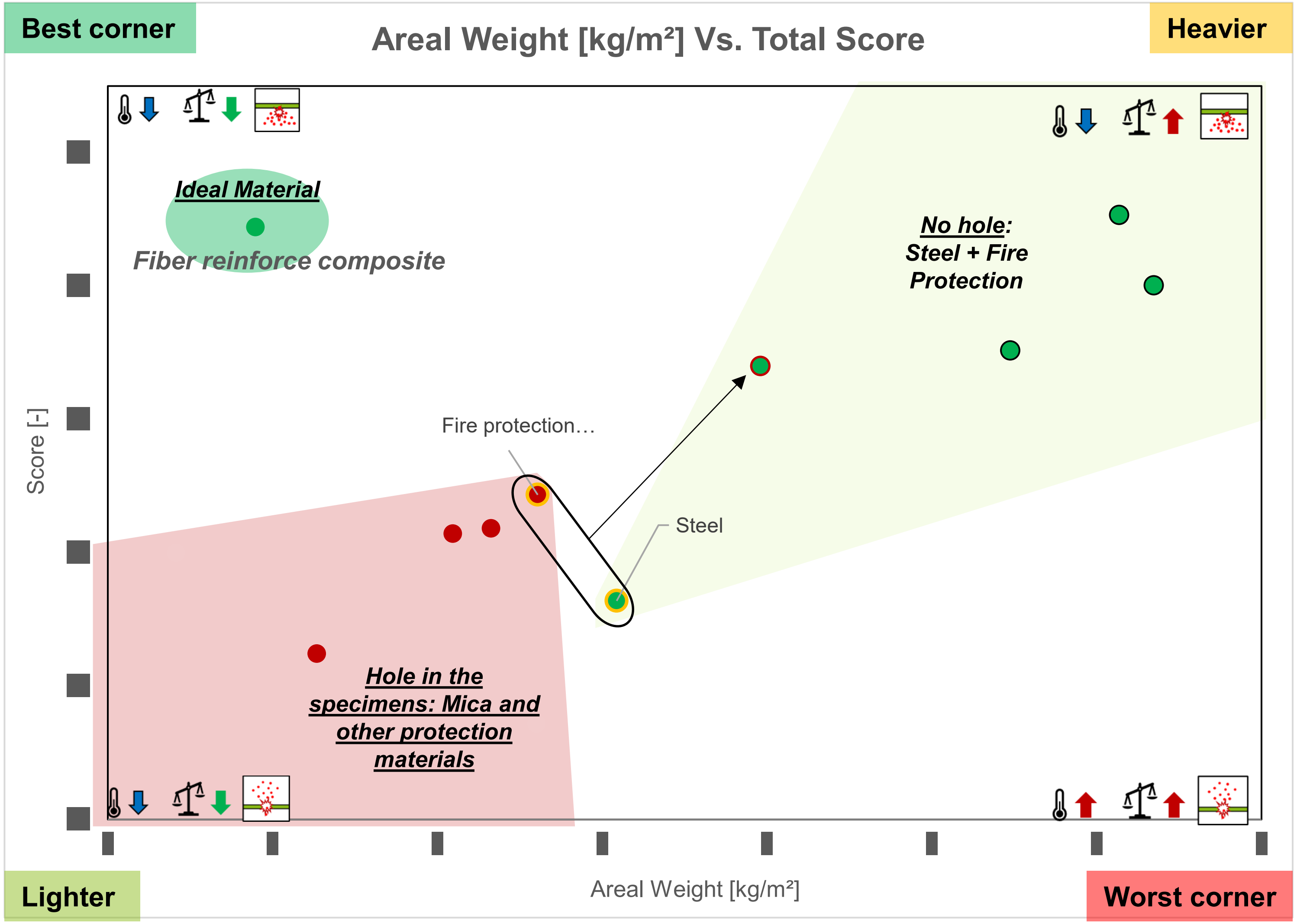
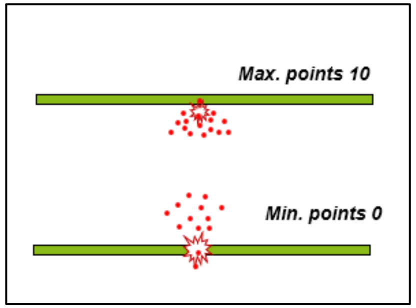
Application-specific challenges to rate material compatibility: Example

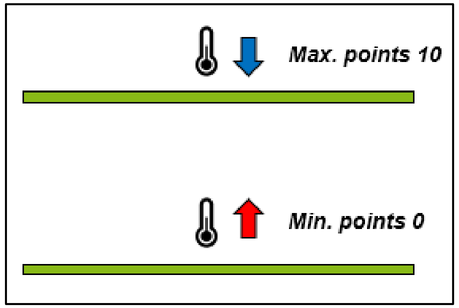


Comparative Analysis: Application-Specific Challenges and cost competitiveness

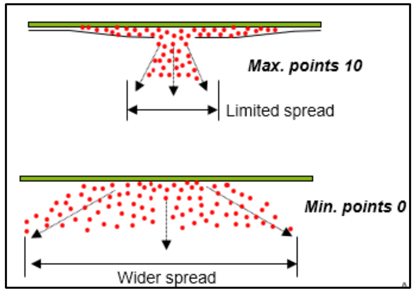
Incorporate cost and weight considerations for a comprehensive understanding in selecting the most suitable materials.



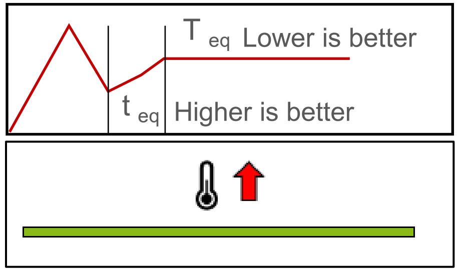
No hole Formation



Backside temperature



Confinement of particles



Equilibrium time and temp.

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First proposal test material matrix

Material	Shielding/protection	Comments
Aluminium t=2mm	-	Reference material
Aluminium t=2mm	Mica	Representing shielded lid
Aluminium t=2mm	Intumescent coating	
Steel t=0.7 mm	-	Alternative for lid, industry standard thickness for steel lid (no same stiffness as Alu)
Glass-FRPP LFT t=3.5mm	-	
Standard SMC glass t=3.5mm	With and without intumescent coating	Resin system t.b.d.
“FR SMC glass” t=3.5mm	-	
Hybrid: glass fabric + standard SMC		
Glass fabric thermoset		
Sandwich honeycomb		
Sandwich foam (FR-PET)		
Your material?		
Your material?		

Advanced Battery Casing Technologies: Application relevant testing

Conclusion

- New battery pack designs evolve rapidly
  - Cell-to-Pack → Now towards cell to BIW (further increase the TR requirements)
  - Designs to better cope with thermal runaway → Design to non-propagation and no penetration
- Many different material solutions exist to protect against fire or bottom impact

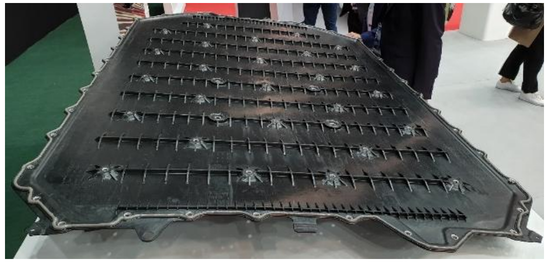
  → Screening and comparison under application relevant conditions are crucial
- Composites show potential for cost saving over aluminium and weight saving over steel
- Enable recyclable designs with polymer composites which has great interest, due to large components (like LID and Bottom protection plate)

  → New opportunities to meet EU EOL regulations

projects, including thermal runaway testing:

https://azl-aachen-gmbh.de/en/projects/

SABIC Battery box. Lid: 1.8 x 1.5 m, t= 2.5 mm
Sandwich, 0.3 mm glass-PP sheet on both sides



Audi Q8 e-tron,
from Polytec

Glass-PP UD tape, cross-ply,
D-LFT in core and ribs
total thickness t=5.5 mm (7 kg lighter than Alu)

THANK YOU FOR YOUR ATTENTION!

CONTACT US WITH YOUR REMARKS AND QUESTIONS!

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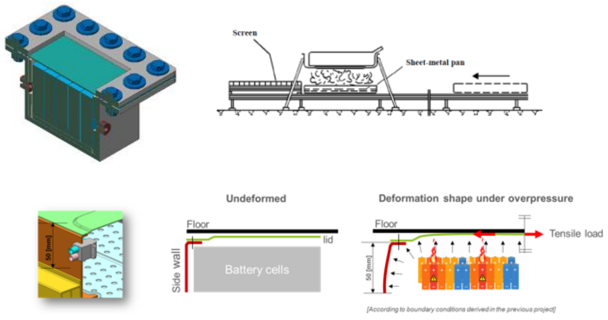
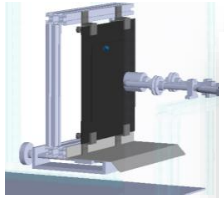
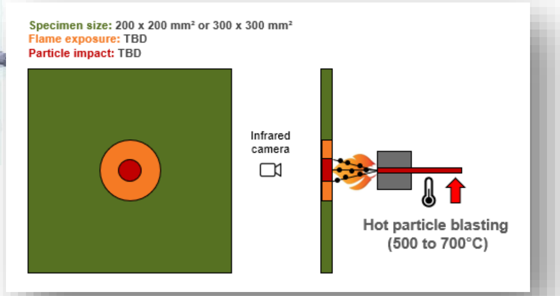
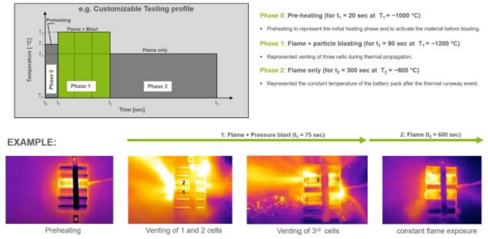
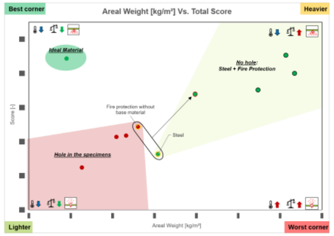
Work Packages











WP1
Analysis of state of the art

- Overview of existing test methods and benchmarking.
- Screening of regulation and interpretation on material level.
- Comprehensive Walkthrough for Test Bench Construction.
- Analysis of knowledge regarding testing of materials for structural and non-structural components of battery casings.

WP2
Development and implementation of improved systems for high-gradient heating and hot particle blasting

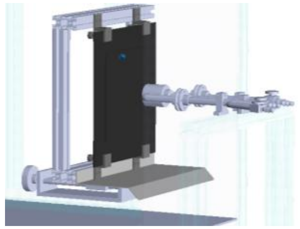
- Design and realization of test device.
- Implementation and integration of hot particle blasting system.
- Calibrations for different flame profiles and blasting intensities.
- Collection of test materials. Participants can provide materials for benchmarking.

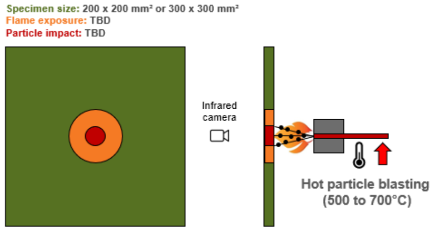
WP3
Implementation of relevant test profiles for different cell chemistries and benchmarking of test results

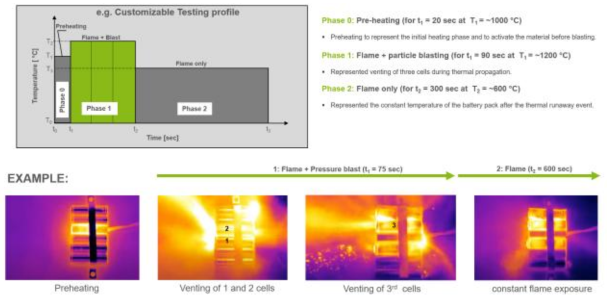
- Deriving application and cell chemistry specific testing profiles e.g. LFP, NMC.
- Test supplied material/ protection layers.
- Application-specific challenges to rate material compatibility.
- One on one comparison of market trending protection solutions including weight and cost indications.
- Guidance to minimum material needs to survive battery fire testing according cell chemistry

Joint Partner Project: Thermal Runaway Testing for Battery Casings

Estimated Timeline







WP 1:
Analysis of state of the art

WP 2:
Development and implementation of improved systems for high-gradient heating and hot particle blasting

WP 3:
Implementation of relevant test profiles for different cell chemistries and benchmarking of test results