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Heat Resistant Components for BEV Traction Batteries

A long range and short charging times play an important role for users of Battery Electric Vehicles (BEVs). This requires lithium-ion battery systems with high performance cells. Thermal runaway is the inherent risk of such battery cells with the potential consequence being severe vehicle damages or occupants' injuries. Oerlikon has developed solutions to minimize the effects of such a process.

Market acceptance of battery electric vehicles is strongly dependent on performance as well as vehicle cost. The traction battery is a significant performance driver but also a major cost contributor. Continuous improvement of driving performance and reduction of costs in short development cycles is therefore essential for market success.

Expectations for high ranges and short charging cycles require batteries with high energy density, which means tight cell packaging within high performance Nickel Manganese Cobalt (NMC) cell types. An inherent risk of such cells is Thermal Runaway (TR), a self-heating of the battery cell in an exothermic degradation of the active mass, resulting in an explosive release of hot and conductive reaction gases through the cell vent. Self-heating is triggered when the cell temperature exceeds a critical limit. Over-heating can be caused by internal or external short circuits (contamination or crash), external heating, over-charging, or a malfunction of the cooling system.

Without a protection concept, this event triggers a TR in further cells by conductive heat transfer to adjacent cells, through the hot gas stream of a venting cell or ignition of the conductive atmosphere due to electrical arcing. This chain reaction is called Thermal Propagation (TP), resulting in severe damage to the battery or vehicle and, in the worst-case, fatal consequences for occupants. The risk of TR can be minimized by design, but not eliminated. A safety concept is

WRITTEN BY

Dr.-Ing. Marcus Spreckels
is Head of Technology for Thermal Insulation Systems at Oerlikon Friction Systems in Bremen (Germany).

Andrew Raistrick, M. Eng.
is Manager Battery/TIS Engineering & BEV Safety at Oerlikon Friction Systems in Nuneaton (United Kingdom).

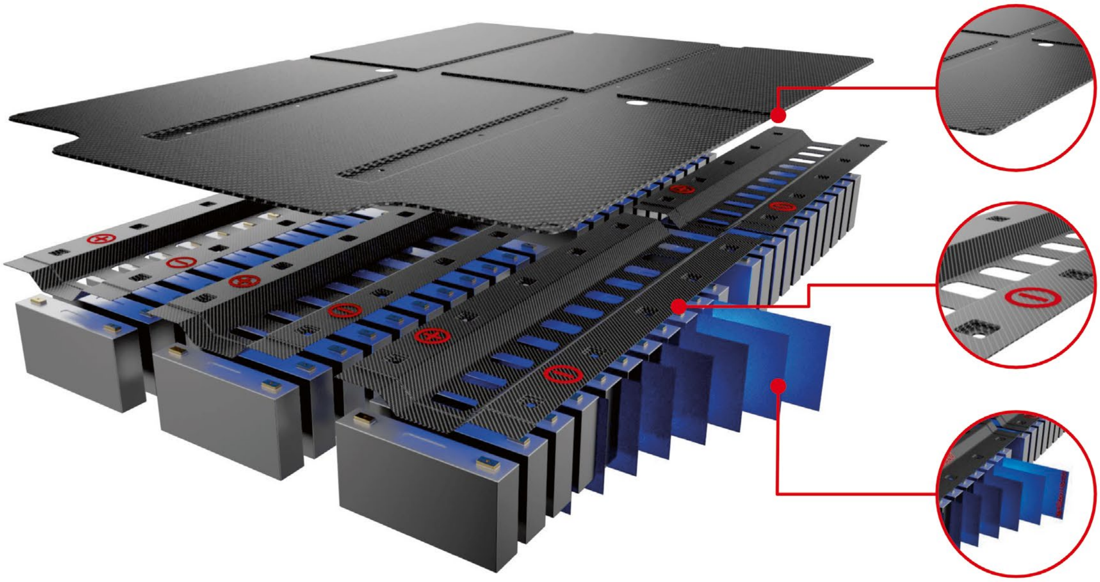

FIGURE 1 Heat resistant components for safety concepts of battery electric vehicles (© Oerlikon)

required to avoid TP and its catastrophic consequences.

SAFETY CONCEPTS AND REQUIRED COMPONENTS

Heat resistant parts such as heat shields or heat barriers, gas guiding components, and cell separators increase the safety of a battery system, **FIGURE 1**. Heat shields are barriers typically located between the cell vent and the battery cover or other parts of the battery enclosure and protect them from the direct impact of the particle-loaded hot gas stream from a venting cell. The heat shield needs to withstand mechanical stress from the particle bombardment combined with thermal stress from the hot gas. In addition, if the temperature of the protected component must be kept below a certain limit, such as the the component melting temperature, an insulating function is also required.

Gas guiding components channel hot gas from the cell vent, including the conducting particles, to uncritical areas and/or build an electrically insulating barrier between High Voltage (HV) components. This eliminates the risk of electrical arcing between HV terminals of different voltage potential.

Separators between single cells inhibit heat transfer from one cell to the adjacent cells. In addition to the thermal function, the separator elements should be able to compensate cell swelling over lifetime, as well as breathing during charging and discharging, while minimizing pressure on the cell stack. Separators ensure that pressure on the cell remains within the optimal range for cycle stability.

The consequence of TR for occupants and the vehicle depends on the effectiveness of the safety concept with one, two or all the before-mentioned components. Four severity levels can be defined, **FIGURE 2**.

LEVEL 1

This level provides enough time for a safe occupant evacuation. No fire or smoke is allowed outside the battery box for 10 min (typical time frame). A heat shield with good thermal insulation protects the mechanical integrity of the battery box and an effective gas guidance prohibits catastrophic electrical arcing during the initial phase of thermal chain reaction. However, it will eventually lead to total vehicle loss. The level 1 is the minimum legal requirement from the United Nations Global Technical Regulation No. 20 (Electric Vehicle Safety (EVS)) [1], which many countries have adopted.

LEVEL 2

TP is contained, and damage is limited to the battery box. Occupants have enough time to safely evacuate; however, some smoke might be observed outside of the battery box. An improved cell separator with high thermal insulation interrupts the thermal chain reaction. An insulating heat shield, as well as gas and particle guidance as described for level 1, complete the safety concept. The vehicle will be towed for repair and the battery can be replaced.

LEVEL 3

The Stop TP or Zero TP concept prevents any escalation of TR. The driver will be notified about a battery failure, but no evacuation is required. A highly effective thermal insulation between cells eliminates the thermal chain reaction. The event is isolated to one cell. Therefore, the performance of the heat shield and gas guidance can be reduced. The vehicle can be towed for the battery to be repaired.

LEVEL 4

In addition to level 3, here, a battery management system still allows the vehicle to be driven to a location where the battery can be repaired.

ENGINEERED SAFETY SOLUTIONS

Concept and design of battery systems are diverse, depending on the strategies and preferences of manufacturers. It starts with cell chemistry, such as lithium-ferrophosphate, NMC or newly

Increasing safety and comfort	Heat shield	Gas guidance	Cell separator
Level 1 **Provide time for safe evacuation**	+ +	+ + +	+ +
Level 2 **No fire outside battery box**	+ + +	+ + +	+ +
Level 3 **Stop-TP / Zero-TP**	+	+ +	+ + +
Level 4 **Stop-TP / Zero-TP and limp-home mode**	+	+ +	+ + +

FIGURE 2 Impact of a thermal runaway and the importance of the safety components (© Oerlikon)

sodium ion batteries and continues with the format, such as pouch, cylindrical or prismatic, through to the cell pack, whether cell-to-module, cell-to-pack or cell-to-body. Each battery system requires a unique safety concept with engineered components. A comprehensive Thermal Insulation System (TIS) is a combination of a thermal insulation material with a smart design.

The basis of a good thermal insulation system is the insulation material, namely an engineered composite that provides the basic physical, chemical, and mechanical properties. The most important is high heat resistance because the material should remain intact as long as possible during TR or even TP.

The other factor of a good solution is design. Designed components should address the specific safety requirements of the battery concept while being light and space-saving. The safety concept should be an integral part of the battery design and considered from the early stages of development.

HEAT SHIELD

The heat shields from Oerlikon has been developed from a multi-layer material in combination with a specific design concept. They have a high temperature resistance of up to 1400 °C, a high mechanical strength against the impact of direct hot gas particles, and good thermal insulation. Materials are built from layers of heat-resistant mineral fiber composite, integrated with additional constituents for mechanical reinforcement to. Adding a heat barrier converts

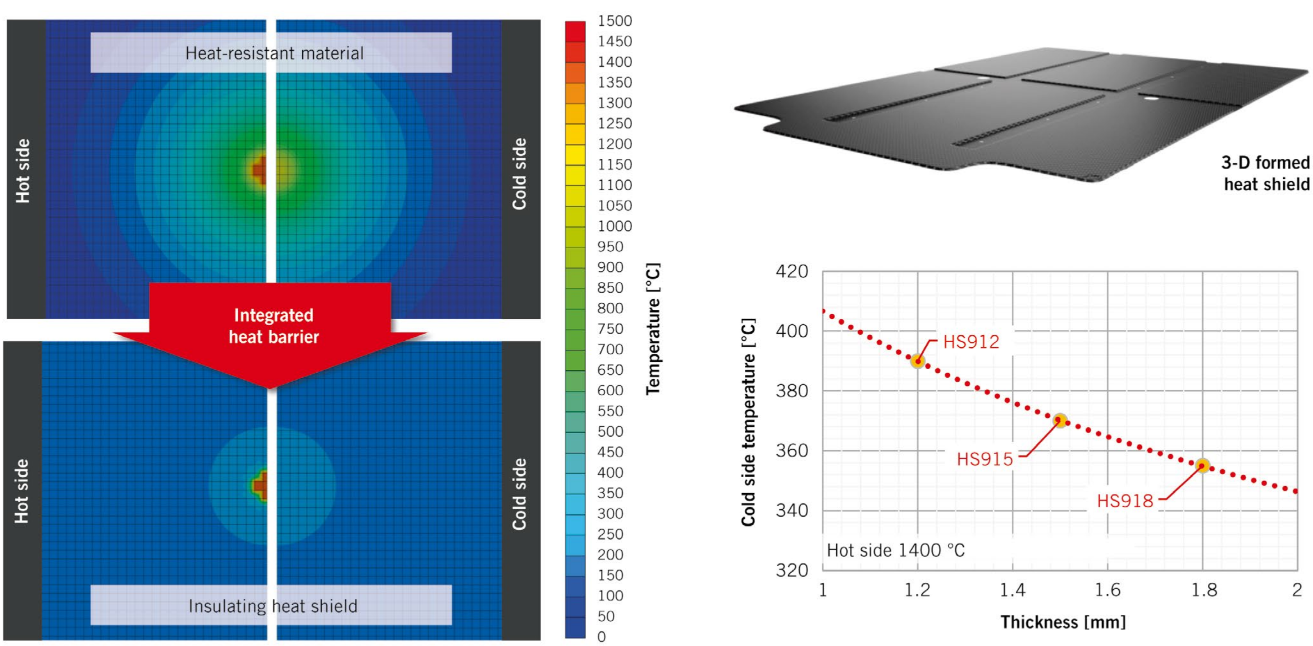

FIGURE 3 The heat barrier upgrades a heat-resistant material to an insulating heat shield (© Oerlikon)

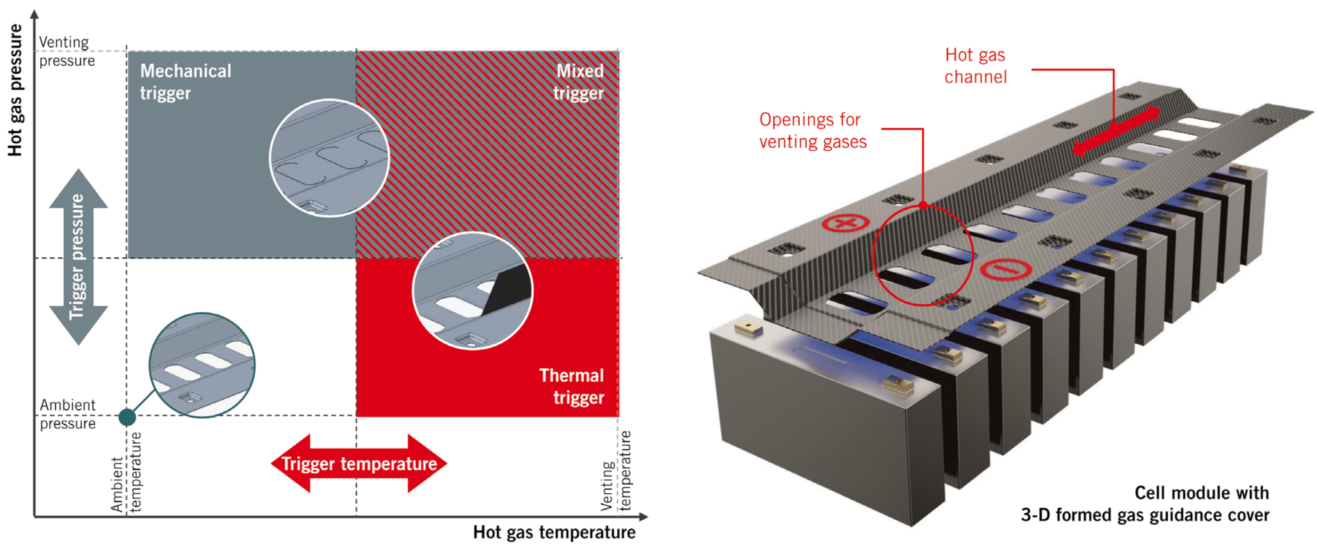

FIGURE 4 Trigger options for venting openings of gas guiding elements (© Oerlikon)

such material to an insulating heat shield. The cold side temperature drops from over 1000 to less than 400 °C at a flame temperature of 1400 °C, **FIGURE 3**. Tailor-made heat shields can also be designed with local heat barriers for temperature-critical areas or areas with high heat impact, for example above the pressure vents of a cell.

At only 1.2 mm thickness, the thinnest heat shield provides resistance against particle impact for at least 15 s while limiting the temperature on the outside to below 400 °C. The temperature limit of typical low-weight lid materials, such as aluminum or sheet molding composite, will not be surpassed. Additional material layers can be incorporated to

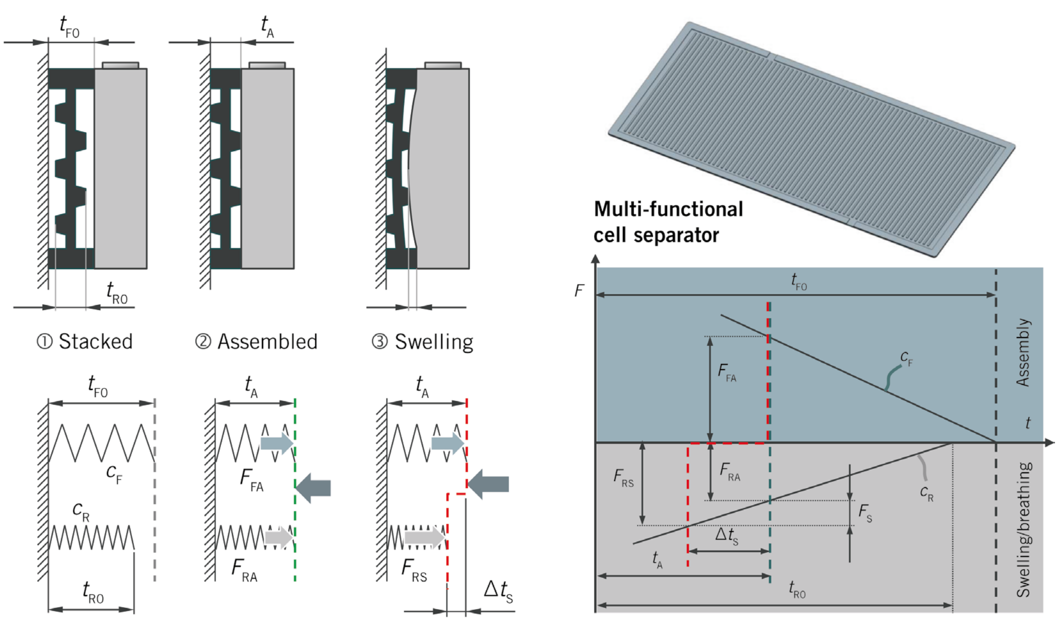

FIGURE 5 Mechanical model of a multi-functional cell separator (© Oerlikon)

increase particle resistance and insulation performance for higher performance cells, or multiple venting events in case of propagation. The insulation performance of such heat shields is shown in **FIGURE 3**. These heat shields therefore exceed requirements for every type of battery cell configuration. The material can be formed three-dimensionally to produce a one-piece heat shield. It can follow the contour of the enclosure to maximize the coverage, protecting all critical areas and allowing it to be integrated tightly into the existing architecture.

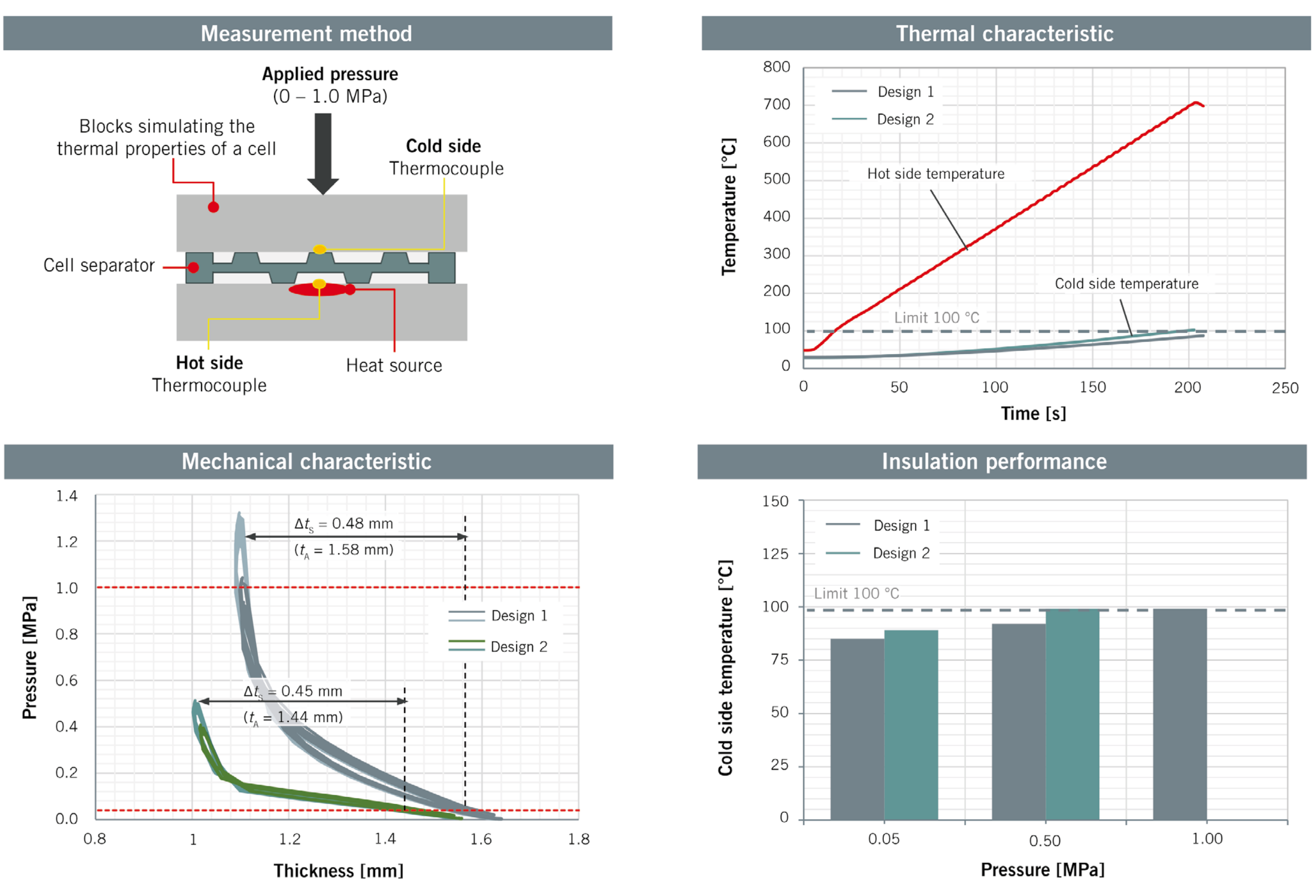

FIGURE 6 Thermal and mechanical characteristics of a multi-functional cell separator (© Oerlikon)

CONTROLLED GAS GUIDANCE

The components responsible for gas guidance play a crucial role in collecting hot gas stream from a venting cell. Their primary function is to safeguard critical components and areas by preventing conducting particles from reaching them. Critical areas include energized, non-insulated surfaces and the space between them. The gas guiding system achieves this by emitting an electrically conducting atmosphere, which establishes an electrically insulating barrier whilst providing protection against thermal resistance.

For effective performance, the material used for these gas guiding elements must be heat-resistant to the extent that it can withstand the hot gas stream, while also requiring electrical insulation properties and mechanical stability. This ensures adequate channels remain intact during a TR event. An ideal choice is a modified multi-layer material; similar to that used for the heat shield.

However, the key focus lies on the design of the entry openings for the hot gases within the gas guiding structure. These openings must remain closed when the cell is intact but must open instantly during a venting event. To address this requirement, a configured mechanism covers the vent opening and is triggered only in response to a TR event. The triggering opening mechanism can be designed according to elevated temperature, pressure from the venting gas, or a combination of both, **FIGURE 4**. A mechanical pressure trigger can be realized by a predetermined breaking point in the gas guiding component; the trigger pressure can be adjusted by the strength of the breaking points. Openings that are held shut by heat-sensitive membrane are thermally triggered, whereby the trigger temperature depends on the membrane material.

A pressure-triggered opening mechanism can be strategically positioned directly above the cell vent to intercept the initial gas impulse. In contrast, temperature-triggered opening mechanisms could be utilized for pouch cells where the venting location is less predictable.

This adaptive approach allows customization of the system characteristics to match the specific type of battery cell and its venting behavior.

CELL SEPARATORS

Cell separators mainly block conductive heat transfer from one cell to the adjacent cell. The Stop TP or Zero TP concept requires that the temperature of a cell should not exceed 100 °C; this is the temperature that triggers the self-heating TR process. Advanced cell separators feature an elastic property to compensate for cell breathing and cell swelling, as well as the assembly tolerances of the cell stack. The required thermal and mechanical properties cannot be solely achieved by the bulk material such as mica composite, aerogel fleece or foam. A supporting design component is required to realize thin cell separators.

The developed cell separator provides two areas with different elastic properties, **FIGURE 5**. A solid frame from an elastomer material compensates dimensional tolerance of the cell stack when assembled into the module or pack; and a rib structure provides lower elasticity in the center to compensate for swelling/breathing. This concept allows an independent dimensional adjustment of the solid frame and the rib structure and, so that the elasticity characteristic can be adapted to the assembly situation and cell characteristic as illustrated by the mechanical model in **FIGURE 5**.

FIGURE 6 shows the results of the thermal and mechanical characterization of two samples with different rib designs. Thermal behavior is almost equal: both samples limit temperature on the cold side to <100 °C despite temperature increases on the hot side from ambient to 700 °C in 200 s. Both designs allow compression of at least 0.45 mm within the typical pressure limits that are crucial for cell cycle stability (minimum 0.05 MPa, maximum 1 MPa). The assembled thickness is between 1.4 and 1.6 mm, which means a compressibility of more than 30 %.

However, the mechanical characteristic is significantly different: The pressure-thickness gradient of design 1 is approximately twice as high than that of design 2. Design 1 is "harder" than design 2. Increased compressibility of >50 % is possible at larger separator thicknesses of 1.8 to 2.0 mm.

REFERENCE

[1] United Nations: Global Technical Regulation on the Electric Vehicle Safety (EVS), May 3, 2018. Online: https://unece.org/transport/standards/transport/vehicle-regulations-wp29/global-technical-regulations-gtrs, access: January 24, 2024

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