FIRE PROTECTION DESIGN CONCEPTS IN A COMPOSITE BATTERY MODULE HOUSING

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1 Abstract

Automotive batteries are making significant strides towards power-dense designs. The development of the housing presents challenges of being lightweight while also ensuring enhanced safety in the event of thermal runaway of the cells. The presented battery study illustrates the methodical development of a module housing concept. By focusing on the advantageous use of composite material technologies, fire protection concepts can be directly integrated into the overall system. Furthermore, the development of the pouch-cell module aimed to simplify the assembly and the integration of a direct tab cooling. The cell pressure preload is also further integrated into the housing. The concept is methodically developed from a blank slate and elaborated upon until it reaches the prototype stage.

2 Project overview

The aim of the composite battery module was born out of the idea to explore and showcase the potentials of modern composite materials in the application of an electric vehicle battery housing. The project was initialized by Sumitomo Bakelite Europe (Ghent) NV, a leader in thermoset resin materials. The Fraunhofer ICT was commissioned to develop and investigate the composite battery module housing. Especially regarding the thermal runaway, the introduction of composites in all areas of the hosing let to the finding of several safety improving features. These can be subdivided in aspects, that prevent thermal runaway in the first place and those which prevent propagation, namely the compartment design and the integrated venting path.

The module consists of 36 butterfly-style pouch cells arranged in compartments and preloaded between the endplates by strapping bands. The terminal sides are completed by the Integrated Connection and Cooling Plates (ICCP) and covered by the Burst Valve Plate (BVP) and the Venting Cover (VC) depicted in Figure 1.

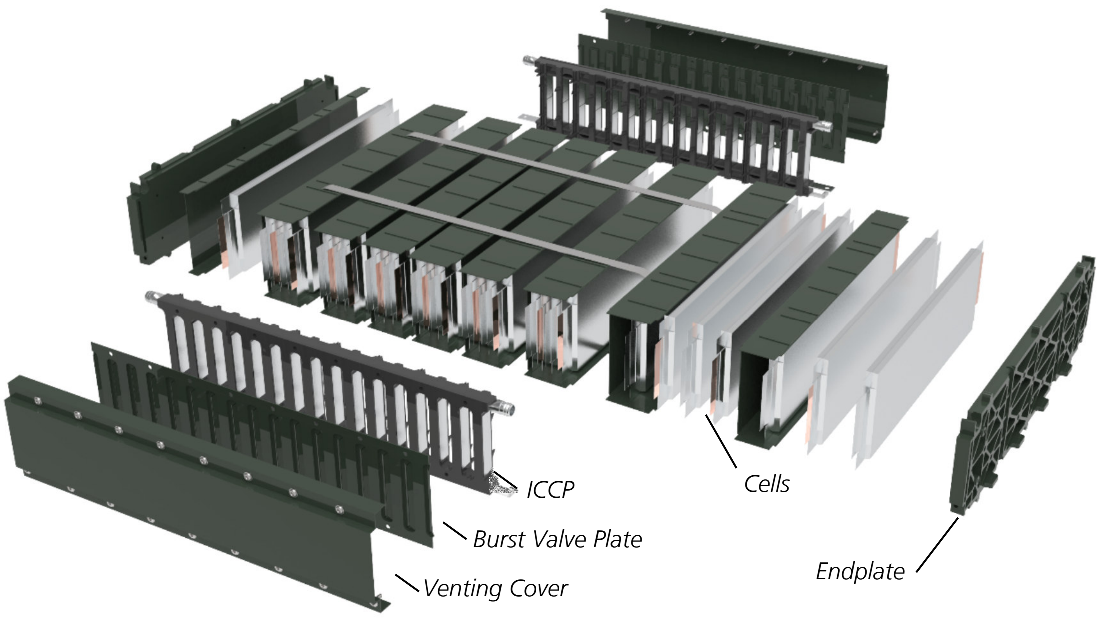

Figure 1: Explosion view of the concepted Module

3 Preventing Thermal Runaway

The thermal runaway in a lithium-ion battery cell is always initiated by one or more of these three mechanics: Electrical-, mechanical- and thermal-abuse. During the thermal runaway these will trigger each other [1]. To prevent thermal runaway in the first place, any cause that could lead to one of these kind of damage on the cell has to be prevented.

3.1 Embedded electronics

In the "Integrated Connection and Cooling Plate" (ICCP) the busbars, the voltage measuring and balancing lines as well as an aluminum cooling pipe ere embedded in Sumikon® EME-G720E, an epoxy based plastic overmold (Figure 2). The fixation of the wires promises a lower risk of connection lost to the battery management system under vibration and a lower risk of loosen busbars leading to a potential external short circuit. In this way the danger of electric abuse is countered.

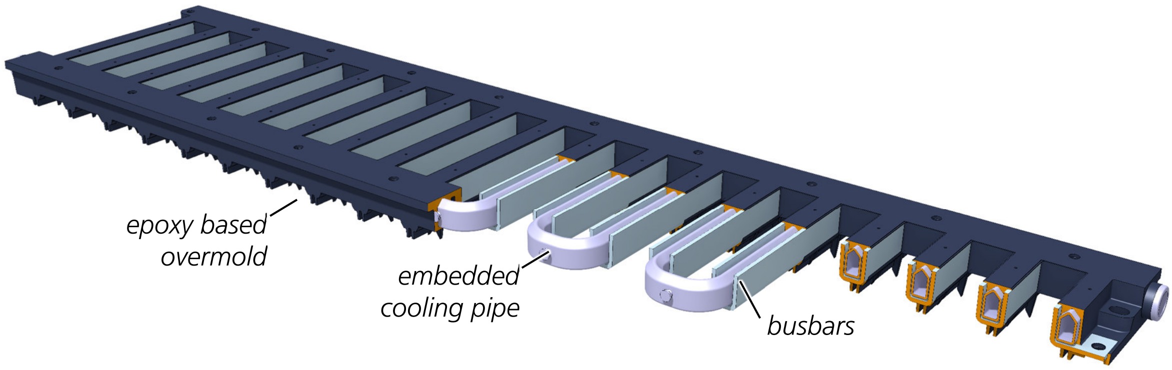

Figure 2: Cutout view of the Integrated Connection and Cooling Plate (ICCP). Embedded BMS wires are not visualized

3.2 Tab cooling system

In the presented composite module, the integrated cooling channel facilitates direct thermal management at the cell tab interface (Figure 2). This way the tab cooling solution presented in [2] is developed further into an industrial manufacturable design. Cooling at this location was chosen to aim for a more even heating of the cell, as the terminals of pouch cells and the busbar connections often represent bottlenecks in the electric current flow with increased ohmic losses. This way, not only potential thermal abuse by hotspots is avoided, also the degradation can be reduced [3]. Additional work by Liebertseder showed, that the cooling location is well suited to cool a "butterfly" cell evenly, but to maximize the cooling power for high currents or to slow down thermal runaway, an additional cooling on one or both of the seam sides of the cell (respectively a bottom or lid cooling in the housing) would be required [4], but was not integrated in the composite module concept.

3.3 Shape optimized Endplates

To prevent the mechanical abuse by an uneven pressure distribution due to the constriction of the strapping bands on the most outer cells, the Endplate shapes were further analyzed. The perspective of the optimization was to calculate the shape, which leads to an even pressure distribution on the cell, when loded by the strapping bands. The optimization was achieved by reshaping the originally flat surface respectively to the not optimized pressure distribution. This optimization led to a decrease of pressure variation by a factor of 7.6, visualized in Figure 3.

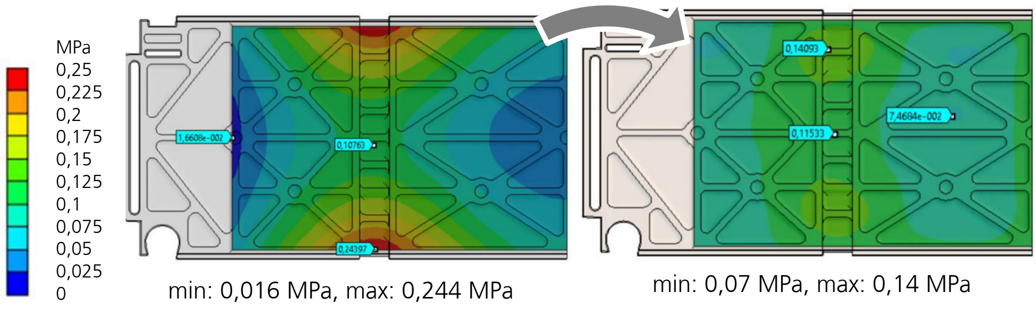

Figure 3: Shape optimization of the endplates

4 Slowing and Stopping Thermal Runaway

4.1 Cell compartment design

The cell stack of one module is drafted to be separated in several cell compartments. Each compartment is enclosed on three sides by a C-shaped housing part (Figure 4). When assembled, the sidewalls interlock with slots on the neighboring part, thus creating a labyrinth seal. The insertion of silicon adhesive into the slot can be used for an improved sealing function.

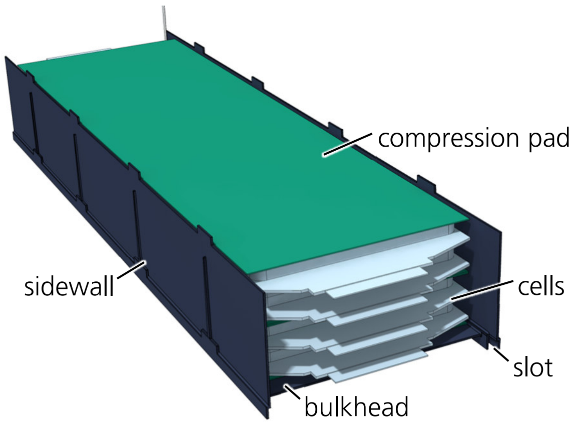

Figure 4: One C-shaped compartment with 4 cells and compression pads

In case of the thermal runaway of a cell the bulkhead walls improve the module safety by preventing the burning gases to reach other cells than those in the same compartment. Therefore, a high temperature stable material was needed for these wall parts. The phenolic resin composite Vyncolit® X655FR provides this characteristic with the tested ability to withstand temperatures of a 2.2 kW flame over 10 min (affected area d=25 mm).

As all cells of one compartment are expected to enter thermal runaway, the number of cells per compartment has a high impact in the expected intensity of a partwise thermal runaway. With four cells per compartment in the design of the composite battery module a more aggressive and lightweight approach was chosen.

The thermal runaway propagation between compartments resulting from heat conduction is countered with the compression pads next to the bulkhead wall, reducing the heat conductivity. For an even more effective suppression of the conducted heat, the insertion of even better heatshields like aerogel [5] should be considered.

4.2 Venting concept

An important aspect of a module wide thermal runaway is the propagation via the venting gases. When a cell enters a heat-temperature reaction loop various reactions (decomposition of the solid electrolyte interface, anode and electrolyte reaction, cathode rection) lead to an increase in temperature and pressure [1]. Finaly the cell will rupture, and the formed gasses vent out of the cell. With increasing temperatures these gases will ignite, leading to a high hazard triggering further cells into thermal runaway (TR) [6].

Therefore, we focused on a save release of the venting gasses through the housing structure. This venting channel assembly is located on the two terminal sides of the LiPo-pouch-cells. As visualized in Figure 5, it consists of gas passage holes in the ICCP, a break-valve-plate and a covering sheet. The later two items are produced from phenolic resin which offers high temperature stability and enables a lightweight design.

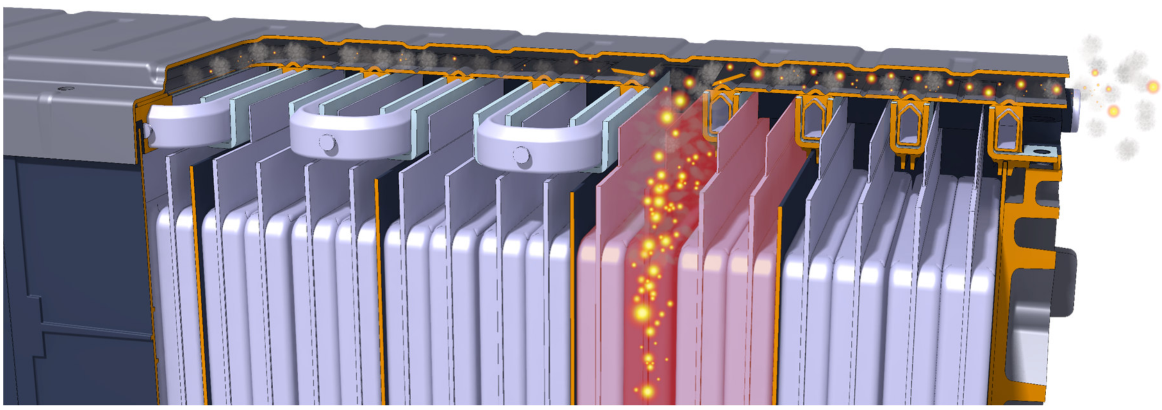

Figure 5: Venting path visualized in a cutout view

4.3 Burst valve design

The task of the burst valve is the safe release of overpressure from the inside of a cell compartment. On the other hand the intrusion of (hot) gases of the TR of a neighboring cells should be prevented. This leads to the requirement of a burst pressure, which is high towards the inside and low (<1e5 Pa) towards the outside.

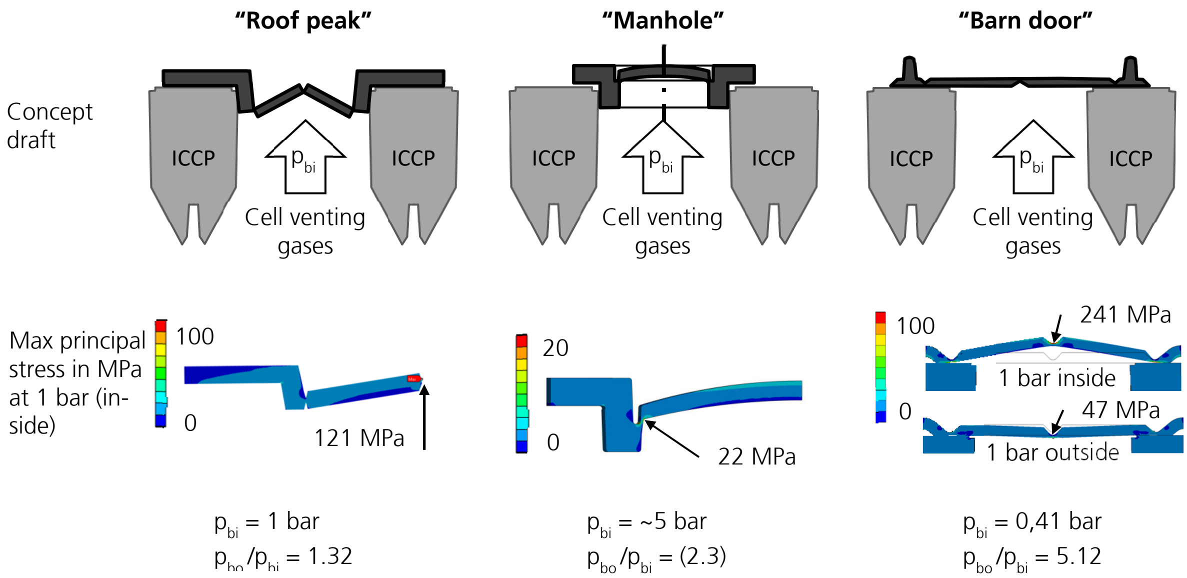

Figure 6: Burst valve concepts with expected burst pressure p_{bi} (inside) in bar and ratio of inside and outside burst pressure p_{bo} /p_{bi}

To achieve this, several concepts were outlined as depicted in Figure 6: The "roof peak" concept based on the mechanic of two beams at an angle and the material property which offers a much lower tensile than compressive strength. Inside pressure leads to tensional stress in the joints, acting as breaking points, while outside pressure leads to compressive load in the breaking points. But as the load in the breaking points was always overlayed with bending stresses, the achieved burst pressure ratio was not as high.
The "manhole" concept was thought to enable very high burst pressure ratios. But in the simulation, there occurs still a slight bending in the seam, so the simulation data did not support this claim. Even more problematic is, that there has to be a thin break seam for manufacturing and sealing purposes connecting the lid to the base. Even the thinnest possible seams leads to high opening pressures.
The in the prototype (Figure 7) implemented "barn door" design uses the rim around the holes of the Integrated Cooling and Connection Plate (ICCP) as a frame to rest the "gates" covering the hole in case of outside pressure. Inside pressure on the other hand leads to high bending stresses in the breaking seams and therefore a low burst pressure.

Figure 7: Compression molded burst valve plate from Vyncolit® X655FR material

5 Summary

In this paper several concepts were presented, demonstrating how composite materials can be used to increase the fire protection in a battery module. These concepts are integrated as features in the Composite Battery Module prototype. To prevent short-circuits, the cooling system and the electronics are embedded in plastics. The cell compartment design, together with the venting concept, including specially designed burst valves, minimizes the consequences in the event of a thermal runaway.

6 References

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