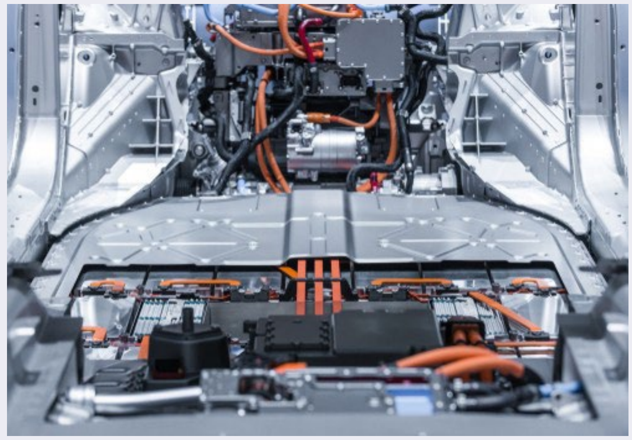
Technical Bulletin

Thermal Runaway

One of the biggest challenges faced by electric vehicle manufacturers is the search for cost-effective and efficient solutions to address the issue of thermal runaway in battery packs. Thermal runaway is a reaction that propagates from one battery cell to another, leading to extremely high temperatures, the potential of dangerous battery combustion and subsequent harm to the vehicle's passengers.

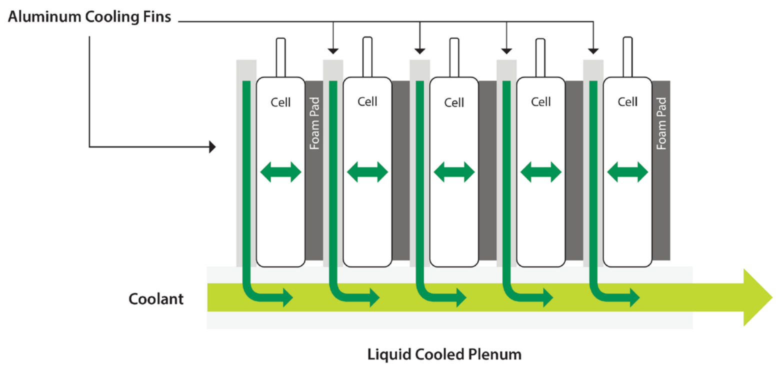


In electric vehicle batteries an increase in energy density elevates the risk of thermal runaway, a chemical reaction in which battery cell temperatures rise rapidly, causing spontaneous combustion of the battery and often the car along with it.

Battery designers must weigh this risk with the consumer's need to have batteries with higher energy density that enable longer range electric vehicles to compete effectively with their traditional internal combustion engine (ICE) counterparts.

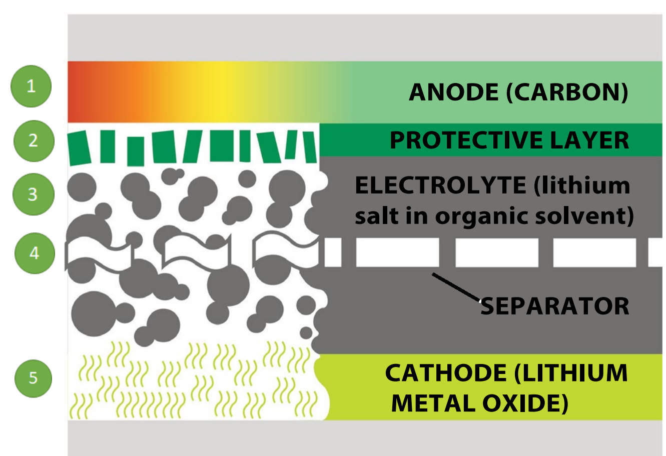
Designers can manage the thermal runaway risk by carefully managing the exposure of cells to temperature within the battery. This Technical Bulletin explores the material considerations for cell-to-cell thermal management to ensure optimum battery safety.

OEMs and battery designers look to reduce the risk of thermal runaway on several fronts. Firstly, the battery pack must be operating at a proper temperature (achieved using cooling systems) and at an optimal pressure via the use of battery compression pads. Secondly, electric vehicle makers incorporate the use of specialty materials between cells and modules - or around the pack - to help slow down or eliminate the propagation of thermal events.



Under normal operating conditions, battery temperature is regulated through active or passive cooling systems. Optimal cell pressures are regulated through compression pads. To add extra thermal runaway protection, designers can add layers or use specialized pads that reduce the speed or likelihood of runaway propagation.

1. Heating begins
2. The protective layer starts to break down
3. Electrolyte breaks down into flammable gases
4. The separator melts, potentially leading to a short circuit
5. Cathode breaks down, which generates oxygen



Mechanisms to Delay or Stop Thermal Propagation within a Battery

When selecting materials to aid in thermal runaway problems, designers should consider designs that can effectively delay thermal runaway without sacrificing reduced battery range or other negative effects that come with excessive weight.

While there are many nuances within each category, the major mechanisms that can be used to delay or stop thermal propagation are insulation, intumescence (char forming), extinguishing, and heat spreading.

Insulation : Insulation is the most common mechanism explored by battery designers. Insulation uses a material or system of materials to prevent heat in one area from spreading to adjacent cells, preventing the propagation of thermal runaway. Materials used for insulation have a low thermal conductivity which makes them excellent at stopping heat transfer. Designers will often look for insulating types of materials to be resistant to burning or melting for maximum protection against the high temperatures found in thermal propagation.

Intumescence : Intumescence works in a similar manner to insulation. However, instead of the material having a very low thermal conductivity at the start, it creates an insulation barrier - via a char layer - when exposed to high temperatures or flame. The char layer is resistant to burning and has a low thermal conductivity, but only be formed when there is room for the material to expand during the intumescent process. Occasionally intumescence materials serve a "just in case" purpose in the battery, providing value in protecting against thermal runaway but serving no other benefit.

Extinguishing : This category could mean many different things depending on the design, but the essence is to extinguish any flame without the battery catching on fire. This could be done using the release of some type of chemical that quenches flames, removing the oxygen from the system, or in some cases, by utilizing special materials that will create and release some extinguishing medium when exposed to heat. Extinguishing systems themselves are tricky to design and expensive to implement into an automobile, but specialty materials that include extinguishing characteristics could offer unique solutions in this space.

Heat Spreading/Sinks : Heat spreading/sink materials are the opposite of insulation materials. These materials have high thermal conductivity and can be used to spread out excess heat, delay the growth of localized hot spots, build a delay in overall temperature rise, or remove heat from danger areas to be released in safer areas within the battery.

Emerging Technologies

Air cooling and liquid cooling have long been the industry standard for battery cooling in electric vehicles. As electric vehicle technology has evolved into using higher energy densities, immersion cooling has gained traction as a high performance option for vehicles. Immersion cooling designs completely submerge battery cells into dielectric fluid.

Rogers Approach

Rogers Corporation addresses thermal runaway via the use of several of the previously outlined mechanism types, combining the value they bring with high performance compression pads for prismatic and pouch cell packs. Our thermal runaway approach leverages the elastic design characteristics of compression pads to provide reliable thermal protection.

At present we are exploring the addition of various barrier or insulation layers to multiple chemistry platforms or specially-formulated materials which will result in dual purpose foams with customizable compression performance and advanced thermal protection.

ProCell™ 800 series composites: ProCell™ series composites are thin foil laminates that can be applied to one or both sides of a foam. The foil serves two main functions: it acts as both a flame barrier and a heat spreader. When applied with compression pad materials like PORON® polyurethane or BISCO® silicone, ProCell composites block direct flame and spread heat out, allowing insulative foams to survive longer during thermal events. ProCell composites are available in two options, both 0.18mm thick. ProCell™ 800 composites utilize a silicone adhesive system while ProCell™ 801 composite materials utilize an acrylic adhesive system. ProCell 800 series composites are commercially available.

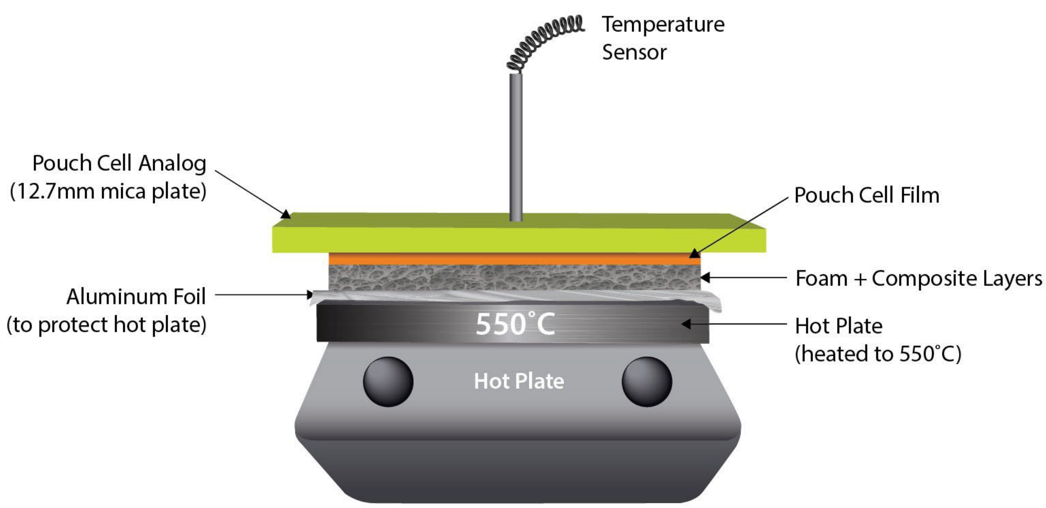
PORON® polyurethane composites: PORON® materials are some of the most commonly requested battery compression pad materials on the market but do not, at present, delay a thermal event caused by high temperatures. With the popularity and success of these materials as compression pads, Rogers is actively investigating how to improve the material's thermal performance. Two different PORON polyurethane composites are under consideration for their ability to provide an extra level of insulation and thermal resistance. Designers would be able to choose their desired formulation of these materials, as well as the firmness and compression curve shape. Samples are available for this development material.

Advanced silicone formulations: Silicone materials are another area of exploration. Standard silicones have inherently good thermal stability and chemical resistance compared to other elastomeric materials but lack the high temperature resistance needed to offer protection during catastrophic thermal events. Rogers has developed new silicone technologies that provide top level protection during thermal events but still maintain the key properties needed for compression pad applications. The materials do not utilize any type of composite, instead relying on special fillers and chemical reactions to improve the innate performance of the battery pad. Early hot plate and nail penetration results have shown excellent performance in delaying thermal runaway in small scale systems. Samples are available for this development material.

Testing and Results

On an ongoing basis, Rogers evaluates many methods for delaying thermal runaway and compares different material solutions. For main evaluations we use an internal hot plate test method as well as external nail penetration testing. We also have the ability to test to various other methods such as direct torch or auto ignition testing upon request.

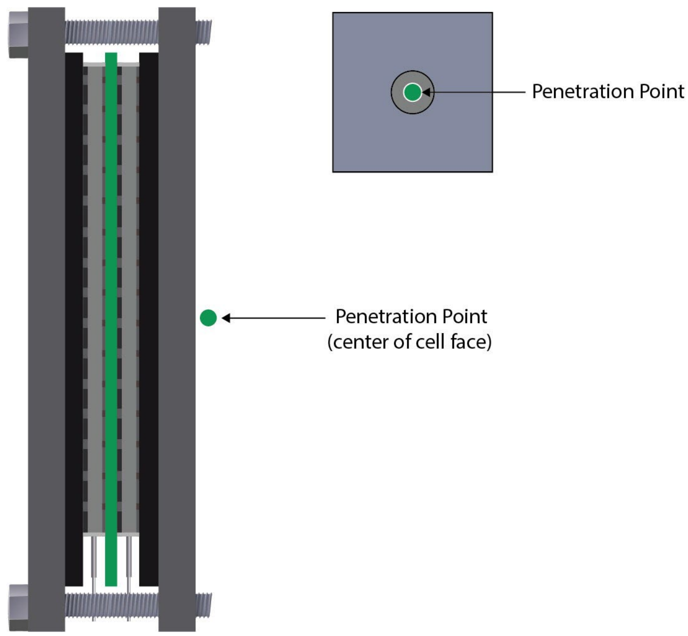
Hot Plate: Hot plate testing is done internally for material evaluation and comparison. It is conducted using a 550°C hot plate, with the test material sandwiched between the hot plate and a thick mica plate. A thermocouple is embedded at the surface. The test is designed to simulate and record temperature rise - the hot plate simulates the cell going into runaway and the mica plate/thermocouple represents an adjacent cell. Materials are compared based on the time delay for the thermocouple to read to 150°C, or the point where thermal runaway would likely propagate within a cell.



Hot Plate Testing: Internal Method

Testing and Results

Nail Penetration: Rogers partners with external labs to perform nail penetration testing on automotive scale pouch and prismatic battery cells. These tests use a stack of cells, one cell is punctured to force thermal runaway. By using actual cells, several thermocouples and voltage meters, we can determine how our materials perform under realistic conditions.



Nail Penetration Test Setup