TECHNICAL PAPER

Silicone Material Solutions for Battery Fire Protection

Lithium-ion battery cell and module/pack design engineers continue to develop improved systems while balancing performance, efficiency and safety considerations. Whether cylindrical, pouch or prismatic cell types are employed in these systems, assembly materials play many important roles in pack longevity, performance and safety. There are a variety of materials for battery fire protection (BFP), both in terms of chemistry type and material form, which must be considered for different cell types. In some cases, a combination of materials can be utilized to optimize performance.

Downselecting BFP materials can be a daunting task due to the wide array of products to consider. Testing materials directly in full module or pack builds is a major endeavor and may not be the most cost-effective way to proceed. To remedy the situation, a thoughtful approach centered on material screening tests can be used. In this paper, we highlight different approaches, based on cell type and material format, and introduce the silicone-based material solutions available from Dow, and discuss screening test methods that can aid in downselecting the appropriate BFP materials.

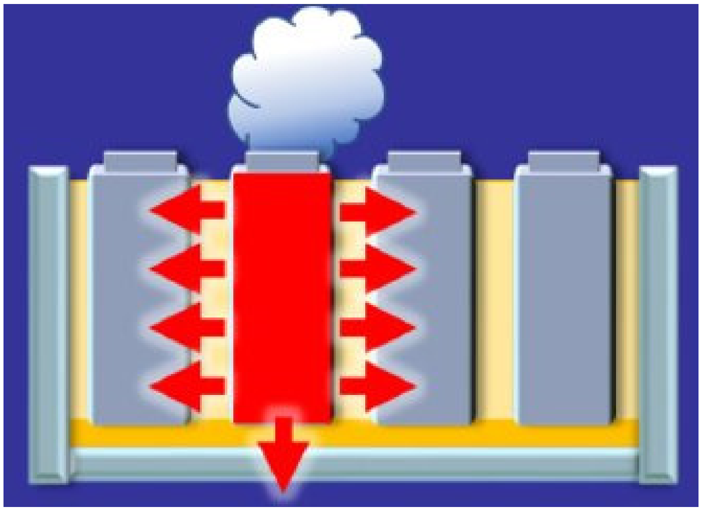
Battery Safety Concerns

When considering overall battery safety, there are two primary areas of concern: the potential for an individual cell to go into thermal runaway; and the potential for the heat generated from the cell in thermal runaway to propagate, known as thermal propagation, causing a thermal runaway in adjacent cells.

Thermal runaway in an individual cell can occur for several reasons, such as an internal short circuit, overheating or overcharging, or impact to or penetration of the cell. It can also arise from manufacturing defects or long-term failure mechanisms within the cell, such as dendritic growth that can cause eventual perforation of the polymer separator between the cathode and anode in the cell. In any of these cases, the result can be a violent reaction that generates a tremendous amount of gas pressure, flame and heat. The resulting pressure build-up within the cell can cause the vent cap or case to rupture and expel flame, hot gases, particles and other combustion materials onto adjacent cells.

The fire and heat generated from an individual cell in thermal runaway can jeopardize the adjacent cells. If sufficient heat is generated from an individual thermal runaway, exposed adjacent cells can go into thermal runaway themselves, thus creating a chain reaction known as thermal propagation (Fig. 1). Thermal propagation can create increased fire risk within a battery module or pack and put occupants of battery electric vehicles (BEVs) or hybrid electric vehicles (HEVs) in danger.

Figure 1: Thermal runaway in a cell can lead to thermal propagation in adjacent cells



As more BEVs and HEVs come to market, standards are being developed to address passenger safety with regards to battery fires. In China, for instance, the standard GB 38031-2020 states that no external fire, explosion or smoke should enter the passenger compartment within five minutes of a battery cell thermal event being detected in a module or pack. The intention of the standard is to allow sufficient time for vehicle occupants to escape to safety before the fire spreads, giving first responders sufficient time to contain the fire. Similar standards are currently being developed for other geographies, as well. In addition, some original equipment manufacturers (OEMs) are creating their own internal targets that go beyond these standards and designing systems for fire containment that give passengers even more time to escape.

Strategies for Mitigating Thermal Events

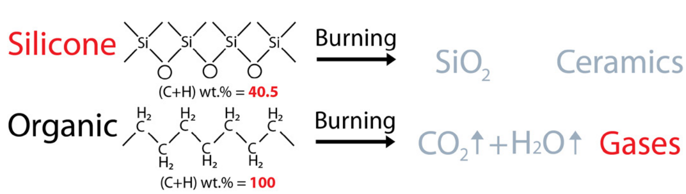
There are several approaches in reducing the potential for thermal runaway and thermal propagation. The first approach is to eliminate the potential for thermal runaway at the cell level. While improvements in cell chemistry and design are continually evolving, they are unlikely to eliminate the risk of thermal runaway. Design engineers must also consider the use of BFP materials for module and pack assembly as a second line of defense. Battery fire protection materials can be used in and around cells, and within modules and packs, for the purpose of containing or mitigating a thermal runaway event and preventing thermal propagation. There are a variety of BFP material types and forms available for cell protection in these applications. A third approach for mitigation of thermal events is the use of BFP materials at the module or pack level, including as barrier materials both inside and outside the module or pack.

Advantages of Silicones as BFP Materials

Silicones have properties that make them excellent candidates for BFP applications. First, silicones are easy to apply or dispense into a module or pack for cell encapsulation and protection. Once incorporated in the module or pack, silicones generate negligible heat when curing, which is important for cell protection during the assembly process. Silicones also provide strength, stability and protection for the cells within the module or pack during battery operation, and can survive many charge and discharge cycles over the life of the unit.

A more critical aspect of silicone performance is their inherent thermal stability. Silicones offer higher bond strength and are therefore more thermally stable than organic materials that could be considered for these applications. Moreover, when exposed to extremely high temperatures, such as those presented in thermal runaway situations, silicones decompose to yield mostly silicon dioxide (silica), which remains an electrically insulative material, whereas organic materials combust to release large volumes of decomposition gases (Fig. 2) and can add fuel to the fire in the case of a thermal runaway or thermal propagation situation. Some organic materials can be engineered with a very high crosslink density to minimize weight loss therefore minimizing the release of fuel gas at high temperatures. But these tend to be very brittle, and when exposed to high temperatures they leave behind a carbon-based char that is not electrically insulating. Also, certain organic materials can release toxic by-products when they decompose, which is not a concern when using silicones.

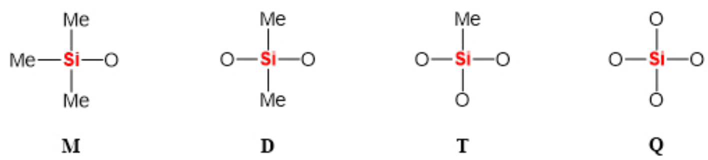
Figure 2: Silicones compared to organics at high temperature



Silicone Material Solutions from Dow

Dow has been a leader in the silicones industry since the 1940s. During its long history of innovations to meet customer needs, Dow has developed and commercialized a full range of silicone and silicone-organic hybrid products utilizing the basic siloxane structural units of M, D, T and Q as depicted in Figure 3. Product families include silanes, siloxane fluids, silicone elastomers and rubbers, silicone resins, organically modified silicones and siloxane-modified organics, and formulated products. Particularly relevant for BFP are liquid silicone rubbers (LSRs), high-consistency silicone rubbers (HCRs), silicone foams formulated from either LSRs or HCRs and silicone resins.

Figure 3: Basic structural units of common silicone materials

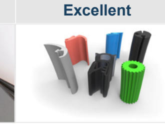


Liquid Silicone Rubber for Gels, Encapsulants and Coatings

Liquid silicone rubbers are formulated with low to medium molecular weight polydimethylsiloxanes bearing vinyl groups and polymethylhydrosiloxane crosslinkers. Various functional additives can be incorporated to fine-tune the properties that are important for BFP, such as thermal conductivity, flame and heat resistance, hardness, density and thermal capacity. Liquid silicone rubbers are typically cured with ppm levels of a platinum (Pt) group catalyst and are formulated into one-part products for heat cure, or two-part products for room temperature cure.

Liquid silicone rubbers are differentiated from other silicone elastomers/rubbers in that they are liquid at room temperature. As such, LSRs are used as potting compounds or low-modulus gels to fill gaps between battery cells and other components, or to encapsulate cells or electronic/electric components to isolate them from each other during a cell failure. During normal operations they protect these components from mechanical vibrations and other abuses. They are also conveniently applied as a liquid coating onto a substrate such as a battery pack cover and then cured to delay or prevent damage to the substrate in the event of failure of one or more battery cells. Typical properties of LSRs are described in Table 1, along with other silicone materials used for battery fire safety to be discussed later.

Table 1: Silicone products for battery fire protection and their typical properties

Properties	SILASTIC™ Liquid Silicone Rubber (LSR)	DOWSIL™ Silicone Foam	DOWSIL™ High Consistency Rubber (HCR)
Curing time [min]	1 - 15	2 – 15	0.5 – 5
Viscosity [Pa.s]	1 - 10	1 – 10	N/A
Density [g/cm³]	1.1 – 1.4	0.1 - 0.5	1.1 – 1.5
Thermal conductivity [W/m.K]	0.3 – 1	< 0.1	0.3 – 1
Compressibility	Good	Excellent	Good
Flame resistance	Very good	Very good	Excellent
			

Depending on the type of battery and the design of the battery assembly, LSRs can play a vital role in enhancing the safety of occupants in an electric vehicle (EV). A selection of application examples is pictured in Figure 4. In the left-hand image, the LSR serves as a battery sealant, offering unparalleled mechanical flexibility at extremely low temperatures and survivability at high temperatures. In the center image, wire and cable assemblies are overmolded with LSR to provide reliability during normal operations and protection against fire in a thermal runaway event. The last example shows a busbar coated with a protective, fire-resistant LSR. Table 2 lists some of the LSR products available from Dow.

Figure 4: Example applications for liquid silicone rubbers in a battery assembly

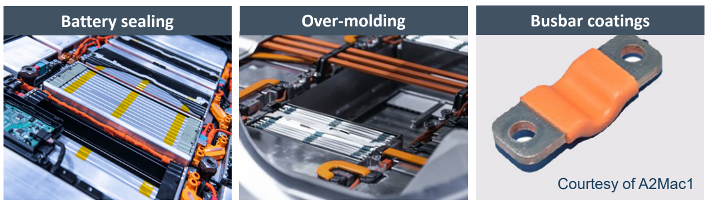


Table 2: Representative LSR products from Dow

Product	Cure Profile	Features & Benefits
SYLGARD™ 170 Fast Cure Elastomer	Fast room temperature	• Two-part 1:1 mix ratio • Fast room temperature cure in ~12 min. • Low mixed viscosity • Moderate thermal conductivity • Medium hardness (Shore A)
DOWSIL™ 3-4207 Tough Gel	Room temperature	• Two-part 1:1 mix ratio • Room temperature cure in 1.5 hours • Very low mixed viscosity • Medium hardness (Shore A) • Primeless adhesion to certain substrates • Good flame resistance
Developmental LSR	Room temperature	• Two-part 1:1 mix ratio • Tunable room temperature cure speed • Tunable viscosity and hardness • Excellent flame resistance

High-consistency Silicone Rubber for Profiles, Sheets and Laminates

High-consistency silicone rubbers (HCRs) are typically high molecular weight polydimethylsiloxanes cured using peroxides at elevated temperatures. Some are cured via a hydrosilylation reaction, but these are not as common. The polymer base can be trimethylsiloxy terminated with no unsaturated reactive groups, or it can have terminal and/or side vinyl groups. Reinforcing fillers are normally incorporated for superior mechanical strength and toughness. For battery protection against thermal runaway, flame retardants are among the important additives for HCRs. Various hardness values are attainable through the control of crosslink density and the selection of the right filler package. Due to their high molecular weight, HCRs are inherently high in viscosity and are solids or semi-solids at room temperature. Although their high viscosity precludes liquid dispense applications, HCRs are particularly suitable for molded parts or extruded/co-extruded profiles.

Figure 5 shows a few representative applications of HCRs in a battery pack. The first shows electric cables coated with fire-resistant HCR, which functions as an electrical insulation layer during normal operation and when exposed to fire. The second graphic shows a molded HCR sheet from a particular HCR formulation and its ceramified surface after being exposed to flame for five minutes. The porous ceramic layer formed normally offers significantly lower thermal conductivity than the HCR before flame exposure, making it an excellent choice as a thermal insulation layer between battery modules or cells as shown in the third application example. In addition to sheets molded from HCR, Dow has developed multilayer laminate solutions featuring an outstanding combination of heat insulation, compressibility and mechanical robustness. Some of these laminate solutions make use of HCRs as one or more functional layers. Table 3 lists some of the HCR products available from Dow.

Figure 5: Example applications for high-consistency silicone rubbers in a battery assembly

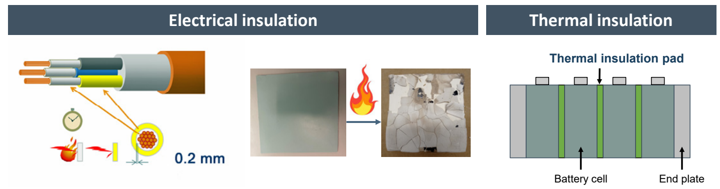


Table 3: Representative HCR products from Dow

Product	Cure Profile	Features & Benefits
SILASTIC™ SH 502 U	Peroxide heat cure	• Non-catalyzed • Blend with peroxide to cure • Low to medium hardness (Shore A) • Flame resistant)
SILASTIC™ SH 1447 U A	Peroxide heat cure	• Non-catalyzed • Blend with peroxide to cure • Medium to high hardness (Shore A) • Flame resistant
Developmental HCR	Peroxide heat cure	• Catalyzed or non-catalyzed • Medium to high hardness (Shore A) • Excellent flame resistance
Developmental HCR	N/A	• Pre-fabricated sheets or profiles • Adjustable thickness • Medium to high hardness (Shore A) • Excellent flame resistance

Silicone Foams for Dispense and Prefabricated Sheets

A range of high-performance silicone foam products are available from Dow. They are based on either LSRs or HCRs, as described above. Chemical foaming mechanisms are used in some, while physical blowing agents are used in others. Chemical foaming refers to a reaction, typically occurring concurrently with or as a part of the curing reaction, which generates gas that nucleates and grows into voids. The concurrent curing reaction solidifies the void structure. The combination of -SiH/HO- and -SiH/-SiVi reactions is most commonly utilized. Physical foaming refers to the use of volatile foaming agents such as liquids with a low boiling point or gas mixed in and entrapped within the formulation.

Compared with LSR and HCRs, foams are lower in density and thermal conductivity, and provide excellent compressibility. Foams based on LSRs have a wide range of viscosities and can be used as pottants and encapsulants, similiar to a typical LSR.

They are also often used as sealants such as formed-in-place foam gaskets (FIPFGs). Foam structures and performance properties such as cell size, open/closed pore ratio, uniformity, density, modulus, compression set, surface adhesion, flame resistance rating and thermal conductivity can all be effectively tuned by varying formulation ingredients. Rheology and reaction kinetics are typically tailored for the specific application.

In some applications, prefabricated foam sheets are desirable. They are routinely used in certain applications such as pouch cell batteries. Foamed silicones are also made from HCR. These foams are molded into a prefabricated shape, or converted in a continuous coating line on a substrate into a roll of flat sheet or extruded to form a profile. Figure 6 shows a few silicone foam application examples. The first is a liquid foam composition being dispensed into a simulated cylindrical cell battery module. The second is an FIPFG, and the third is sheets of prefabricated silicone foams. Table 4 lists some silicone foam products from Dow.

Figure 6: Example applications for silicone foams

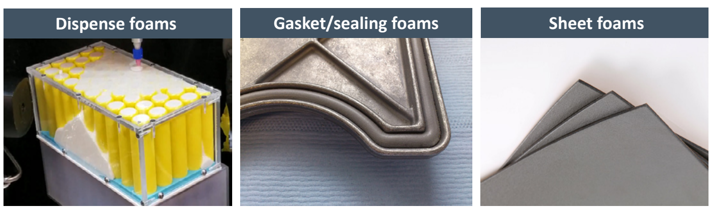


Table 4: Representative HCR products from Dow

Product	Cure Profile	Features & Benefits
DOWSIL™ 3-8209 Silicone Foam	Room temperature	• Two-part • Dark gray • Low to medium hardness • Can be dispensed and cured directly on parts
SILASTIC™ 8257 Silicone Foam	Fast room temperature	• Two-part • Black • Low hardness • Designed to be dispensed and cured directly on parts
DOWSIL™ 3-8235 RTV Foam	Room temperature	• Two-part • White • Low to medium hardness • Low density • Excellent fire resistance
DOWSIL™ EF-6525 RTV Foam	Room Temperature	• Two-part • Low mixed viscosity • Long working time • Low density • Good fire resistance
Developmental Foam	Room temperature	• Two-part • Tunable Color • Low to medium hardness • Low density • Low thermal conductivity • Good compressibility • High flame resistance
Developmental Foam Sheets	N/A	• 1.5 – 10 mm thick • Low to medium hardness (Shore 00) • Low density • Low thermal conductivity • Good compressibility • High flame resistance

Silicone Resins and Coatings Based on Silicone Resins

Silicone resins that make use of much higher content of T and sometimes Q structural units are much more tightly crosslinked siloxane networks than silicone elastomers and rubbers, when cured. This tighter network significantly reduces or eliminates some of the thermal degradation pathways commonly seen in polydimethylsiloxanes. Combined with reduced organic content, these resins have the best flame resistance and thermal stability among silicones. They are either cured by a condensation reaction between silicon alkoxy and silicon hydroxyl groups, or by a hydrosilylation reaction between silicon hydride and silicon vinyl groups.

Silicone resins can be formulated in a wide variety of viscosities, ranging from low-viscosity liquids to solids that melt at different temperatures, and their curing speed can be tuned to suit application needs. Mechanically, cured resins can be quite rigid, potentially reaching a Young's modulus of more than 1 GPa without relying on reinforcing fillers. The M, D, T, Q compositional space allows basically any modulus between the values typical of a silicone elastomer (0.1 to 2 MPa) and that of a rigid resin to be readily attained. As a supplier fully integrated with every step of the silicone production process, Dow has a full range of silicone resin products to serve battery fire protection needs.

These characteristics make silicone resins some of the best choices as matrix resins for coatings that are resistant to high temperatures and/or environmental exposures. In addition, and particularly relevant to BFP, is the tunable ceramification behavior of silicone resins under flame exposure. Carefully selected silicone resins, used by themselves or with ancillary additives, form a ceramic layer of sufficient mechanical integrity under fire exposure to resist penetration by flames and hot particles. Table 5 lists some silicone resin products from Dow.

Table 5: Representative silicone resin products from Dow

Product	Cure Profile	Features & Benefits
DOWSIL™ RSN-804 Resin	Heat Cure	• Resin in a liquid carrier • High silicone dioxide content • High hardness • Low viscosity for easy formulation
DOWSIL™ RSN-6018 Resin	Heat Cure	• Solid • Dissolvable in low viscosity formulation ingredients • Medium to high hardness • Medium to high silicon dioxide content
Developmental Resin-based coating	Room temperature	• Two-part • Medium to high hardness • Designed to ceramify in flame for flame/ hot particle resistance • Tunable rheology for various coating processes

Suitability of Silicones for Processing Methods Used in Battery Applications

Liquid silicone rubbers, HCRs, silicone foams and silicone resins, offered by Dow under the brand names SILASTIC™, DOWSIL™, SYLGARD™ and XIAMETER™ are suitable for a wide range of processes used for battery applications. Formulated products generally can use the same processes as the silicone systems they are based on. Table 6 summarizes some typical applications and the product/process combinations that can be used.

Table 6: Processes and appropriate silicone products for various battery applications

Application	Process				
	Coating roll/dip/knife/ spray/flat stream	Injection mold	2K Dispense	Compression/ transfer mold	Extrude/ calendar
Cell/fuse encapsulation		●	● ★		
Seals/gaskets/spacers		● ✚	● ★	✚	✚
Vibration reduction	●	● ✚	● ★	✚	✚
Compression pads/cushions	●	● ✚	● ★	✚	✚
Flame/thermal resistance	● ♦	● ✚ ♦	● ★ ♦	✚ ♦	✚
Coatings	● ♦		● ♦		✚
Cable insulation					✚

Cure Type: Room temperature — ● LSR, ★ Foam, ♦ Resin; High temperature — ✚ HCR

SILASTIC™ silicone elastomers by Dow DOWSIL™ silicones by Dow

As mentioned earlier, LSRs have lower viscosities than HCRs, which makes them well suited for a range of coating and dispensing processes. They can be easily injection molded into a prefabricated shape for assembly in the battery pack or molded around a specific component to offer sealing and protection. In contrast, HCR and HCR-based formulations can be injection molded, compression molded or extruded/calendared into a prefabricated shape or profile to be assembled into the battery pack. In certain applications, co-extrusion or co-molding with a component of the battery pack can be used to achieve good adhesion and minimize downstream assembly time.

Silicone foams are generally two-part products with low to medium mixed viscosity, and they are well suited for dispensing processes. They can be directly dispensed to locations in the battery pack and cured in place. Alternatively, they can be dispensed onto a sheet-making line to produce pre-cured foam sheets that are installed in designated locations. Such pre-formed foam sheets provide excellent vibration damping between cells during vehicle operation, or compression that is sustained through charging/discharging cycles and battery aging – plus fire and thermal resistance unmatched by organic polymer foams.

Silicone resins and resin-based products can be coated, injection or compression molded, or dispensed as liquids to cure at room temperature. As described above, they are used where superb flame and thermal resistance is needed.

Materials Testing and Representative Test Data

Material suppliers should, at a minimum, provide data on BFP material properties that are aligned to their customers' applications. Any additional testing can be helpful in material downselection to speed up the qualification process. It is beneficial for material suppliers to develop in-house testing capability and make the results available to prospective customers and design partners.

A hierarchal testing approach can be used for screening and the selection of materials for BFP applications. Typical hierarchal tests for BFP materials comprise the following:

1. Testing of material properties before and after curing based on their alignment to performance requirements
2. Flame exposure tests, such as UL 94 or higher-energy flame testing, including high-temperature flame with a particle blast
3. High-temperature thermal conduction and/or conductivity testing
4. Cell-to-cell testing using BFP materials
5. Mini-module or cell cluster testing with BFP materials
6. Full module or pack level testing with BFP materials

In this section, we describe two of these tests in detail and present some example results.

High-temperature thermal conduction test

In this test, illustrated in Figure 7, a square material specimen is sandwiched between two compression plates, with a heater plate set beneath the sample. The heater plate can be set at a high temperature, for instance, between 600 °C – 700 °C, as specified by the customer. The compression plates can also be controlled to apply specific pressure to the material specimen. Thermocouples are installed on both the hot and cold sides of the sample to measure the temperature delta in the assembly structure. The time to temperature on the insulated side is measured during the test to gauge the material's insulation performance. Simultaneously, a qualitative assessment of the material's flammability resistance can be performed. An overall positive test result would indicate the sample material can insulate the cold side thermocouples against a temperature rise over a specified length of time without catching fire or deteriorating. Again, the particular temperature and time threshold conditions for the test are usually assigned by the potential customer.

Figure 8 shows a typical result for this test. If the result looks encouraging to the customer, it could lead to further evaluation of the material, for instance, using cell-to-cell testing.

Figure 7: High-Temperature thermal conduction test

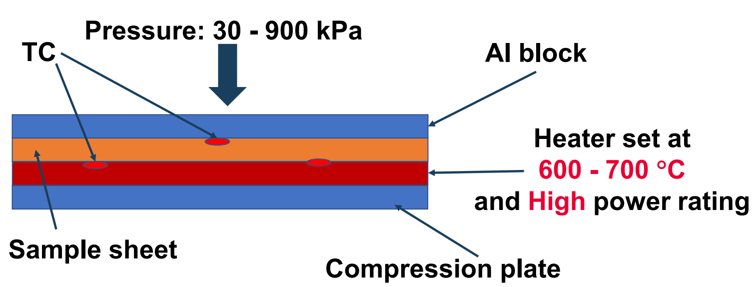
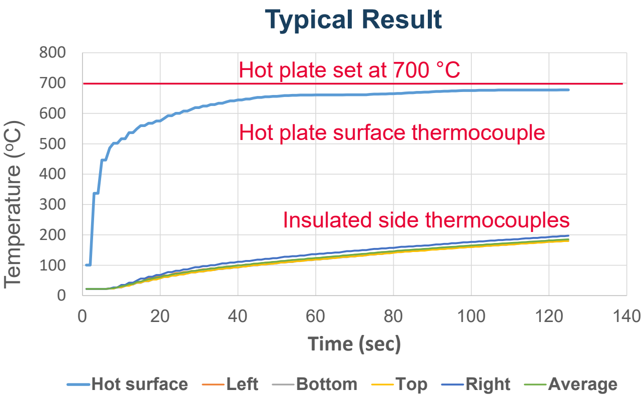


Figure 8: Example High-temperature conduction test result for silicone material

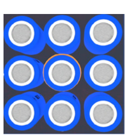
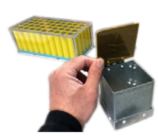


Mini-module or cell cluster testing with BFP materials

If a given material candidate performs well in the preceding test, moving to tests using actual battery cells may be warranted. These mini-module tests can further pre-screen materials before proceeding to full modules or packs, which are highly resource-intensive to test.

Mini-module tests can be performed using different cell types; however, in this case, a cylindrical cell-based mini-module is used. This test involves assembly of a small cell array in a box or other container, with thermocouples installed on the cells and on the container to monitor the temperature. The cells can be arranged in a straight array (rows and columns), or they can be offset or arranged in some other cluster pattern. Gaps between cells in the box can be controlled using specially designed spacers. Usually the cell gaps fall within a range consistent with what is used in an actual module, for instance 0.8 mm to 2.0 mm (Fig. 9).

Figure 9: Mini-module test set-up

Mini-module	Thermal event initiation	Testing
 • 3x3 array • Panasonic 18650 cells • Cell spacing of **0.8 mm**	 Central cell wrapped with a **high temperature wire** to create the thermal event	 Mini-module placed in a small canister and tested: • **Unpotted** • **With silicone foam**

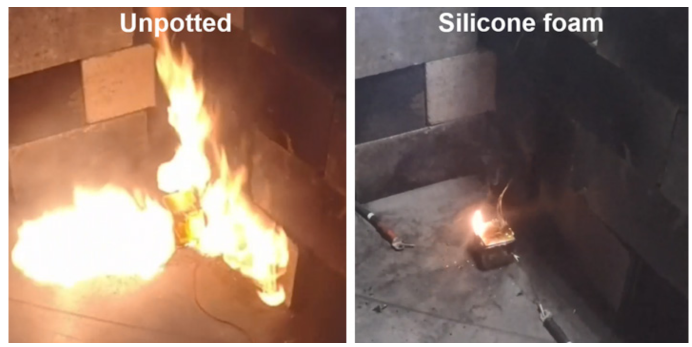
Typically when conducting mini-module testing, a control mini-module is tested as well for comparison. This control mini-module is simply an un-filled box with the cells installed without any insulative material encapsulating them. During the actual test, the center cell of the mini-module is purposely forced into thermal runaway using penetration with a nail, over-charging or over-heating. In the testing described here, an overheating method was used to initiate thermal runaway in the center cell (Fig. 9). In several control tests, the thermal runaway initiated in the central cell caused sufficient temperature rise within the box to initiate thermal propagation throughout the remaining cells.

To evaluate BFP materials, the mini-module box can be filled with a dispensed liquid silicone material. The silicone material will fill in around the cells and then cure inside the box to fully encapsulate the cells. As with the control, the overall purpose of material testing is to observe whether the center cell, after initiation of thermal runaway, will heat the adjacent cells sufficiently to cause thermal propagation. In a successful test, the encapsulant material will insulate and protect the adjacent cells from the center cell thermal runaway event and thus mitigate thermal propagation.

Several Dow silicone materials have performed successfully in mini-module testing, including silicone elastomer encapsulants and lighter-weight silicone foam encapsulants. In each case, the silicone encapsulant material mitigated thermal propagation in the mini-module.

Figure 10 shows two images comparing an unpotted control test (left), which indicates complete thermal propagation to all cells, with a silicone foam material test (right). The minimal flame shown was due to the burn-off of electrolyte solution after the center cell thermal runaway. There was no thermal propagation in the silicone foam material test.

Figure 10: Mini-module control test vs. silicone foam encapsulant test



It is difficult for an image to convey the full intensity of the flame generated from the thermal propagation in the control test vs. the successful mitigation of thermal propagation in the material test. A better representation of the test results is shown in a video on Dow's channel: Battery module cell assembly and protection. One can observe from the video the major impact the Dow silicone encapsulant can have in mitigating thermal propagation resulting from thermal runaway in a battery cell.

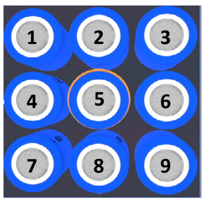
Figure 11 shows before and after pictures of mini-modules filled with silicone elastomer and silicone foam encapsulants. In each example, one can observe combustion residue around the center cell's vent cap. The primary conclusion in each test case is that thermal propagation to the adjacent cells was averted due to the performance of silicone encapsulant or foam, which insulated and protected the cells.

Figure 11: Mini-module tests using silicone encapsulants

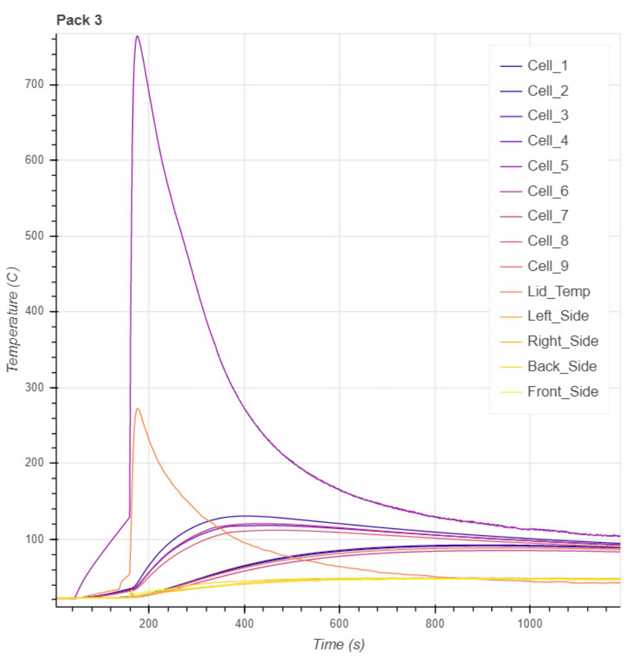
DOWSIL™ Silicone Encapsulant		DOWSIL™ Silicone Foam	
Before	After	Before	After

Thermocouples were also installed to record temperatures during the mini-module testing. Typically, thermocouples are affixed to each cell and to positions on the outside of the mini-module test box. Figure 12 shows recorded temperature results from a mini-module thermal runaway/thermal propagation test. The center cell (purposely overheated to thermal runaway) ignited at about 130 °C and reached an overall temperature greater than 750 °C. The next-highest temperature was recorded from the mini-module box lid, which reached 280 °C (the lid thermocouple was positioned directly over the center cell's vent cap). The third-highest temperature, at about 120 °C, was recorded from thermocouples installed on the cells in the cross positions (cells 2, 4, 6 and 8), located in closest proximity to the center thermal runaway cell. The lowest temperatures, at about 100 °C, were recorded on the cells in the corner positions (cells 1, 3, 7 and 9), which are the furthest from the center thermal runaway cell. The results of this test showed that the silicone foam encapsulant sufficiently insulated the adjacent cells and prevented thermal propagation.

Figure 12: Mini-module test temperature results



Position	Temperature °C	
	Unpotted	DOWSIL™ Silicone Foam
Central cell (5)	> 1,000	> 750
Cells (2, 4, 6 & 8)	> 1,000	~ 120
Cells (1, 3, 7 & 9)	> 1,000	100
Lid of the canister	> 1,000	280



Conclusion

Battery fire protection materials are an important consideration for use in lithium-ion battery modules and packs. New and novel screening tests are being developed to aid in downselection and the qualification of materials for BFP applications. The type of cell used in the battery module/pack design, whether cylindrical, prismatic or pouch, can determine the appropriate BFP material forms to be considered. Material forms include dispensed liquids, coatings, prefabricated sheets and high-viscosity moldable products. Within each form factor there can be multiple material types to consider, depending on target properties for specific BFP applications.

Dow's performance silicones are offered in multiple form factors that have been adopted as battery fire protection materials by OEMs over the last decade. They can be dispensed directly into a module or pack, or coated, molded, or otherwise processed into sheets and other profiles to align with specific lithium-ion cell types and module/pack manufacturing processes. Once silicones are assembled within a lithium-ion battery module or pack, their unique material properties offer performance benefits under normal operation of an EV and in the event of a battery thermal runaway, where they provide fire protection and propagation mitigation. Various silicone-based solutions from Dow can help battery manufacturers, automotive OEMs and designers achieve the right level of protection required for diverse battery applications.

For further discussion and support with BFP material selection, please contact your Dow technical representative or submit your request at dow.com/contact and visit dow.com/battery.

Images: dow_40644846737, dow_58529603199, dow_62758749510, dow_68015286145, dow_68015286694, dow_69606694255, dow_69606695656 and safety cable sketch by Bruno Cuocci, Technical Development & Scientist, Dow.

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