MITIGATING THE RISK OF THERMAL RUNAWAY PROPAGATION WITH GORE BATTERY INSULATION TECHNOLOGY

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Summary

In the rapidly evolving world of battery technology, ensuring the safety and reliability of battery modules is paramount. One of the critical challenges faced by battery manufacturers is protecting battery modules from thermal runaway propagation, a phenomenon that can lead to catastrophic failures. This paper introduces GORE Battery Insulation technology, a non-flourinated* high-performance thermal barrier solution specifically designed to enhance battery safety. It provides an in-depth understanding of the technology, its benefits, and its applications in battery modules. Included is data from a specific case study with Grid Storage BESS modules, demonstrating the superior thermal propagation protection enabled by the insulative material developed by Gore.

Introduction

Driven by the increasing demand for energy storage solutions in various applications, battery technology has seen significant advancements over the past few decades. As the energy density of batteries continues to improve, so does the need for effective thermal management solutions to ensure their safe and reliable operation. Thermal runaway propagation is a critical issue that can compromise the safety and performance of battery modules, making it essential to develop innovative protective solutions that can mitigate this risk.

Figure 1: GORE Battery Insulation

GORE Battery Insulation represents a breakthrough in the thermal management of battery modules. This innovative technology (Figure 1) is a non-flourinated* composite material supplied in roll form or convertible to customer-specific singulated pads in a variety of available thicknesses. By providing high thermal resistance at elevated temperatures, GORE Battery Insulation provides protection against thermal runaway propagation and enhances the overall safety of battery systems at installed thicknesses much lower than alternative solutions. The Gore material is also non-particulating, flexible, and easy to form and cut. This paper introduces the technology including technical performance, benefits, and real-world applications which demonstrate its effectiveness as a high-performance thermal insulation solution.

*Per- and polyfluoroalkyl substances (PFAS) not intentionally added

Problem Statement

Thermal runaway is a complex process that can be triggered by various factors, such as overcharging, internal short circuits, or external heating. Once initiated, thermal runaway can rapidly propagate through the battery module, causing a chain reaction that leads to the release of heat, gas, and potentially hazardous materials. This can result in severe damage to the battery module, posing safety risks to users and potentially leading to catastrophic failures. To avoid this outcome, most battery modules employ both active propagation control, such as battery management systems and active cooling, along with passive measures, such as thermal insulation and flame barriers between cells. However, inclusion of an effective thermal barrier inevitably reduces the volumetric energy density of the module. When considering a passive propagation solution such as insulation, the battery designer must consider this cost in volumetric energy density.

Current insulation solutions such as ceramics and aerogels offer sufficient thermal resistance performance but can face difficulty in installation and issues with particulation, which can be problematic for sensitive electronic components. Specific particulation concerns include:

- Electrical Short Circuits: Shed particles could be abrasive and wear away insulators in the module or absorb moisture in high humidity conditions increasing the likelihood of high resistance shorts over insulated surfaces.
- Thermal Management Issues: Particles can obstruct cooling pathways, reducing the efficiency of thermal management systems. This can lead to uneven temperature distribution and hotspots, which can accelerate cell degradation and increase the risk of thermal runaway.

To address particulation concerns, these solutions often require encapsulation in some sort of polymeric envelope or pouch which negatively impacts thermal conductivity.

A second concern arises from the compressibility of traditional insulation materials. Often, thermal barriers are designed to also act as compression pads, providing stress management as batteries swell during use. However, compliant materials can thin over time under compression cycling arising from charge/discharge protocols which may result in detrimental effects. Specifically:

- Loss of Thermal Resistance: Over time, compressible insulation materials may lose their ability to maintain consistent thermal conductivity. This can result in uneven heat distribution and hotspots, potentially accelerating cell degradation and increasing the risk of thermal runaway.
- Irreversible Mechanical Deformation (Compression Set): Prolonged compression can lead to compression set of insulation materials. This deformation can reduce the effectiveness of the insulation, creating gaps and diminishing thermal protection.
- Aging and Material Fatigue: Continuous compression and thermal cycling can cause traditional insulation materials to age and fatigue. This can lead to a loss of elasticity and compressibility, compromising the material's ability to provide consistent thermal insulation.

These challenges can negatively impact battery performance and safety, making it essential to find a more effective insulation solution.

Solution Overview: GORE Battery Insulation Technology

GORE Battery Insulation technology offers a comprehensive solution to the challenges faced by current insulation materials. The thin, lightweight, material is designed to provide high thermal resistance at high temperatures, making it an effective choice for battery modules. It is nearly incompressible under typical pressures, (including end-of-life (EOL) pressure conditions), ensuring long-term durability and consistent thermal and mechanical performance. Additionally, this technology is simple to install and available in non-particulating forms at a variety of thicknesses. When compared to traditional insulation solutions, GORE Battery Insulation stands out for its thinness, thermal performance, and ease of use.

Table 1 summarizes the technical performance of GORE Battery Insulation material:

Property	Value
Thermal Conductivity at 100°C	<45 mW/m·K
Thermal Conductivity at 500°C Face Temperature	<50 mW/m·K
Thickness	0.25-1.0 mm
Dimensional Tolerances	±5%
Density	<0.4 g/cc
Dielectric Breakdown	>15 kV/mm
Compression Stress Deflection at 10% Strain	1 MPa
Compressive Set	<0.5%

Table 1: GORE Battery Insulation Material Performance

Thermal Performance

GORE Battery Insulation's high thermal resistance at elevated temperatures is a key differentiator from other insulative solutions. This property enables the material to help mitigate thermal runaway propagation at installed thicknesses much lower than typically required for alternate insulation, thereby enhancing the safety of battery modules. The data in Figure 2 illustrate this thermal resistance performance. In this experiment, a sample of GORE Battery Insulation material was placed on a cold plate and then quickly exposed to a heated stainless-steel plate on the opposite side to simulate a rapid temperature rise such as would occur in a thermal runaway event. An array of thermocouples recorded temperatures of the heated mass and back (cold) side of the insulation.

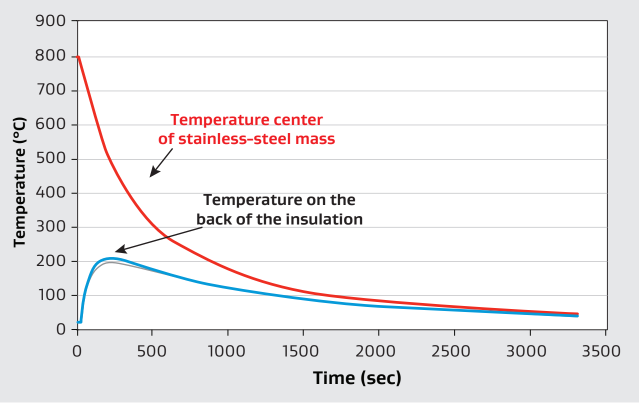


Figure 2: GORE Battery Insulation Technology High Temperature Test Measurement

As shown in Figure 2, even when exposed to a large thermal mass at 800°C, the Gore insulative material provided an effective, persistent thermal barrier, and the temperature on the opposite side of the insulation layer barely achieved 200°C.

Mechanical Performance

The incompressible nature of the Gore material ensures that its thermal resistance properties remain consistent over time, even under typical cyclic operating pressures and EOL conditions. This long-term durability is crucial for battery installations with extended warranties, as it ensures that the insulation material will continue to provide thermal protection throughout the battery's lifespan. The data in Figure 3 demonstrate GORE Battery Insulation technology's mechanical stability and resistance to compression set. In this experiment, samples of the material were initially subjected to a significant compression stress of 1000 kPa, and the resultant strain was measured. The samples were then conditioned with 350 cycles of compressive load up to 2000 kPa, followed by a post-cycling strain measurement.

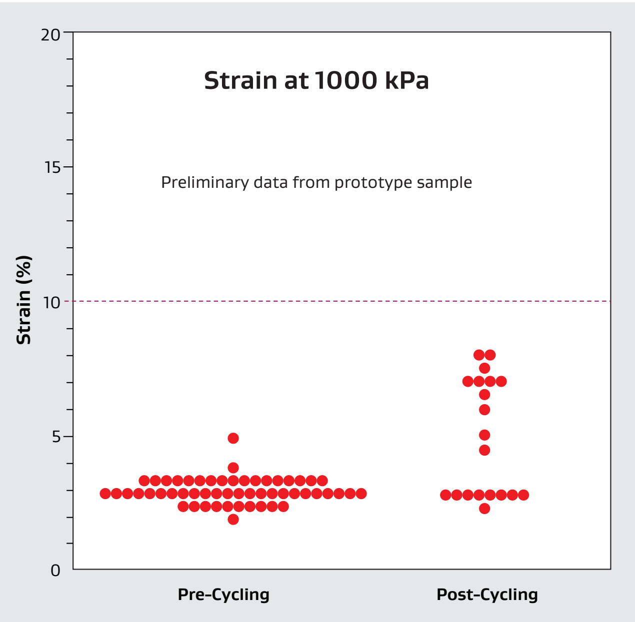


Figure 3: Compression Strain at 1MPa, Pre- and Post Cycling

The data in Figure 3 demonstrate that the compression strain remained well below the 10% tolerance, and that Gore technology is highly resistant to compressive load and compression set, even after 350 cycles. This data is particularly notable when compared to alternative compressive insulation systems which are designed to compress nearly 50% at <300 kPa of applied stress.

Whereas alternative technologies attempt to provide both thermal protection and compression control in a single product, pairing GORE Battery Insulation technology with a separate engineered compression layer may offer a thermal protection solution that is not compromised due to unpredictable dimensional deviations.

Uniformity & Ease of Installation

Ease of installation is another significant advantage of the GORE Battery Insulation technology. The material is produced in roll form making it cuttable and easy to handle during assembly. In addition, the tight ±5% thickness manufacturing tolerances (Figure 4) of the material ensure consistent stack dimension, further reducing manufacturing uncertainty and ensuring precise alignment of subcomponents in the module. This simplifies the installation process, reducing labor costs and minimizing the risk of errors. Additionally, the technology's non-particulating form ensures that it does not release particles that could interfere with the battery's operation, further enhancing its performance and reliability.

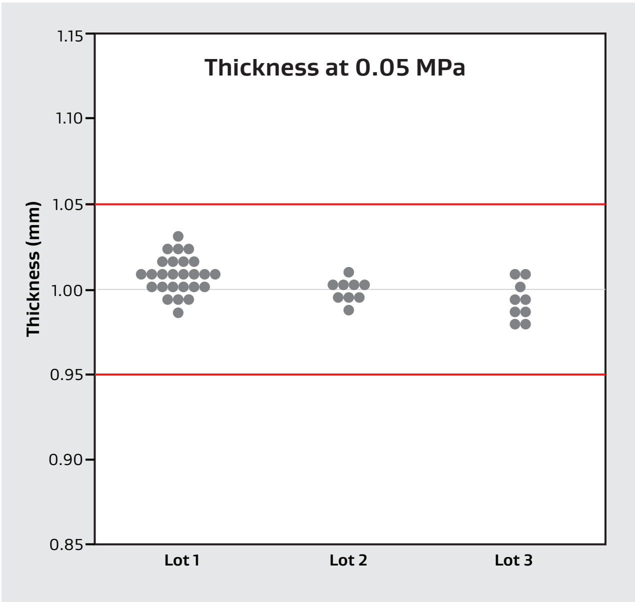
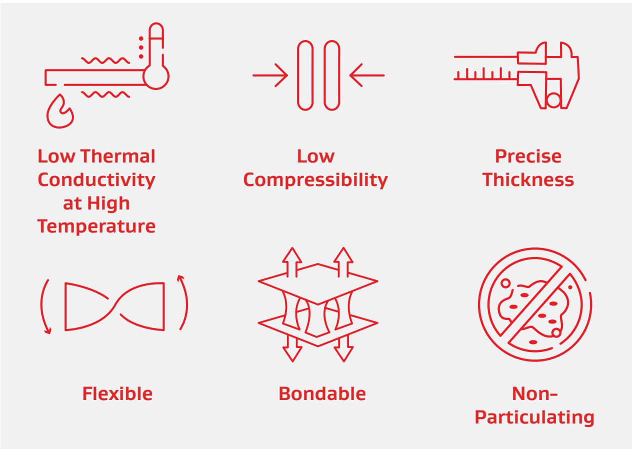


Figure 4: GORE Battery Insulation Material Thickness Tolerance

When compared to other insulation solutions, GORE Battery Insulation technology offers several key advantages. Its thinness, high thermal resistance, incompressible nature, ease of installation, and non-particulating form make it a superior choice for battery modules. These features address the common challenges faced by current insulation materials, providing a reliable and effective solution for thermal management in battery systems.

Comparative Summary



Application Scenarios

GORE Battery Insulation technology can be effectively used in various battery module designs, including prismatic and pouch battery cells. Its versatility allows it to be integrated into different battery configurations, enhancing overall battery safety and performance.

In prismatic battery cells, the material can be integrated into the module design to provide effective thermal insulation between individual or groups of cells, as shown in Figure 5. This helps to minimize heat transfer and provide a barrier against thermal runaway propagation, ensuring the safety and reliability of the battery module. The thinness, uniformity, ease of installation, and non-particulating form of GORE Battery Insulation material further enhances its suitability for prismatic battery cells, as it simplifies the assembly process and reduces the risk of errors.

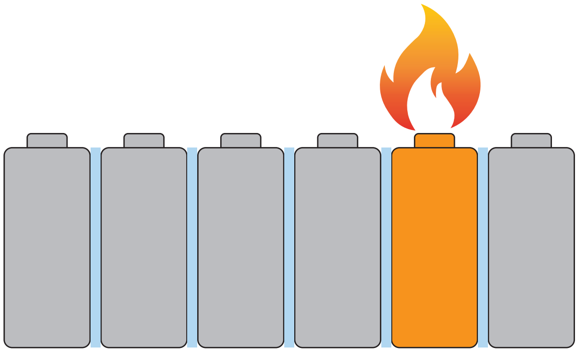


Figure 5: Insulating Between Adjacent Cells Can Inhibit Thermal Propagation

Pouch battery cells also benefit from the use of this technology. The Gore material's high thermal resistance and incompressible nature help to maintain consistent thermal management over time, even under typical pressures and end-of-life (EOL) conditions. This is particularly important for pouch battery cells, which are often subjected to significant mechanical compression cycling during operation. GORE Battery Insulation technology's long-term durability helps to maintain consistent thermal resistance properties, providing reliable performance throughout the battery's lifespan.

Case Study: Our Next Energy, Inc. (ONE) Our Next Energy, Inc. (ONE) is a Michigan-based energy storage company focused on developing advanced battery technologies to accelerate the adoption of electric vehicles and expand stationary battery energy storage solutions (BESS). ONE approached Gore when their latest grid-level BESS required an effective thermal management solution to ensure its safe and reliable operation. ONE's design required a high degree of thermal resistance along with dimensional stability (compression resistance) in a minimally thick form. GORE Battery Insulation technology was evaluated for suitability across multiple performance metrics.

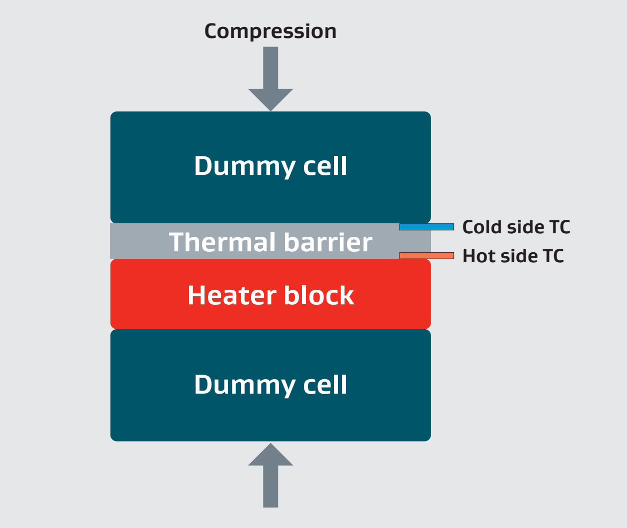


Figure 6: ONE Thermal Runaway Propagation Simulation Testing Configuration

Thermal propagation tests using live cells can be costly, hazardous, and environmentally destructive. To minimize the needed frequency of this testing, ONE designed a test setup to create A-to-A comparisons of different thermal barrier solutions. Figure 6 shows the testing configuration. By using ceramic heaters in a dummy block of aluminum, temperature conditions representative of thermal runaway conditions can be achieved without committing significant resources. Thermocouples are used to measure the temperature of the heater block (cold side of barrier) as well as on an adjacent dummy cell (hot side). By using the same test configuration for multiple different barrier types, the relative performance of different materials becomes clear. A large limitation of this testing is the omission of controlled compression to simulate the cell expansion which occurs during actual thermal runaway.

Figure 7 contains the temperature data and compares the results from a layer of the GORE Battery Insulation material (blue lines) to 3x thicker layer of cork (red lines) and a 1.6x thicker layer of alternative silicon foam commercial insulation (green lines).

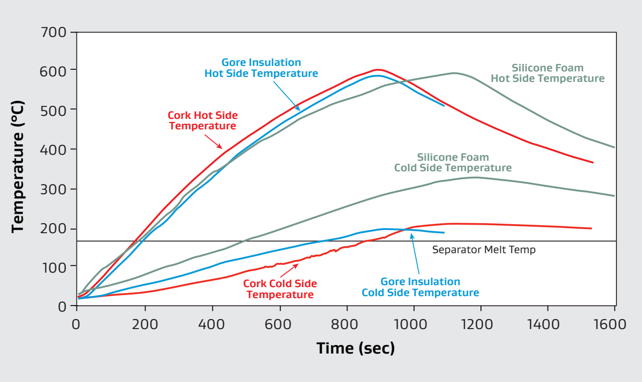


Figure 7: Performance Comparison of GORE Battery Insulation technology versus Alternative Insulation Solutions in a Thermal Runaway Simulation Test

The data in Figure 7 demonstrate that the layer of Gore's insulative material outperforms both the the 3x thicker layer of cork and the the 1.6x thicker silicone foam solution. This is evident from the suppression of the cold side temperature, which stabilizes below 200°C, indicating over 350°C of temperature reduction at the peak thermal excursion.

In addition to the thermal propagation simulation test, ONE engineers also performed a full module thermal runaway propagation test. In this experiment, a layer of GORE Battery Insulation material was placed between every third cell, with a compliant viscoelastic material placed in the alternate junctions to accommodate cell swelling. The image in Figure 8 shows the test module after the thermal runaway test and demonstrates that the Gore material effectively suppressed thermal runaway propagation, which was limited to only two cells of the full array. This result demonstrates that GORE Battery Insulation technology is an effective barrier to not only resist but ultimately prevent thermal runaway propagation in this module test.

Figure 8: ONE Battery Module After Thermal Runaway Propagation Test, Showing the Prevention of Thermal Runaway to Adjacent Cells Enabled by GORE Battery Insulation Technology

After a thorough evaluation of the Gore material for thermal runaway propagation prevention in BESS modules, ONE engineers provided the following assessment:

"After significant investigation, ONE has identified that GORE Battery Insulation is the best solution to meet our customer trade-offs of system cost, size, and thermal propagation performance. Alternatives such as traditional aerogels, silicone foam-based solutions, phase change materials, and even cork were evaluated but in our module design no other material was able to stop thermal runaway from propagating across barriers to adjacent cells at a practical thickness and cost. One reason for GORE Battery Insulation's superior results is the limited change in thermal conductivity at higher temperatures compared to traditional materials experiencing a loss of insulative properties at such elevated temperatures. However, an equally critical characteristic of this material is its effective incompressibility which is able to resist the violent cell swelling that occurs during runaway. Other solutions like aerogel are far more compressible resulting in increased thermal conductivity over a shorter length. This change in form under high pressure also makes it difficult to evaluate material efficacy without running testing using live cells. For these reasons, ONE is excited to see Gore scale this product to meet the growing needs in the energy storage space, enabling system integrators to safeguard against such a catastrophic failure mode."

Conclusion

The importance of thermal management in battery modules cannot be overstated. As the energy density of batteries continues to improve, so does the need for innovative insulation solutions that can mitigate the risks associated with thermal runaway propagation. GORE Battery Insulation technology represents a breakthrough in thermal management technology, offering a comprehensive solution to the challenges faced by current insulation materials.

The differentiation and benefits of Gore's insulative technology based on customer testing make it a compelling choice for battery manufacturers looking to enhance safety and performance. The material's high thermal resistance, incompressible nature, ease of installation, and non-particulating form address the common challenges faced by current insulation solutions, providing a reliable and effective solution for thermal management in battery systems.

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