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Customizing compression range to help control pressure between cells and extend EV battery lifespan

David Gries, 3M Automotive and Aerospace Solutions Division

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Abstract

Electric vehicle (EV) battery designs are constantly evolving, making pressure management a delicate balancing act. Proper between-cell cushioning is needed to help accommodate volumetric expansion that can occur over the lifespan of the cells. However, cushioning materials take up precious space that could otherwise be devoted to increasing battery energy density. This paper explores how to strike this balance in pouch cell battery designs by customizing the compression range of the cushioning material. An advanced cushioning material from 3M can be tailored to precise design needs to provide a wide compression range at relatively low thicknesses. Consistent pressure can be achieved even with limited between-cell space, helping EV OEMs protect cells, ensure reliable performance and extend EV battery lifespan.

Introduction

As the electric vehicle market grows, more attention is being paid to lithium-ion battery design. To promote the wide adoption of EVs, OEMs are striving to increase battery density and extend driving range, all while easing consumer concerns about battery failure and thermal runaway.

These are competing priorities because increasing battery energy density requires larger cell volumes, leaving little space for added safety measures. Larger cells need variable pressure control across the face to account for volumetric expansion that can occur over the lifespan of the cells: swelling, breathing, etc. While the right between-cell cushioning can provide the needed compression, any battery space dedicated to cushioning is dead space that does not contribute to energy density or driving range.

Achieving effective pressure control while minimizing dead space and maximizing energy density is thus a fundamental challenge of modern EV battery design. Effective, space-efficient cushioning materials are needed to help protect cells during expansion and help increase battery lifespan.

The importance of compression between cells

All lithium-ion EV battery cell types — cylindrical, prismatic and pouch — experience volumetric expansion. As cells charge and discharge, they expand and contract. Expansion can be observed due to factors including cell type, electrode material, voltages and more. Cells can also volumetrically change over time due to cycling-related changes to electrodes such as lithium dendrite growth.

A cell's ability to maintain charging capacity throughout its lifespan thus depends on whether the between-cell cushioning materials can provide proper compression to help accommodate volumetric expansion. Without this, lithium-ion batteries will have much shorter lifespans.

Constraining cells so they cannot move is not an option. Cells must be allowed to expand and contract throughout their lifespans, a process known as cell breathing [1]. Rigid constraints that do not account for breathing can create so much internal force that electrodes within the cells can be crushed or shattered, leading to battery end of life.

Allowing cells to expand and contract free of constraint is not optimal either. Cycling between charge and discharge will eventually create a rippling on the electrodes. This can result in delamination — loss of contact between the solid electrolyte interface layer and the electrode — as well as reduced capacity retention [2].

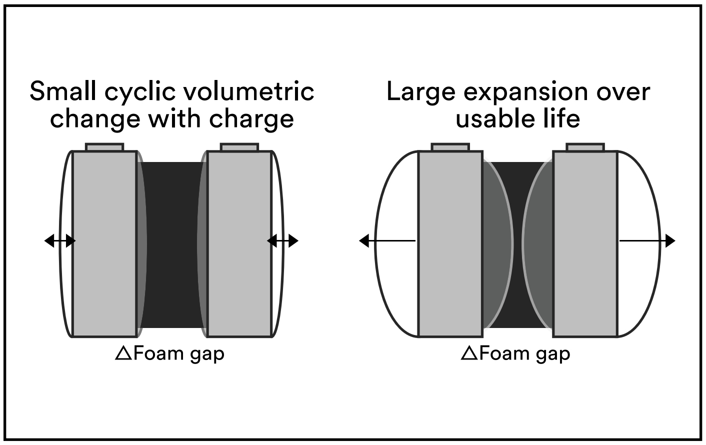

Figure 1: Cell breathing causes small cyclic expansion and contraction; cell swelling causes large, gradual and irreversible expansion.

The optimal solution is to carefully customize between-cell compression to accommodate cell expansion and meet the needs of specific cell and battery designs. Compression requirements vary greatly by cell form factor and packaging, with each cell type posing unique challenges.

Prismatic cells, for example, are contained within rigid metal housings. These housings hold the cells in place and can accommodate small forces without the need for cushioning materials. However, as cells expand over time, cushioning may be needed to accommodate higher forces and ensure consistent contact of the electrolyte with the electrodes.

Pouch cells, by contrast, possess no rigid housings at all. They exhibit a strong cyclic behavior of expansion and contraction, and a certain minimum pressure is needed to hold them in place at all times. Based on customer feedback received by 3M, pouch cells typically require 20 kPa of back pressure at beginning of life. By end of life, following significant cell expansion, this pressure can be as high as 300–500 kPa. Pouch cells thus require cushioning materials with a very wide compression range. Additionally, the future will likely see the continued development of solid-state batteries, which will likely involve substantially higher between-cell pressures.

Compression force deflection

In sum, to accommodate volumetric cell expansion, improve uniform cell performance and extend EV battery lifespan, cushioning materials must provide consistent restoring force between cells as they expand [3]. This ability to apply force is called compression force deflection (CFD). CFD is measured in kPa and varies based on compression percentage, or the percent change in cushioning material thickness (Δt) relative to its initial thickness ($t_{initial}$). The larger the compression percentage, the more CFD is exerted.

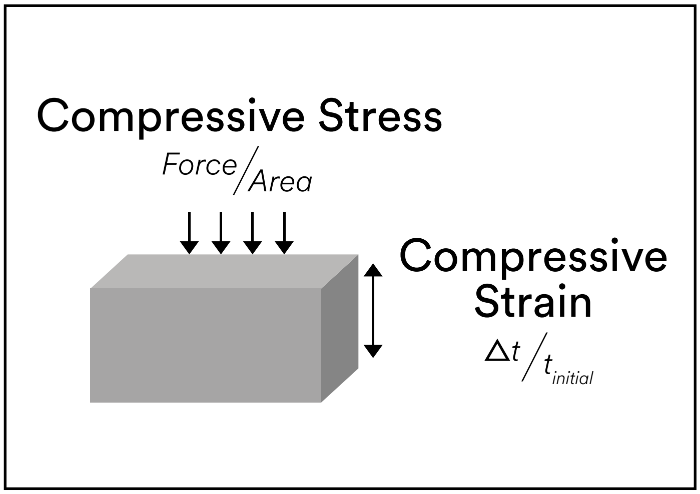

Figure 2: CFD is compressive stress, or the force divided by the area of the foam; compression percentage is a form of compressive strain, defined as Δt divided by $t_{initial}$.

CFD is thus a form of stress, while compression percentage is a form of strain. CFD and compression percentage are used to understand the acceptable expansion of a cell, with force versus total displacement as the key parameter. An effective between-cell cushioning material should provide relatively consistent CFD over a broad range of displacements.

Optimizing between-cell cushioning for consistent CFD

An advanced between-cell cushioning foam has been developed by 3M to help protect pouch cells as they expand and contract. 3M™ Cell Expansion Foam SJCEF Series is a polymeric foam featuring a nonlinear compressive force response. It can help EV OEMs achieve consistent pressure control across a wide compression range.

Figure 3: 3M™ Cell Expansion Foam SJCEF Series.

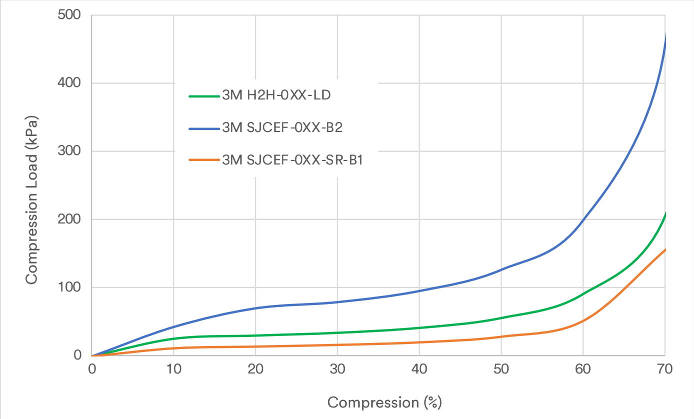

Figure 4: The stress–strain curve for various expansion foam materials from 3M.

Consider the stress–strain curve in Figure 4, which shows the compression performance of two different samples of 3M™ Cell Expansion Foam SJCEF Series and one sample of 3M™ Cell Expansion Foam H2H.

- For low compression (up to around 20%), the foam exhibits elastic behavior. There is a roughly linear relation between compression and CFD.
- For moderate to high compression (around 20% to 60%), the cell walls of the foam buckle and the stress–strain curve reaches a plateau. CFD remains largely constant relative to compression.
- For very high compression (above 60%) there is an almost exponential increase in CFD. This extreme region, where the foam cell walls collapse and come into contact with one another, is called densification.

The plateau region of the curve is key. In this region, called the compression plateau, the foam applies relatively consistent CFD across a wide compression range. In other words, the foam exerts nearly constant force back on cells independently of how much the cells expand and deflect the foam.

A wide compression plateau is one of the most important features of a space-efficient cushioning material. The wider the plateau, the larger the design window and smaller the between-cell gap. Ordinarily, a thick cushioning material is needed for a wide compression plateau. However, 3M Cell Expansion Foam SJCEF Series features a microcellular structure to help provide a wide compression plateau at thicknesses of 1.0–2.0 mm. This broad thickness range, including thin profiles, helps accommodate a variety of cell designs while reducing the footprint of non-cell components.

3M Cell Expansion Foam SJCEF Series can be customized to precise design needs to provide a wide compression plateau. During installation, the foam is compressed through the linear elastic region until the compression plateau is reached, which is the operational range of the material. Staying within this range helps maintain effective and consistent cushioning throughout the lifespan of the cells. This is crucial for addressing evolving battery pack compression needs and enabling the next generation of EV battery designs.

Additional product details

3M Cell Expansion Foam SJCEF Series products are flame retardant and can be customized to meet OEM specifications. A wide range of CFD and customizable compression plateau can help ensure reliable performance during repeated charging and discharging cycles over the cell lifespans. Moreover, the foam is highly resilient. The foam features a self-adhering surface to enable installation without requiring additional adhesives. This helps lower costs and reduce process steps while facilitating rework and repositioning during assembly. See Table 1 for more details.

Table 1: Additional details on 3M Cell Expansion Foam SJCEF Series.

Property	Value
Material	Microcellular polyurethane
Color	Black
Release liner	Silicone-coated polyester film 0.075 mm
Foam thickness	1.0–2.0 mm
Adhesion	30–80 gf/in
Roll size	550–1,035 mm (width) × 50–100 m (length)

For additional details on foam thicknesses and customization options, please contact a 3M application engineer.

Innovation born of customer needs

For nearly a century, automotive industry leaders have tapped into the material science expertise of 3M to help them overcome key design challenges. Our most successful innovations are infused with customer insights throughout the development process, and 3M Cell Expansion Foam SJCEF is a prime example. By providing a wide compression plateau at relatively low thicknesses, this advanced cushioning material can help OEMs meet pressure control requirements and ensure reliable performance, all while minimizing the footprint of non-cell components and maintaining high battery energy density. In a world of ever-evolving EV battery designs, where every inch of space counts, striking this balance is essential.

3M continues to develop relationships with our EV OEM customers, and our scientists collaborate directly with them to address their design specifications and help solve their unique challenges. 3M can respond quickly, tailoring material properties to develop EV battery solutions that meet specific application needs. 3M is committed to working bench-to-bench with customers to ensure successful implementation.

3M reserves exclusive EV battery technologies for select customers actively innovating in this area. Click here to request an in-person meeting to discuss and learn more.

3M.com/evbattery

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Automotive and Aerospace Solutions Division
3M Center
St. Paul, MN 55144 USA

Phone 1-800-328-1684
Web 3M.com/evbattery