ENABLING NEXT-GENERATION EV BATTERIES WITH THERMALLY CONDUCTIVE ADHESIVES

Holger Schuh, Roger Calixto, Phillip tho Pesch

ABSTRACT

In this paper, we explore trends in future electric vehicle (EV) battery design with a focus on the cell-to-pack configuration and how Thermally Conductive Adhesives (TCAs) play an important multi-function role in enabling optimal battery operation. Moreover, we discuss the ecosystem of technologies around the development of TCA materials, such as thermal, mechanical and rheology characteristics, performance modeling and simulation, material application technologies and the importance of addressing end-of-life (EOL) issues of EV batteries by building a sustainable circular economy for recovery, reuse, and repurposing of raw materials.

INTRODUCTION

With the rapid growth and adoption of electric vehicles, OEMs and battery manufacturers are turning to technology to make EVs more efficient and affordable. Engineers, seeking ways to optimize the battery and its components for long range, safety, and reliability, are turning to the "Cell-to-Pack" configuration for next-generation battery design.

Most EV battery packs are built in a Cell-to-Module configuration where groups of battery cells are housed in modules that are stacked and interconnected within a case that provides structural support and thermal management. In the new Cell-to-Pack configuration, modules are eliminated, and the battery is packed with cells placed directly on the cooling plate / metal case. This configuration simplifies the assembly, enabling a reduction in cost, weight, and complexity. However, it also brings a new set of requirements in terms of assembly materials.

INTRODUCTION – CONTINUED

Thermally Conductive Adhesives (TCAs) are key Thermal Interface Material (TIMs) used in Cell-to-Pack configurations, providing structural bonding and thermal conductivity. In this configuration TCAs are dispensed on the inside of the battery case and cells are then stacked in the case to create the battery pack structure. In this arrangement, TCAs provide both structural integrity and thermal management, enabling optimal battery operation for next-generation EV battery systems.

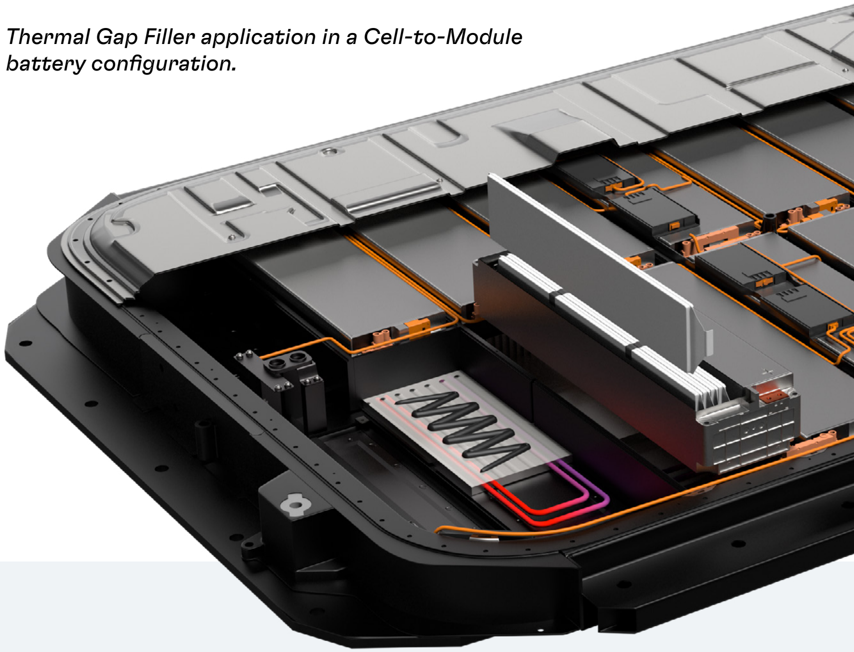
TIM AND BATTERY DESIGN TRENDS

EV manufacturers are ambitiously striving to build lighter, less complex, less costly electric vehicles with battery systems that are more compact, have longer ranges and higher energy densities. These goals bring new and more demanding requirements for TIMs in their various applications in the battery.

In the Cell-to-Module configuration the use of a Thermal Gap Filler is common to manage heat flow from the module to the cooling plate. Whereas the use of a TCA is more common in the Cell-to-Pack configuration due to its dual functionality, supporting structural integrity of cells through strong adhesion, and thermal management by conducting heat from the cells to the cooling system.

Regardless of the design approach and cell arrangement, thermal management is critical for lithium-ion battery systems. If not managed effectively, excess heat can create serious safety issues in the battery, and consequently the vehicle and its passengers.

TIMs are widely used to transfer heat from battery cells to the cooling system, and function in a myriad of ways that are critical to the overall operation of an EV battery system, namely:



Thermal Gap Filler application in a Cell-to-Module battery configuration.

Improved Heat Dissipation:
TIMs are designed to improve thermal conductivity and reduce contact resistance by filling air gaps, allowing for faster and more efficient heat dissipation from battery cells to the cooling system.

Reduced Thermal Stress:
TIMs help reduce temperature gradients and hotspots within the battery pack, minimizing the risks of thermal stress and thermal runaway, a serious safety hazard that can cause battery fires.

Enhanced Safety:
By improving thermal management processes in the battery, TIMs help prevent dangerous thermal runaway conditions and other serious safety hazards associated with excess heat in the battery.

Extended Lifespan:
By reducing temperatures and thermal stresses on the battery system, TIMs reduce the rate of capacity fade (charging capacity degradation), extending battery lifespan.

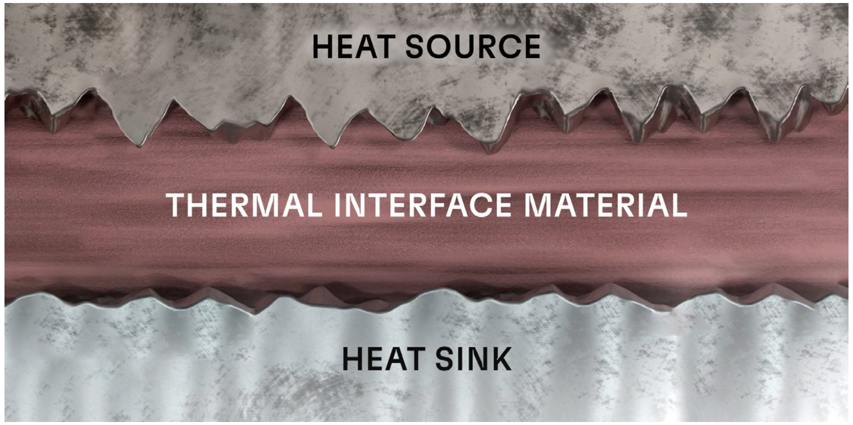
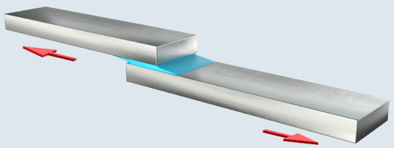


Illustration of TIM

TIM AND BATTERY DESIGN TRENDS – CONTINUED

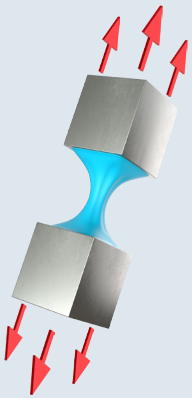
The structural integrity of EV batteries is also critical for ensuring safety, reliability, and performance. Structural Adhesives play an important role in the mechanical integrity of battery packs by bonding together various components, such as the cells, modules, and casing. Structural Adhesives create long-lasting joints between dissimilar materials such as aluminum, steel, and plastics, and allow for the elimination of traditional mechanical fastening methods such as bolts and welds.

Structural Adhesives used in EV batteries must withstand high mechanical loads, as well as exposure to temperature extremes, humidity, and other harsh environmental conditions. The following methodologies are used to test the performance:

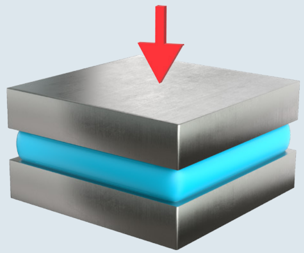


Shear Loads:
These are generated when two adhered surfaces are sliding against each other in a parallel directions and can be caused by vibration, shock, or thermal cycling.

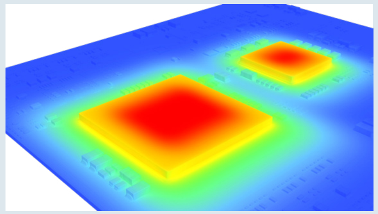
Peel Loads:
These are generated when two adhered surfaces are pulled apart from each other in a perpendicular direction and can be caused by impact, bending, or torsion.



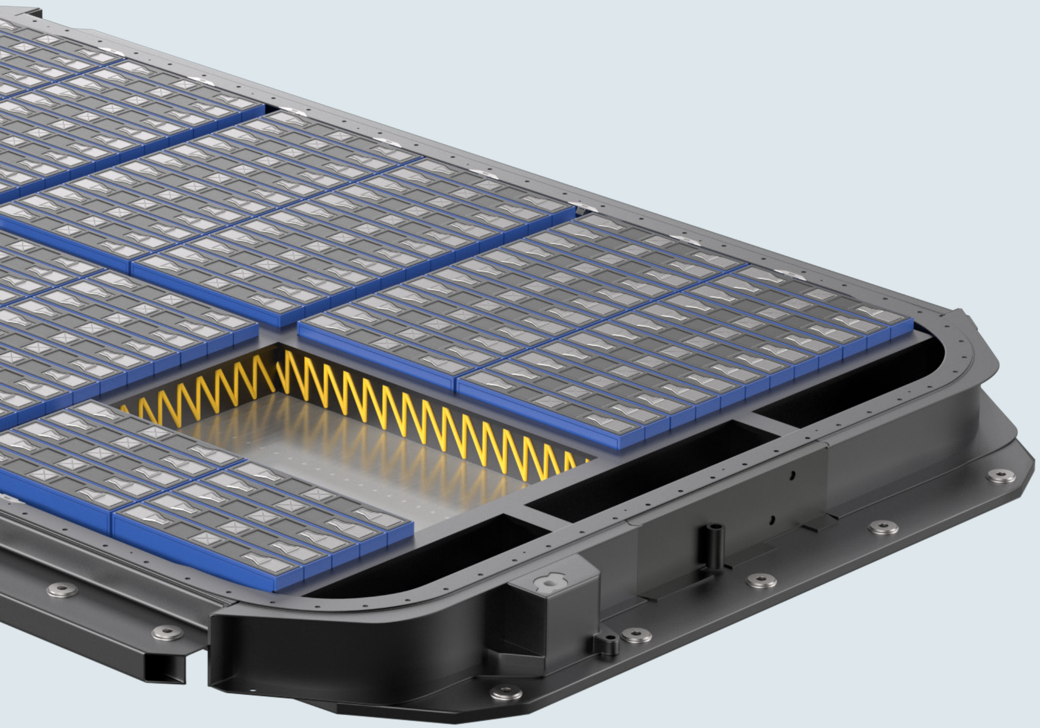
Tensile Loads:
These are generated when an adhesive is subjected to a pulling force in a single direction and can be caused by external loads such as the weight of the battery or vehicle, or internal stresses generated by thermal expansion or contraction.



Compressive Loads:
These are generated when an adhesive is subjected to a compressive force in a single direction and can be caused by external loads such as the weight of the battery or vehicle, or internal stresses generated by thermal expansion or contraction.



Thermal Characterization:
With standardized ASTM5470 test methods.



Structural Adhesive applications in the battery pack for structural bonding.

TIM AND BATTERY DESIGN TRENDS – CONTINUED

TCAs are multifunctional materials, combining both the thermal conductivity of TIMs and the structural bonding of Structural Adhesives. Selecting the right TCA with the optimal combination of thermal and structural performance characteristics is not a simple task. When selecting a TCA, it is important to consider all relevant design and performance parameters for the application.

SELECTION CRITERIA FOR THERMALLY CONDUCTIVE ADHESIVES

The multifunctionality of TCAs provides thermal management and structural integrity in demanding high-power high-temperature EV battery applications.

When evaluating a TCA for structural performance, it is important to consider the relevance of structural safety in the application. For example, a TCA's bonding characteristics could play a critical role in mitigating negative outcomes from potential for crash events. Selection criteria for structural performance includes:

- **Bond strength specifications:** These are determined through testing methods such as Elongation to Break, Youngs Modulus, Lap Shear Strength, and Tensile Shear Strength.
- **Type of surface on which the TCA is to be applied:** TCAs are formulated to adhere to multiple substrates such as aluminum, polyethylene terephthalate (PET) or substrates with surface with coatings.

When evaluating thermal performance, it is essential to consider relevant aspects of mechanical and cooling system designs to identify where thermal management is needed, where it would be most effective, and how much heat the system is generating. Selection criteria for thermal management includes:

- **Thermal conductivity specifications:** These are measured in W/mK and are determined by the specific formulation of polymer resin and conductive filler.
- **Temperature stability rating:** This is typically specified as the operating temperature range and is determined by the material's formulation. TCAs can be formulated to withstand severe environmental conditions.
- **UL Flammability rating:** This is determined by standard UL testing. UL ratings help engineers determine how usable a material is for a particular purpose.

TCA materials also have specifications related to assembly processes such as dispensing and curing. For example, material viscosity, working time, and curing schedules will influence TCA material selection.

A variety of TCA material formulations are available. Selecting the most suitable form for a specific application requires a detailed understanding of the design, the substrates involved, and the assembly processes utilized.

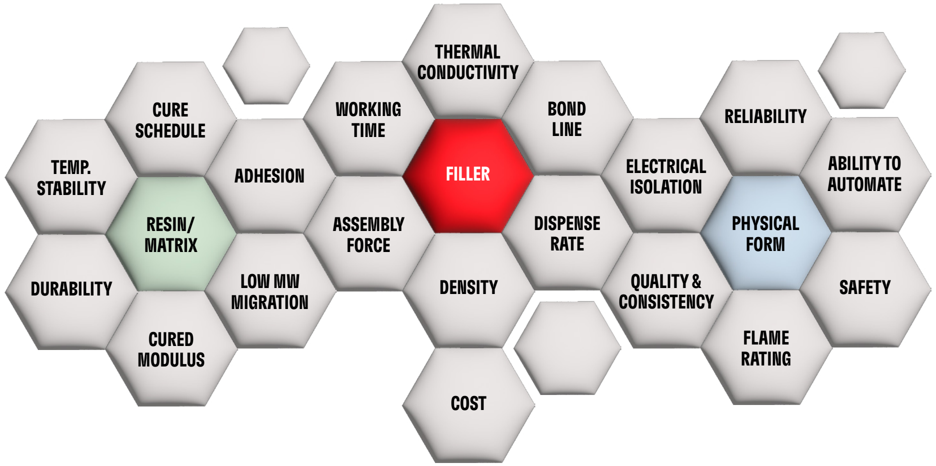


Illustration of key building blocks for TIMs that determine final performance, handling, and format of the material.

MODELING AND SIMULATION TOOLS

Because TCAs must support both structural and thermal performance of a battery pack, they must adequately transfer mechanical loads during operation, protecting adjacent components against harsh conditions such as high and low frequency vibrations, torsional loads, etc., all while maintaining optimal heat transfer characteristics. The complexity of combining mechanical and thermal requirements into a single material makes modeling and simulation particularly useful for evaluating TCA material performance in EV battery designs.

Heat generation, heat dissipation, cooling capacity, energy efficiency, noise-vibration-harshness (NVH) and crash-crush performance of the entire EV battery system can be predicted using modeling and simulation methods.

1D analytical models, Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) are three modeling and simulation techniques often used to help engineers select the right TIM materials and optimize battery design.

- 1D analytical models consist of simplified, linear, node-to-node, mathematical models useful for fast simulations. It is an effective method of quickly evaluating the behavior of the battery pack and its peripheral components using mass and energy conservation laws.
- FEA is a 3D computational method used to predict the mechanical and thermal behavior of interacting materials within the battery system. Using cohesive or continuum mechanics approach, FEA allows engineers to model various design and material options in a matter of hours, rather than the days or weeks it would take to produce physical prototypes.
- CFD is a specific 3D computational method used to predict fluid flow in EV battery cooling systems. Thermal management performance insights can be obtained quickly, resulting in a more reliable and efficient final product.
- CFD techniques are also fundamental for predicting the high viscous rheological flow characteristics of TCA materials during application and can be used to identify optimal dispensing patterns and compressive force profiles.

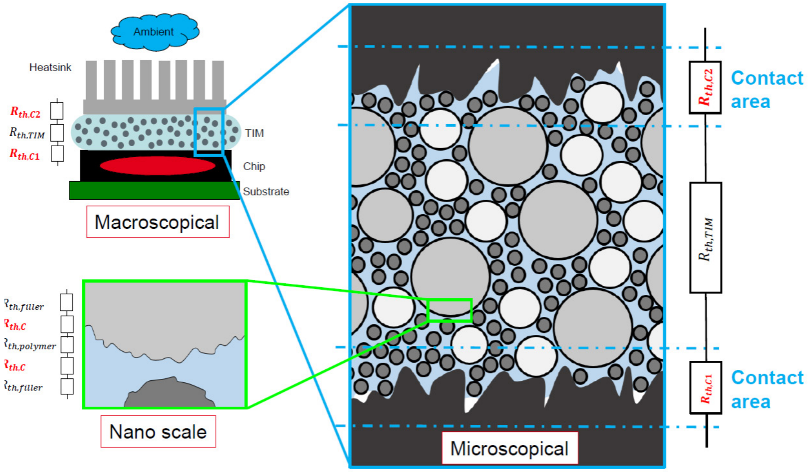
All three techniques have their own limitations, such as computational complexity, accuracy, and need for validation. However, when combined in a hybrid approach, they provide important insights that can be used as design optimization opportunities for overall improved battery performance.

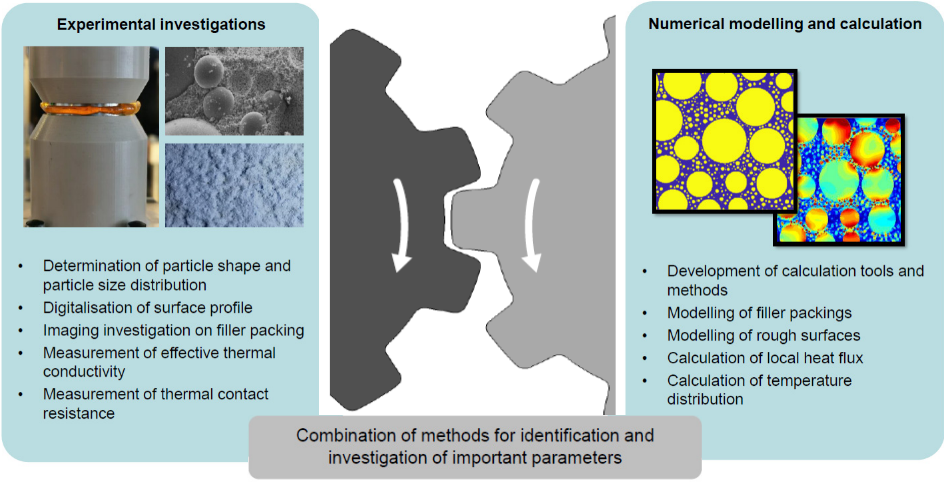
THE DESIGN-TO-TARGET APPROACH OF TCA FORMULATION

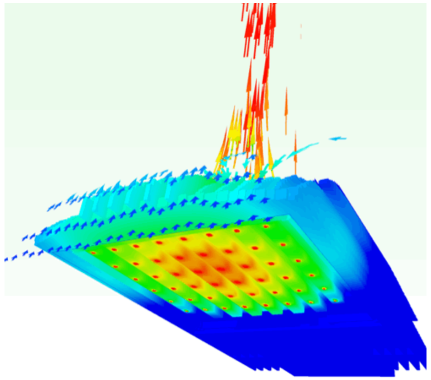
The formulation process of TCAs consists of choosing and mixing several materials and additives, presenting a challenge that can be highly time and resource consuming. Therefore, the use of modeling and simulation software tools can increase the overall efficiency of the TCA product development cycle.

TCAs are composite materials. Their thermal and rheological properties result from interactions between the polymer matrix and the filler, which accounts for up to 90% of the volume of the mixture. Validated simulation methods can predict how those two parts interact, allowing chemists to find the best ratio to achieve target thermal and rheological behaviors before physically mixing materials. This translates into a faster, resource-efficient, and a more sustainable method of TCA product development.

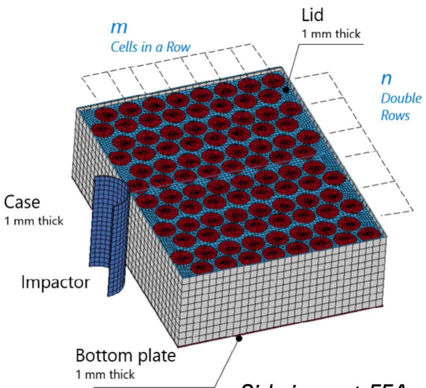
Illustration of TIM Product Development Technologies (Source: ZFW Stuttgart)







Thermal flow modeling



Side impact FEA model

HENKEL'S TCA PORTFOLIO OVERVIEW

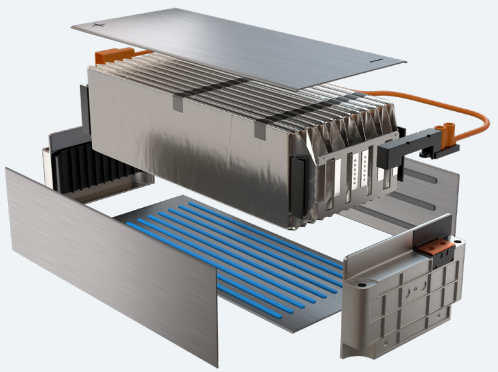
Henkel's global presence and experienced teams of innovators and product development experts are supported by world-class laboratories and equipment technologies as well as an extended network of academic and industrial partners. This solid foundation supports our well-diversified portfolio and solid innovation pipeline of products to address both current and future market needs.

Henkel's broad TIM portfolio features materials with various properties including:

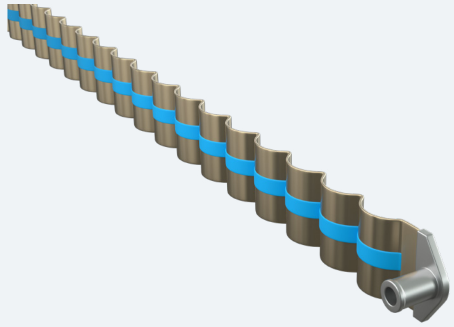
- Thermal conductivity ranges between 1.2 and 3.4 W/mK,
- Bead dispensable TCAs,
- Slump or sag resistant TCAs,
- Injectable TCAs for small cavities and small cavity filling where modules and packs are pre-assembled,
- Lap Shear Strength of 1 MPa to 10 MPa (Gap Fillers are generally at max 0.3 MPa),
- Elasticity (Elongation to Break) from 3 to 25%
- Formulations that bond to a variety of surfaces such as aluminum, PET, KTL and dielectric coatings

With Henkel's expertise in product development, innovation and know-how, our portfolio is always growing to address new challenges.

TCAs can be formulated for different battery designs and cell types.



Battery module with pouch cells



Cooling tube for cylindrical cells

TCA PROCESSING

High throughput is a key requirement from a production standpoint and high expectations are placed on the dispensing rates of TCAs. There is a presumption that TCAs should dispense similarly to Thermal Gap Filler which can run at dispensing rates up to 100 ccm/sec. However, due to their unique formulation and filler packaging, TCAs possess different rheology and dispensing behavior.

Therefore, early engagement and collaboration between Product Development and Application Engineering, as well as having an equipment partner in place to support customers along the way, is essential to successful matching of material, equipment, and process.

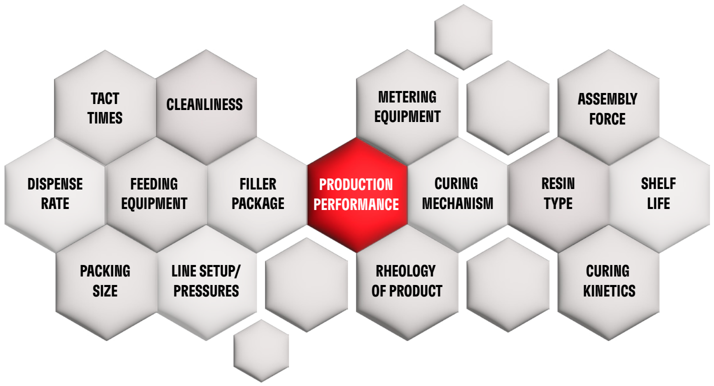
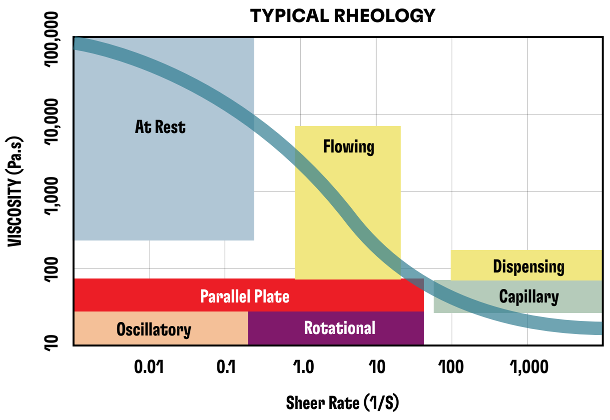


Illustration of the building blocks that determine the production performance of the material.



Example of rheology plot.

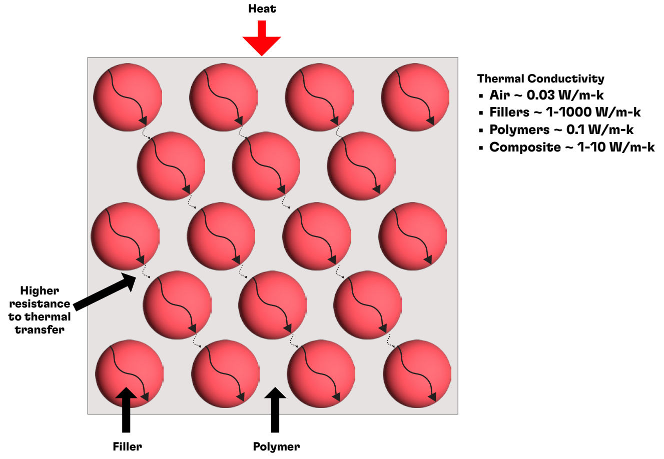


Illustration of filler in a polymer matrix.

Understanding rheology of matrix and filler enables chemists to support and streamline material behaviors for processing and application, whether bead dispensing or injection dispensing.

TCA PROCESSING – CONTINUED

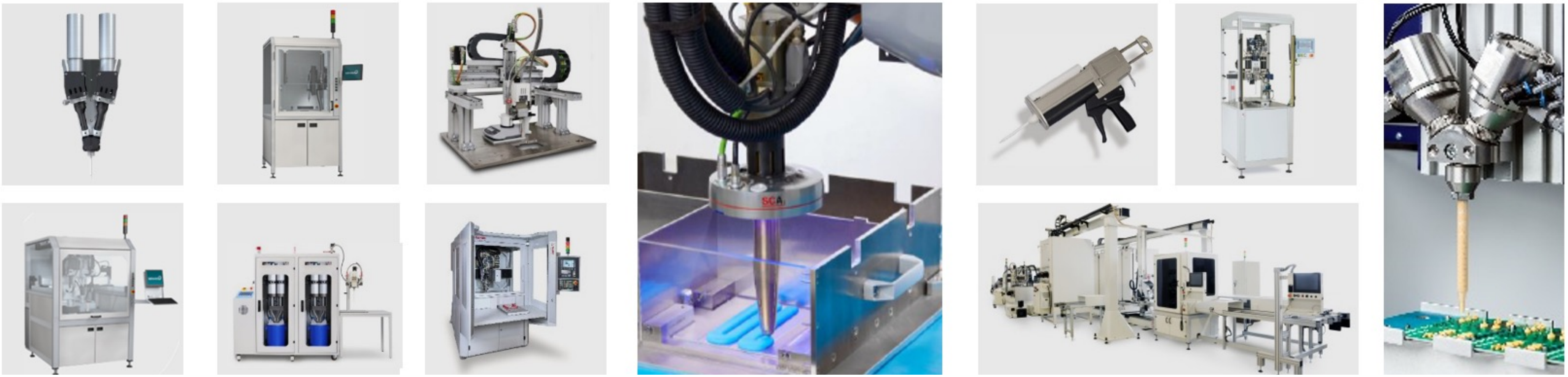
Henkel partners with an extended network of dispensing equipment manufacturers. This collaboration enables a seamless integration of equipment with TCA products and hassle-free equipment support throughout a product's lifecycle.

With a variety of different and fast-changing requirements from OEMs and battery manufacturers, Henkel's strong relationships within the equipment arena ensure consistency in delivering the best customized equipment-material solutions to the customer.

Henkel's partnerships with research institutes and academia also enable collaboration with innovation experts and external partners for co-developing solutions and technologies for next-generation EV batteries.

Bead dispensing

Injection dispensing



Examples of dispensing equipment from Henkel's network of partners.

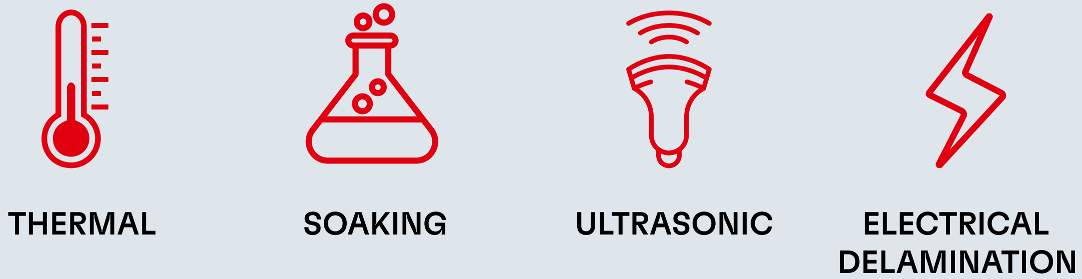
BATTERY SUSTAINABILITY

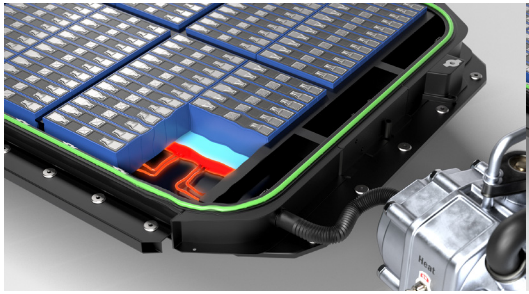
With the rapid rise in EV production, large volumes of batteries will reach their end-of-life (EOL) in the coming years. Therefore, it is increasingly important to build a circular economy for EV batteries by addressing battery repair, remanufacturing, and high-recovery recycling technologies. At Henkel, we are collaborating with OEMs and battery manufacturers to develop sustainable battery materials with debonding mechanisms for seamless disassembly at EOL.

Henkel is currently in the advanced stages of product development of battery materials that will enable those sustainability measures. Functional materials such as debondable structural adhesives and debondable thermally conductive adhesives will enable OEMs and battery manufacturers to include debond-on-demand solutions into EV batteries, thereby extending the maximum lifetime of batteries and easing the dismantling process for EOL applications.

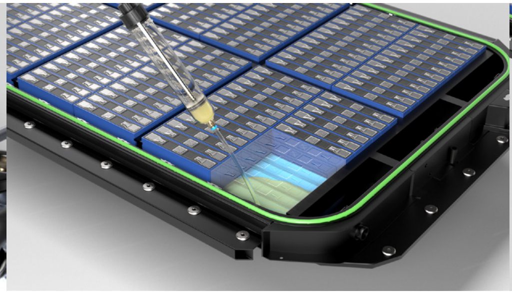
Based on different triggers such as temperature, electric delamination, ultrasound, electromagnetic radiation or soaking, structural adhesive will be debondable, allowing the non-destructive dismantling of the whole battery pack. This will be highly advantageous in terms of both repairability and recyclability. Early engagement with customers is key since developments that facilitate a debonding mechanism need to be considered from a material perspective, and also the battery design needs to allow for debonding mechanisms.

Different Triggers for Adhesive Debonding

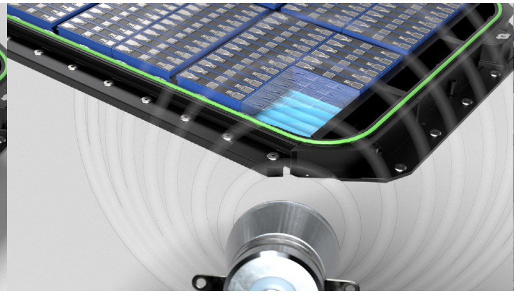




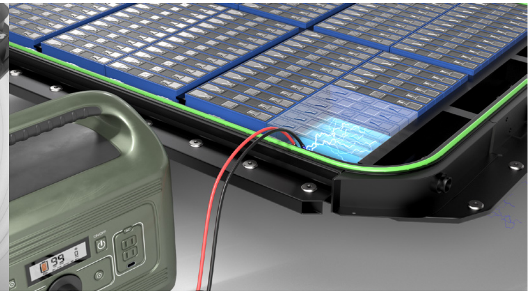
Thermal Debonding



Soaking Debonding



Ultrasonic Debonding



Electrical Debonding

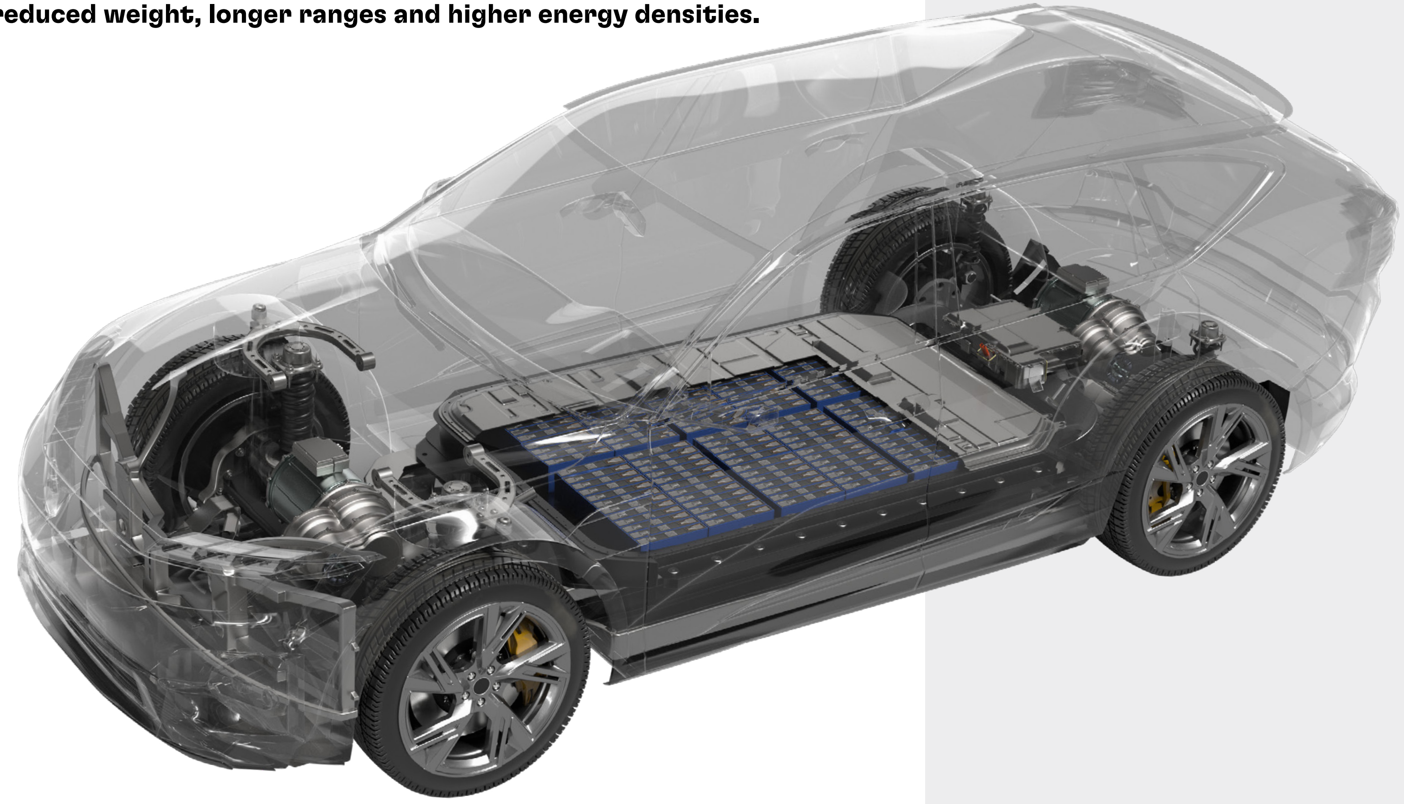
CONCLUSIONS

There is a variety of EV battery designs in the marketplace today, with different battery cell types and overall configurations, each requires performance optimization, safety, and long-term reliability.

The recent emergence of the Cell-to-Pack configuration for next-generation battery design simplifies battery assembly, enabling a reduction in cost, weight, and complexity. However, it also brings a new set of requirements in terms of assembly materials.

TCAs used in new Cell-to-Pack battery configurations have multiple functions, providing structural bonding, structural support, and thermal management. Combining all required thermal and structural performance characteristics into a single TCA material is not an easy task. It requires significant technical expertise. Henkel, a leading global provider of material solutions for electronics, with world-class laboratories and equipment technologies, is proud to support OEMs and EV battery manufacturers with a broad portfolio of EV battery solutions that address current and future market needs.

Henkel - Enabling safer, more efficient, and more sustainable EV battery designs with reduced weight, longer ranges and higher energy densities.



EUROPE
GERMANY
Henkel AG & Co. KGaA
(Headquarters) Henkelstraße 67
40589 Düsseldorf
Phone: +49.211.797.0

AMERICAS
U.S.A.
Henkel Corporation
32100 Stephenson Highway
Madison Heights, MI 48071
Phone: +1.248.583.9300

ASIA-PACIFIC
CHINA
Henkel (China) Investment Co., Ltd.
Building 7 & Building 6 (5F - 6F),
The Springs Center
No. 99 Jiang Wan Cheng Road
Yang Pu District, Shanghai 200438
Phone: +86.21.2891.8000

Get In Touch With Us

henkel-adhesives.com