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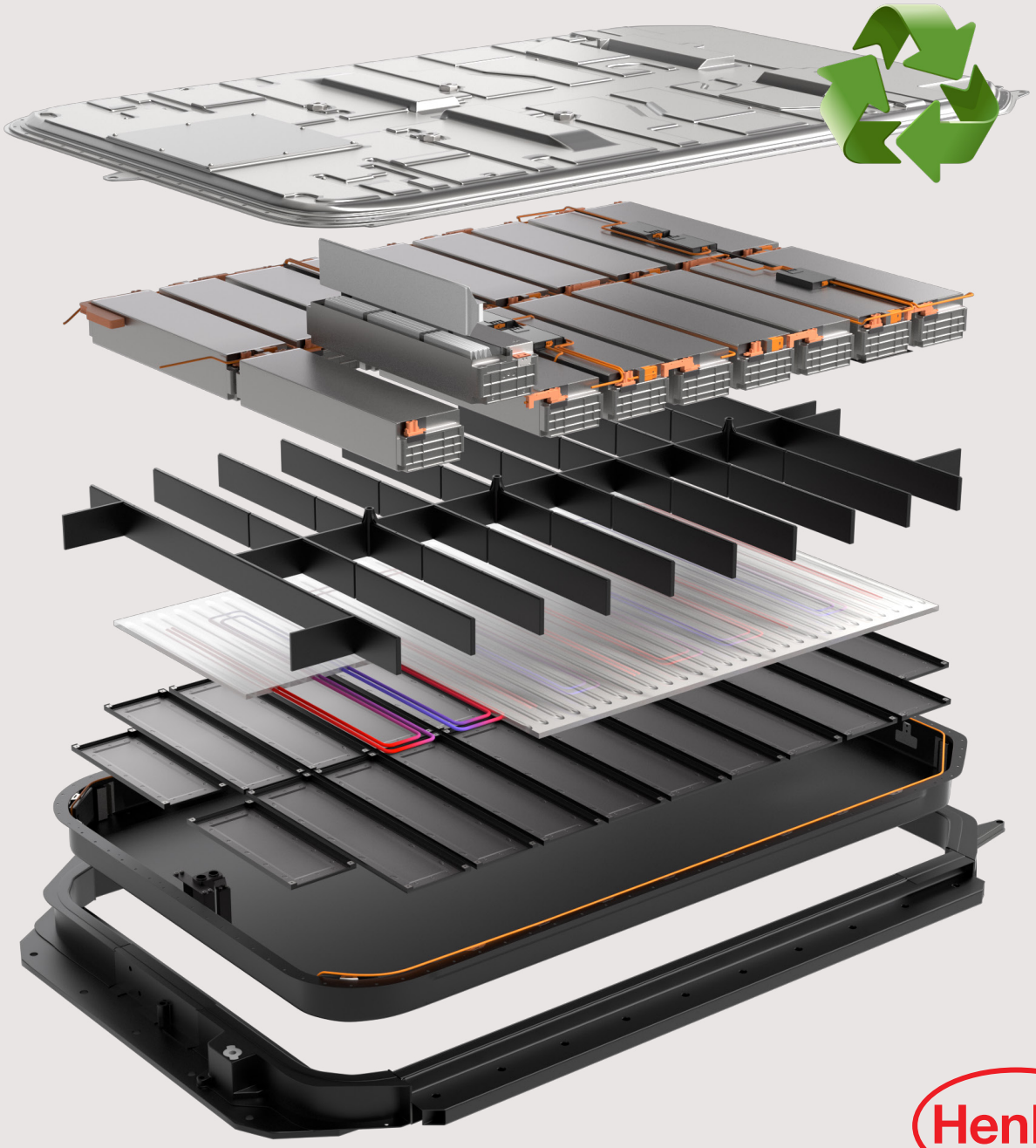
HENKEL SOLUTIONS

ENABLING A CIRCULAR ECONOMY FOR EV BATTERIES



Henkel

CONTENT

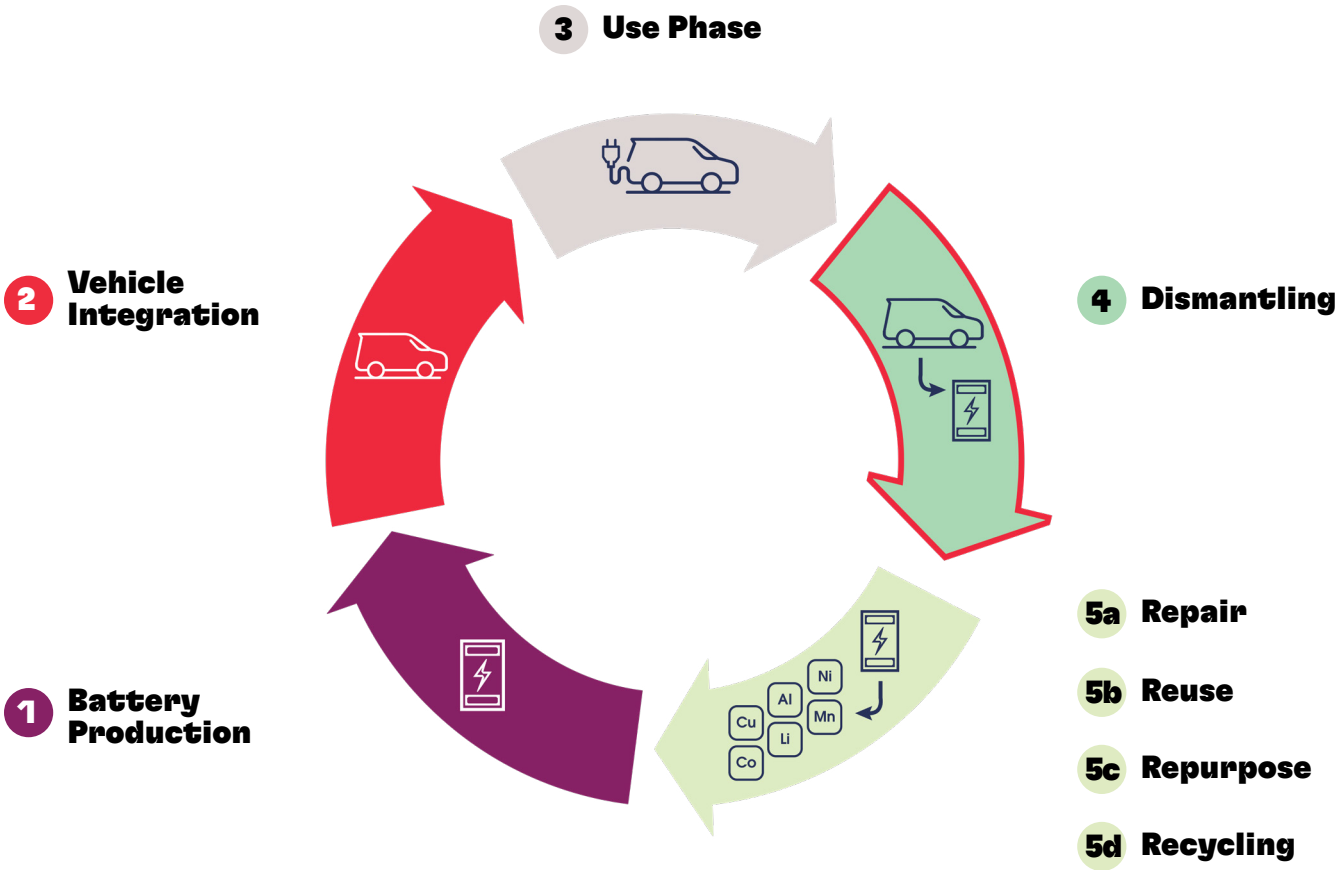
Different Aspects of Circularity: 4Rs

Repair: Experience shows that recalls do happen in the EV and battery industry. Though never desired, being prepared for this and being able to reopen battery packs in order to exchange and repair modules/cells in a non-destructive manner is essential.

Reuse: Taking advantage of healthy batteries (e.g. State of Health (SOH) >80%) at the vehicle's end-of-life, those batteries can be integrated in used EVs that are in need of a refurbished battery. Being able to remove and repair single modules is, therefore, of both environmental and commercial interest.

Repurpose: As soon as the SOH reaches a certain limit, EV batteries should further be utilized in applications such as stationary energy systems or less demanding mobile applications. Therefore, it is crucial to be able to open and manipulate battery modules and cells without inflicting damage on them.

Recycle: Accordingly, efficient and state-of-the-art recycling technologies will be used to recover valuable metals. During the initial step of disassembly, valuable and mono-fraction materials (e.g. aluminum housing) can already be separated yielding in higher recovery rates.

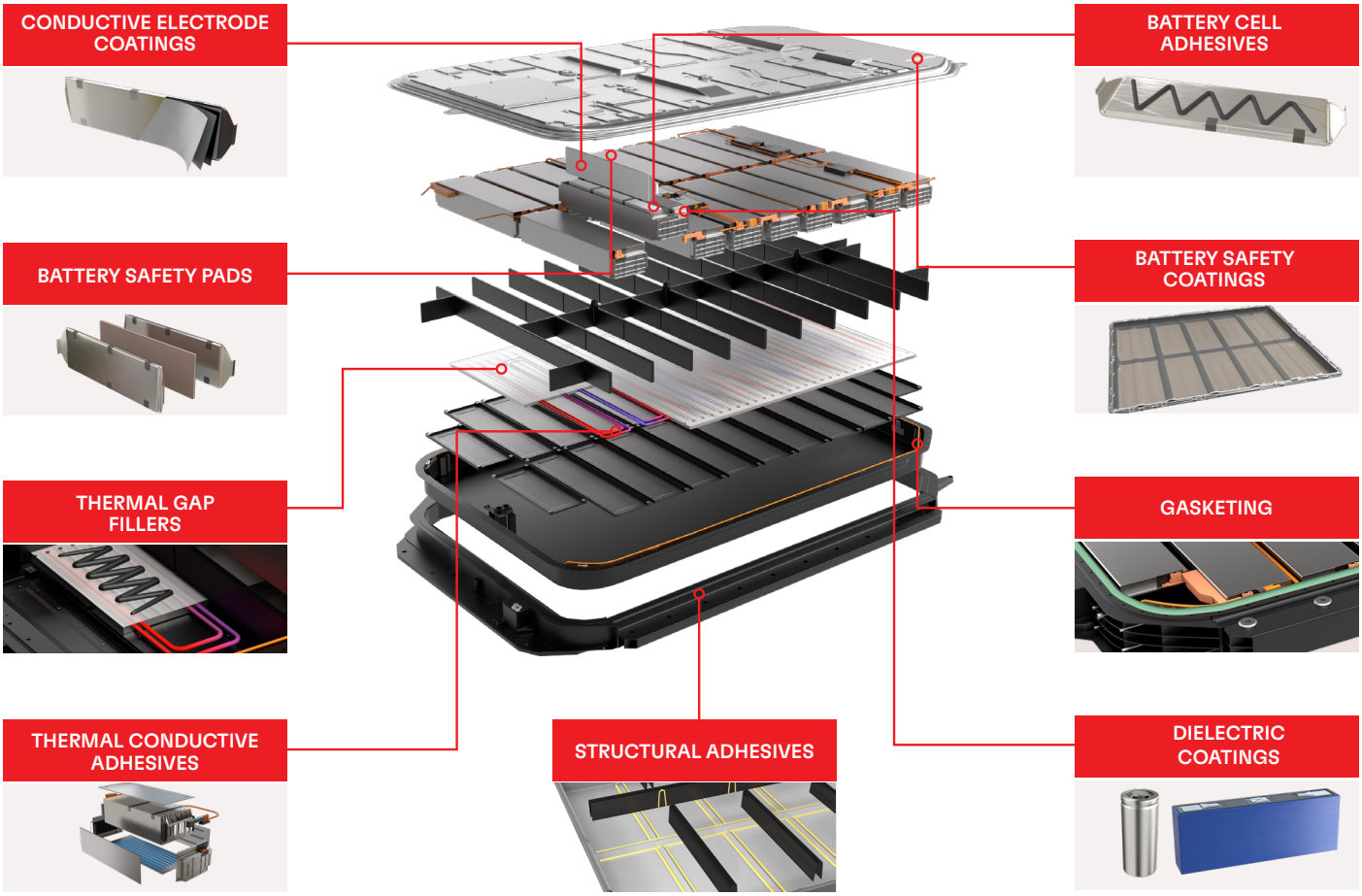


Debondable Adhesives as a Key Technology for Enabling EV Battery Circularity

In today's EV batteries, adhesives, thermal management materials, and sealants are crucial elements:

- **Cell assembly adhesives** are used to mount battery cells with good adhesion and high bonding strength (e.g. LOCTITE® AA 3963)
- **Thermal gap fillers** are suitable for applications where a high dispensing throughput is required in combination with a high thermal conductivity (e.g. BERGQUIST® TGF 2010 APS)
- **Thermally conductive adhesives (TCA)** will play an increasingly important role as new battery designs, such as cell-to-pack and cell-to-chassis, go into development. Combining thermally conductive properties with structural properties are the key requirements for those materials
- **Structural Adhesives for battery packs** are challenged with high requirements regarding a structural, primerless bonding at a high production speed (e.g. TEROSON® MS 9399)
- **Gasketing for battery pack housings** have the utmost requirement of sealing and protecting the battery pack from the external environment, ensuring a reliable lifetime performance. Adhesive properties may be included, but also the reopening of the battery pack and therefore the serviceability plays a key role (e.g., LOCTITE® ESB 5100)

All described adhesives and thermal interface materials have something in common, that as of now, they are engineered for their first-life application. Being able to include a debondable trigger in battery materials will enable circularity for both, an extended product life-cycle (repair, re-manufacture, reuse) and for keeping the materials with high recoveries in the material loop (recycling).



Benefits Of Debonding for OEMs and Battery Manufacturers: Economic & Regulatory

The market for debonding of batteries is not yet fully established, but it is expected to experience an exponential growth due to:

Economic Attractiveness

- **Repair:** Having a repair concept for an EV battery has a high economic benefit for the OEM due to the high cost of the battery overall (up to 40% of the total EV). Furthermore, the right to repair from an end consumer point of view will be crucial to fulfill. Debondable adhesives and sealants enable a concept for repairability.

- **Second-life:** Preserving value and extending the life of batteries is in the interest of the OEM. Applications for second life include e.g. home storage and less demanding mobile applications.

- **Recycling:** Recycling reduces the need for virgin raw materials and conserves resources. Debonding allows for high recovery rates due to an early separation of materials in the recycling process. Dependencies in the battery raw material value chain can be reduced significantly if recycled materials are kept in the loop.

Regulatory framework in key markets with mandatory requirements for batteries with regards to second-life applications and recycling

- The European Union is setting up a holistic framework to enable sustainability in the battery ecology. The update of the battery regulation and the battery passport will both promote a second life of batteries as well as mandatory recycling targets.

- China already has high battery recycling specific targets in place that are expected to further increase over the coming years

- As of now, no explicit US federal policies that cover lithium-ion battery (LIB) recycling are in place, but there are ongoing discussions for a possible framework for future LIB recycling

Different Enablers and Triggers of Debonding

Temperature:

- Heating of bonding area leads to softening, decomposition or expansion of adhesives‘ polymers
- Cryogenic cooling of the bonding area results in impaired flexibility and brittleness of the adhesives‘ polymers

Chemical:

- Application of solvents facilitate expansion of adhesives‘ polymers
- Application of surface-active substances creates a separating layer between bonded materials
- Release of encapsuled plasticizers under defined circumstances causes softening of the adhesives‘ polymers

Magnetic:

- Electromagnetic heating (induction) leads to softening, decomposition or expansion of the adhesives‘ polymers

Mechanical:

- Weakening of the adhesive bond via heating of the bonding area followed by the application of mechanical force
- Application of high mechanical force
- Application of targeted mechanical force by use of separation tools

Electrical:

- Electrical delamination through applying voltage and thus obtaining a weak boundary layer that leads to accumulation of the adhesives at interfaces

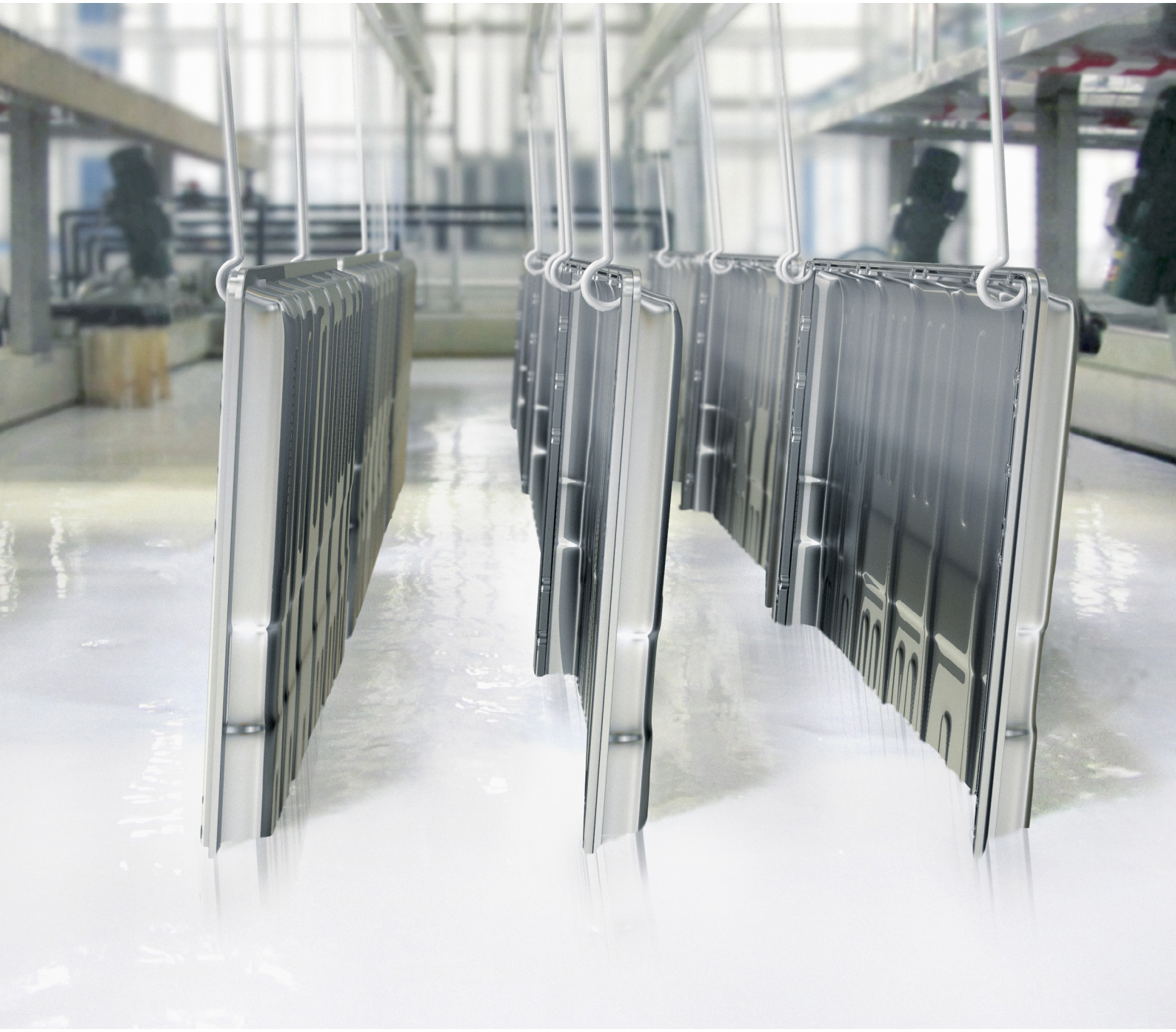
Different Battery Designs and Challenges in Debonding

- Battery designs and variants are expected to increase dramatically over the next decade
- Both battery design (module design, cell-to-pack & cell-to-chassis) and battery cell format (cylindrical, prismatic, pouch) influence possibilities in producing recycling-friendly batteries
- Next to design for cost, design for producibility and design for performance, the aspect of design for sustainability will move up to be considered as a crucial aspect
- Adhesive technologies will be needed for all variants of battery designs, therefore allowing debonding is key for enhanced product lifetime and closing the material loop

Henkel Solutions Overview

Surface Treatment

BONDERITE® C-NE 20 is an aqueous neutral cleaner with multi-metal compatibility which can be applied by immersion and is compatible with a wide range of metals. It is composed of salts of organic acids, non-ionic surfactants and alkanolamine and is ideal for removal of cooling lubricants, punch and drawing agents, lap, and honing residues. The application of BONDERITE® C-NE 20 will furthermore **lower the adhesion** of selected bonds allowing for **easier removal** of parts thus **enabling second use of battery modules**. This product can be applied by immersion and creates a hydrophobic film.



Gasketing

Henkel developed a gasketing material, LOCTITE® ESB 5100, allowing rapid production integration and fulfilling environmental testing criteria. The hot-applied elastomer has unique tackiness, stays soft and is **easily removable for battery serviceability and repair.** The formulation is a silicone-free, corrosion resistant material with excellent adhesion to plastics and aluminum and has self-healing properties.

Thermal Interface Materials

Henkel developed a two-component, silicone-free, liquid gap filler, BERGQUIST® TGF 2010 APS. The material has a dispensing speed of 80 cc/second and is easily compressible. The thermal conductivity of 2.0 W/mK provides ample heat dissipation while balancing filler load and minimizing the effects of dispensing equipment abrasion. A **low pull off force** allows for in-line aftermarket repair as well as **non-destructive dismantling of battery modules** for **reuse, re-manufacturing, and recycling** applications.

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The data contained herein is intended as reference only. Some products/package sizes may not be available in your country or region or may have a lead time. Please contact your local Henkel subsidiary for assistance and recommendation on specifications and applications of these products.

henkel-adhesives.com/emobility

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