Realizing Possibilities: Thermal Management for Electric Vehicles and Electronics
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How will you meet consumer expectations for continuous improvement in battery-powered devices?

As battery-powered technologies become commonplace, consumers expect:

- Longer battery life
- Higher performance
- Smaller devices
- Safer use
- Better value

However, the features that make these batteries so appealing—like smaller size and higher power—also mean an increase in heat.

Because smaller and more powerful batteries produce more heat, thermal management materials become a key factor in producing high-performance battery packs.
Electric vehicles—including automobiles, buses, trains, off-road vehicles, watercraft, and aircraft—are here to stay. It is no surprise that original equipment manufacturers (OEMs) want smaller, lighter, and less expensive components that save space and reduce costs while boosting power efficiency and increasing vehicle range.

Vehicles with longer ranges and/or higher horsepower require high power density from electrical components such as batteries, motors, generators, and their associated power electronics.

A key challenge in developing higher-power-density electronics for electric vehicles and other applications is to manage the heat generated by smaller, high-power devices such as on-board battery chargers, DC/DC converters, and motors and their inverters. Thermally conductive potting compounds are proving to be an ideal method for rapidly and effectively conducting heat away from power components to the heat sink.

Using thermal management materials that provide a unique combination of high thermal conductivity and low viscosity reduces both maximum temperature rise and the time to reach a stable temperature, while maintaining electrically insulating properties. Viscosity is a material’s resistance to flow. Low viscosity, or easier flow, allows for the displacement of air within the application, which improves the rate at which heat is removed. Such benefits improve efficiency and component lifetime, thereby enabling high-performance chargers and power electronics.

It is no longer an affordable proposition to think of thermal management as an unnecessary cost. Longer battery life, higher performance, safer uses, and better value require tailored thermal management solutions.

A cost-targeted solution for thermal management optimizes process and improves product performance. In the following pages, learn about thermal management materials and their applications.
Thermal Management Markets and Products

Thermal management materials comprise a variety of heat transfer technologies designed to manage heat issues and increase the limits of product power density in a variety of markets.

## Markets

- Automotive
- Lighting
- Energy
- Transportation applications
- Laptops and smartphones
- Industrial applications
- Microelectronics

## Products

**Potting and Encapsulation**
- Silicones, epoxies, and urethanes

**Gels and Greases**
- Silicones

**Gap Fillers and Adhesives**
- Silicones, epoxies, urethanes, and acrylics
Thermally Conductive Chemistries

Silicones
Silicones offer flexibility in a wide temperature range (-75°C to +200°C), making them among the most versatile chemistries. The right silicone products can help protect fragile electronic components and modules where high-temperature resistance and permanent flexibility are top priorities. Silicones come in filled or unfilled varieties of platinum-cured or condensation-cured materials. Silicones are rated automatically as UL RTI 150, and many have UL 94 V-0 ratings.

Urethanes
Urethanes are useful when high temperature resistance is not required. For electronic packaging, urethanes work best in low-temperature applications where stress-sensitive electronic devices need a barrier against water or vibration. Low-viscosity urethanes range from soft gels to semi-rigid casting materials, customized to fit a variety of applications.

Epoxies
Epoxies provide versatility, durability, adhesion, chemical resistance, and high-temperature tolerance across applications. In addition, epoxies vary from extremely flexible to highly rigid casting materials, either filled or unfilled, which are thermally and/or electrically conductive and flame retardant.

Acrylcs
Acrylic-based adhesives are primarily used to bond metals, composites, and a number of thermoplastic materials. They require little to no surface preparation or primers, and they cure at room temperature. Acrylics deliver impact resistance, excellent low- and high-temperature performance, desirable in-service fatigue life, and high structural strength in bonded assemblies.
I. Introduction

Thermally Conductive Application Examples

**Battery Packs**
As battery technologies evolve to offer increased energy density, the ability to manage heat during charge and discharge cycles is crucial for optimizing performance. Compatibility and process customization for the different cell types is key. Cylindrical cells typically need adhesives or pottants. Pouch cells typically use gap fillers. Prismatic cells can use all three types: adhesives, pottants, or gap fillers.

**Motors**
Heat robs a motor of power and shortens its life. Thermally conductive epoxy and silicone potting and encapsulants help manage heat, increasing power density and the life of the motor. Studies have shown a temperature decrease of up to 50°C or an increase in power output up to 30% when using LORD CoolTherm® materials.

**Chargers**
Encapsulants and gap fillers improve heat flow in inductors and transformers, optimizing performance during charging and increasing product longevity. Encapsulants with low viscosity flow easily into the tiniest crevices, enabling better impregnation of irregularly shaped magnetic components and helping to displace air and reduce inductor hum. When using pre-potted components, gap fillers can even provide a thermal interface between the component and heat sink.

**Power Electronics**
To extend the life of power electronics, it is necessary to maintain low thermal resistance and protect components from shock, moisture, and debris. Low-viscosity, highly thermally conductive potting and encapsulants provide a robust thermal interface and protect delicate electrical components. Other thermal interface materials—gels, greases, adhesives, and gap fillers—will not only improve heat flow but also provide excellent isolation and vibration damping.
What is Potting and Encapsulation?
Potting and encapsulation is a general term for materials used to contain electronics in a housing. Successful application of a potting and encapsulation product requires balancing various properties of the material. Viscosity is a key consideration, as high-viscosity products are difficult to apply and cannot displace as much air as lower-viscosity products.

Why Do Electronics Need Potting and Encapsulation?

- Thermal management
- Structural assembly
- Flame retardation
- Improved reliability and product life
- Protection from harmful conditions and environments
  (Examples: temperature control, shock and vibration mitigation, audio damping, electrical insulation, water protection, and chemical protection)

Types of Potting and Encapsulation

Thermal management materials have different names depending on their end-use:

**Casting**
Coatings create a thin layer of material over the electronics.

**Encapsulation**
Encapsulants encase the electronics without a housing.

**Potting**
Pottants cover all the electronics in a housing.

**Sealing**
Sealants cover a part of the electronics in a housing.
Application Examples

Potting and encapsulating materials are used in the following applications:

• On-board chargers
• Inverters
• Wireless charger pads
• Battery packs
• Electronic ignition coils and engine control modules
• Ride level and wheel speed sensors
• Tire pressure sensors
• Lighting ballasts and HID lighting
• Capacitors, switches, connectors, and relays
• DC/DC converters
• Engine/transmission controllers

Coating materials are used in the following applications:

• Lid sealing
• Circuit board component assemblies
• Battery assembly
• Radio boards
## Potting and Encapsulation

### Key Properties to Consider for Potting and Encapsulation

<table>
<thead>
<tr>
<th>Property/Attribute</th>
<th>Measured as</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesion Strength</td>
<td>Shear Strength (MPa)</td>
<td>• Required for holding parts together. Could combine with external clamps&lt;br&gt;• Can change depending on conditions (cure stage, humidity, temperature, etc.)</td>
</tr>
<tr>
<td>Elastic Strength or Stiffness</td>
<td>Young’s Modulus (MPa @ °C)</td>
<td>• High modulus&lt;br&gt;  › Material is not &quot;re-workable,&quot; high adhesion, components will be damaged if material is removed&lt;br&gt;• Low modulus&lt;br&gt;  › Materials are “re-workable,” low adhesion, adapt well to surfaces, accommodate expansion mismatches</td>
</tr>
<tr>
<td>Heat Dissipation</td>
<td>Thermal Conductivity (W/m·K)</td>
<td>• Single material dissipates heat from various components and in three dimensions&lt;br&gt;• Balance with viscosity (↑TC = ↑Filler content = ↑Viscosity)</td>
</tr>
<tr>
<td>Environmental Protection</td>
<td>Moisture Absorption %, etc.</td>
<td>• Moisture/chemical barrier&lt;br&gt;• Protect from vibration/physical damage/reverse engineering (IP concerns)</td>
</tr>
<tr>
<td>Dispensing Ease/Flow</td>
<td>Viscosity (cPs @ °C)</td>
<td>• Low viscosity allows easier fill of gaps between components&lt;br&gt;• High viscosity = process difficulties when potting&lt;br&gt;• Balance with heat dissipation</td>
</tr>
<tr>
<td>Density</td>
<td>Specific Gravity (SG)</td>
<td>• Shows how dense a material is when compared to water (the standard)&lt;br&gt;• Water: SG = 1, Cement: SG = 3.15, Ethanol: 0.78, SC-320: 3.1</td>
</tr>
<tr>
<td>Gel Time</td>
<td>Minutes/Hours</td>
<td>• Time it takes from the introduction of a catalyst to formation of gel. *Gel is the time after which no further flow is possible.</td>
</tr>
</tbody>
</table>
Gap Fillers and Adhesives

What Are Gap Fillers and Adhesives?

Gap fillers are thermally conductive materials designed to manage varying or uneven surfaces by adding component stability, vibration control, and electrical insulation to the device. Next-generation gap fillers are designed for use in large-volume applications (liters/part vs. milliliters/part).

Adhesives can add structural strength to electronic components and provide both thermal conductivity and high bond strength.

Why Do Electronics Need Gap Fillers and Adhesives?

- Thermal management
- Stability of final structural assembly
- Vibration protection
- Heat removal or transfer
- Cosmetic or design appeal
- Improved reliability and product life
- Protection from harmful conditions and environments (Examples: temperature control, shock and vibration mitigation, electrical insulation, water protection, and chemical protection)

Application Examples

LORD Corporation engineers will work with you to determine how best to meet your design’s thermal management requirements.
### III. Gap Fillers and Adhesives

#### Key Properties to Consider for Gap Fillers

<table>
<thead>
<tr>
<th>Property/Attribute</th>
<th>Measured as</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>Shore OO (0-100)</td>
<td>• Scales overlap. See examples:</td>
</tr>
<tr>
<td></td>
<td>Shore A (0-100)</td>
<td>‣ Gummy bears: 10 Shore OO</td>
</tr>
<tr>
<td></td>
<td>Shore D (0-100)</td>
<td>‣ LORD Gap fillers: ~50 Shore OO</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‣ Pencil eraser: 62 Shore OO / 20 Shore A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‣ Shoe heel: 60 Shore A / 30 Shore D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>‣ Hard hat: 80 Shore D</td>
</tr>
<tr>
<td>Heat Dissipation</td>
<td>Thermal Conductivity (W/m·K)</td>
<td>• Single material dissipates heat from various components and in three dimensions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Balance with viscosity (↑TC = ↑Filler content = ↑Viscosity)</td>
</tr>
<tr>
<td>Electrical Insulation</td>
<td>Dielectric Strength (kV/mm or V/mil)</td>
<td>• Moisture/chemical barrier</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Protect from vibration/physical damage/reverse engineering (IP concerns)</td>
</tr>
<tr>
<td>Dispensing Ease/Flow</td>
<td>Viscosity (cPs @ °C)</td>
<td>• Shear-thinning (i.e. feels like toothpaste or mayonnaise)</td>
</tr>
<tr>
<td></td>
<td>Thixothropy (Thix. Index)</td>
<td>• Thixothropes don’t sag. They have a high viscosity when moved at slow speeds, and a low viscosity when moved at fast speeds (e.g. mayonnaise)</td>
</tr>
<tr>
<td>Density</td>
<td>Specific Gravity (SG)</td>
<td>• Shows how dense a material is when compared to water (the standard)</td>
</tr>
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<td></td>
<td></td>
<td>• Water: SG = 1; Cement: SG = 3.15; Ethanol: 0.78, SC-320: 3.1</td>
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<tr>
<td>Gel Time</td>
<td>Minutes/Hours</td>
<td>• Time it takes from the introduction of a catalyst to formation of gel</td>
</tr>
</tbody>
</table>

**For adhesives, the following should also be considered:**

| Adhesion Strength       | Shear Strength (MPa)                             | • Required for holding parts together. Could combine with external clamps  |
|                        |                                                  | • May change depending on conditions (cure stage, humidity, temperature, etc.) |
What Are Gels and Greases?

Thermally conductive gels are one-component, silicone interface materials that exhibit very low thermal resistance properties compared to other thermal interface materials currently available.

Thermally conductive greases are non-reactive silicone or polyether material designed for applications where the heat sink may later need to be removed easily from the device. Like gels, greases also exhibit very low thermal resistance properties.

Why Do Electronics Need Gels and Greases?

LORD offers a broad portfolio of gels and greases to meet unique specifications. LORD gels enhance stable thermal performance by resisting pump-out. Our thermal interface materials provide excellent isolation and vibration damping.

<table>
<thead>
<tr>
<th>TIM Type</th>
<th>$k_{TIM}$ (W/mK)</th>
<th>Characteristics</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| Greases  | 1 - 6             | • Typically one-component silicone system with ceramic particles  
• Low viscosity liquid, $G' > G''$ | • High thermal conductivity  
• Thin BLT (25-50 µm)  
• Low viscosity  
• No curing required | • Susceptible to pump-out and phase separation |
| Gels     | 2 - 3             | • Typically silicone or olefin systems with ceramic or metallic particles  
• Solid material, $G' > G''$ | • Conforms to surface roughness before cure  
• Thin bond line (25 µm)  
• No pump-out  
• Reworkable/low stress  
• Good 85% RH/85°C | • Curing is necessary  
• Lower $k_{TIM}$ than greases  
• Less adhesion strength than adhesives |
Developing expert thermal management solutions requires a thorough understanding of both the engineering industry’s top business needs and the best applications for each thermal management material.

The next wave of thermal management solutions is liquid-dispensed gap fillers, which have a lower interfacial resistance and can be applied in whatever pattern to fit whatever design change. In addition, the thermal performance of the gap filler is independent of part tolerances.

**Thermal management solutions should take into account the following factors:**

- **Thermal conductivity**: The rate at which heat passes through both the material being protected and the material providing the protection (TIM), measured in Watts per meter Kelvin or W/(m·K)

- **Thermal impedance**: The measured heat flow through the thermal interface material assembly, as opposed to it being a property of a single material

LORD liquid-dispense gap fillers provide lower thermal impedance than thermal pads having comparable bulk thermal conductivity and thickness. This result is largely due to the ability of the gap filler to readily conform to microscopically rough surfaces of the adjoining substrates, which consequently greatly lowers the interfacial impedance. Better thermal performance coupled with ease of assembly, low applied forces, ability to span large, variable bond lines, and lower cost make gap fillers a logical choice as a thermal management material.
What is a Meter, Mix, Dispense System?

Meter, mix, dispense equipment is used to dispense adhesives from bulk containers. Due to the high volume/high flow rate applications that are commonly associated with LORD gap filler materials, automated MMD processes are used in an effort to minimize material waste and cycle times and reduce overall cost.

Why Use MMD Equipment?

- Mixes two-component polymer systems accurately and consistently
- Dispenses low viscosity or high viscosity with mix ratios anywhere from 1:1 to 100:1
- Maximizes production efficiencies by mechanically agitation and degassing material prior to dispensing, whereas cartridges require materials to be agitated and degassed manually prior to packaging
- Performs highly repetitive shot volumes
- Enables high-volume production
- Reduces waste (disposal of cartridges)
- Saves costs: bulk adhesives cost less than cartridges in a cost/volume and can usually provide a return on investment in one to four financial quarters depending on the production volumes

LORD has partnered with many equipment manufacturers that specialize in dispensing these types of materials. A LORD representative can answer any questions you might have about the automated MMD processes of LORD gap filler materials.
Thermal Management in Transportation Applications

Electrification in all transportation sectors is driving requirements for motors with ever-higher power densities. Good thermal management in electric machines and their power electronic drives can minimize losses, particularly copper ($I^2R$) losses, and yield improved performance, reliability, and efficiency.

Research shows that a potting or encapsulation process using high-thermal-conductivity material from LORD Corporation can dramatically decrease the operating temperature of an electric machine at a given load. Further research has revealed significant decreases in operating temperature that correlate to higher motor efficiency and double-digit increases in output power when using a high-thermal-conductivity material. Additionally, these motors are highly resistant to cracking during severe thermal cycling, paving the way for designing long-lasting, thermally efficient motors that can achieve more power/torque at smaller sizes.

Motors potted with thermally conductive materials can achieve better performance than unpotted motors. Our studies show that:

- Hot spot temperatures of motors impregnated with high-thermal-conductivity materials are generally 40°C to 45°C cooler than a varnish-only motor and about 20°C cooler than a motor potted with a standard epoxy.
- During accelerated age testing, motors potted with CoolTherm® EP-3500 encapsulant lasted the longest and exhibited no stress cracks in the potting material.

The decrease in hot spot temperature, depending on current, can enable motor designers to:

- Increase achievable power/torque for a given motor size
- Decrease the motor size for the required power/torque
- Greatly increase the lifetime of the motor by decreasing the operating temperature

Integrating a LORD solution during the design phase is ideal, as the motor can be designed to maximize ease of potting and take full advantage of the high thermal conductivity of the potting material.
World-class thermal management solutions improve your product’s durability, safety, and performance while enhancing your brand.

LORD transforms innovative ideas into long-term value for our customers. Contact us to learn more about how industry-leading CoolTherm® products can be customized and scaled to meet your unique needs.

**LORD CoolTherm® Potting and Encapsulation**  
LORD CoolTherm® thermally conductive epoxy and silicone encapsulants help manage heat, enabling you to increase the power density and life of your motor. LORD studies have shown a temperature decrease of up to 50°C or an increase in power output of up to 30% when using LORD CoolTherm® materials.

Our thermally conductive encapsulants provide electrical isolation and protection, and their low viscosity enables better impregnation and displacement of air.

- Improve performance: LORD encapsulants facilitate optimum heat transfer because of their high thermal conductivity and low viscosity.
- Protect electronics: LORD potting compounds provide protection from dust and moisture and reduce vibrations.
- Reduce component stress: LORD encapsulants exhibit low shrinkage upon curing.

**LORD CoolTherm® Gap Fillers**  
Thermally conductive gap fillers get the best performance out of your components by filling in crevices and minute spaces that create inefficiencies. They are a stay-in-place solution and cure as a gel, easing the stresses caused by thermal differences and flex.

- Low-outgas options: LORD offers low-ppm siloxane solutions for sensitive electronic applications.
- Shock protection: LORD gap fillers remain tacky and soft to damp vibration.
VII. LORD Thermal Management Solutions Improve Your Product and Brand

**LORD CoolTherm® Adhesives**

Formulated for standard MMD equipment, LORD CoolTherm® adhesives provide your application with structural integrity. Our thermally conductive adhesives not only provide mechanical rigidity but also a thermal connection where heat is a problem.

- Improve design flexibility: No longer constrained by mechanical fixtures and able to bond a wide variety of substrates.
- Protect electronics: LORD thermally conductive adhesives provide electrical insulation for high-voltage and low-voltage applications.

**LORD CoolTherm® Gels and Greases**

LORD offers a broad portfolio of gels and greases to meet your unique specifications, including gel designed to provide efficient heat transfer from flip-chip microprocessors, PPGAs, BGAs, microBGAs, DSP chips, graphic accelerator chips, and other high-wattage electronic components. The gel is formulated to inhibit bleed, separation, and pump-out that are typically observed in many thermal interface materials.

**Example:** CoolTherm® SG-21 grease can be used with a variety of devices including flip-chip microprocessors, PPGAs, BGAs, microBGAs, DSP chips, graphic accelerator chips, and high-speed memory devices. The thixotropic characteristics of CoolTherm® SG-21 grease will hold the heat sink in place until it is mechanically attached.

LORD gels enhance stable thermal performance by resisting pump-out.
For more than 40 years, LORD Corporation has specialized in developing world-class thermal management solutions for demanding applications. LORD Corporation's product lines include potting and encapsulation materials, gap fillers, adhesives, gels, and greases in a variety of chemistries: silicones, epoxies, urethanes, and acrylics.

LORD partners with you to provide leading-edge solutions for heat-producing products, helping you deliver the value and performance your customers expect.

LORD customized solutions are made possible by technical expertise and deep knowledge of how best to serve customers.

Best-in-Class Product Performance

- CoolTherm® product portfolio with a range of solutions
- Proven and tested products that endure and protect
- Focus on safety for components and devices
- Protection against heat, vibration, and other harmful conditions and environments

Solutions That Solve a Problem

- Various chemistries and applications
- Tailored products and formulations

Quick to Market

- Product portfolio diversity
- Custom formulations
- Faster development

A Valuable Business Partner

- Global reach
- Direct access to LORD technical support team and inventors
- Cost-effective collaboration

Experience

- 40+ years of customization for specific product performance requirements
- Expertise in EV, microelectronics, and LED markets
- Collaboration with OEMs and Tiers
IX. About LORD Corporation

LORD Corporation is a diversified technology and manufacturing company developing highly reliable adhesives, coatings, motion management devices, and sensing technologies that significantly reduce risk and improve product performance. For more than 90 years, LORD has worked in collaboration with our customers to provide innovative oil and gas, aerospace, defense, automotive, and industrial solutions.

With world headquarters in Cary, North Carolina, USA, LORD has approximately 3,000 employees in 26 countries and operates 19 manufacturing facilities and 10 R&D centers worldwide.

LORD.com/CoolTherm

Customer Support Center (in United States & Canada)
+1.877.ASK.LORD (275.5673)
Values stated herein represent typical values as not all tests are run on each lot of material produced. For formalized product specifications or specific product end uses, contact the Customer Support Center.

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