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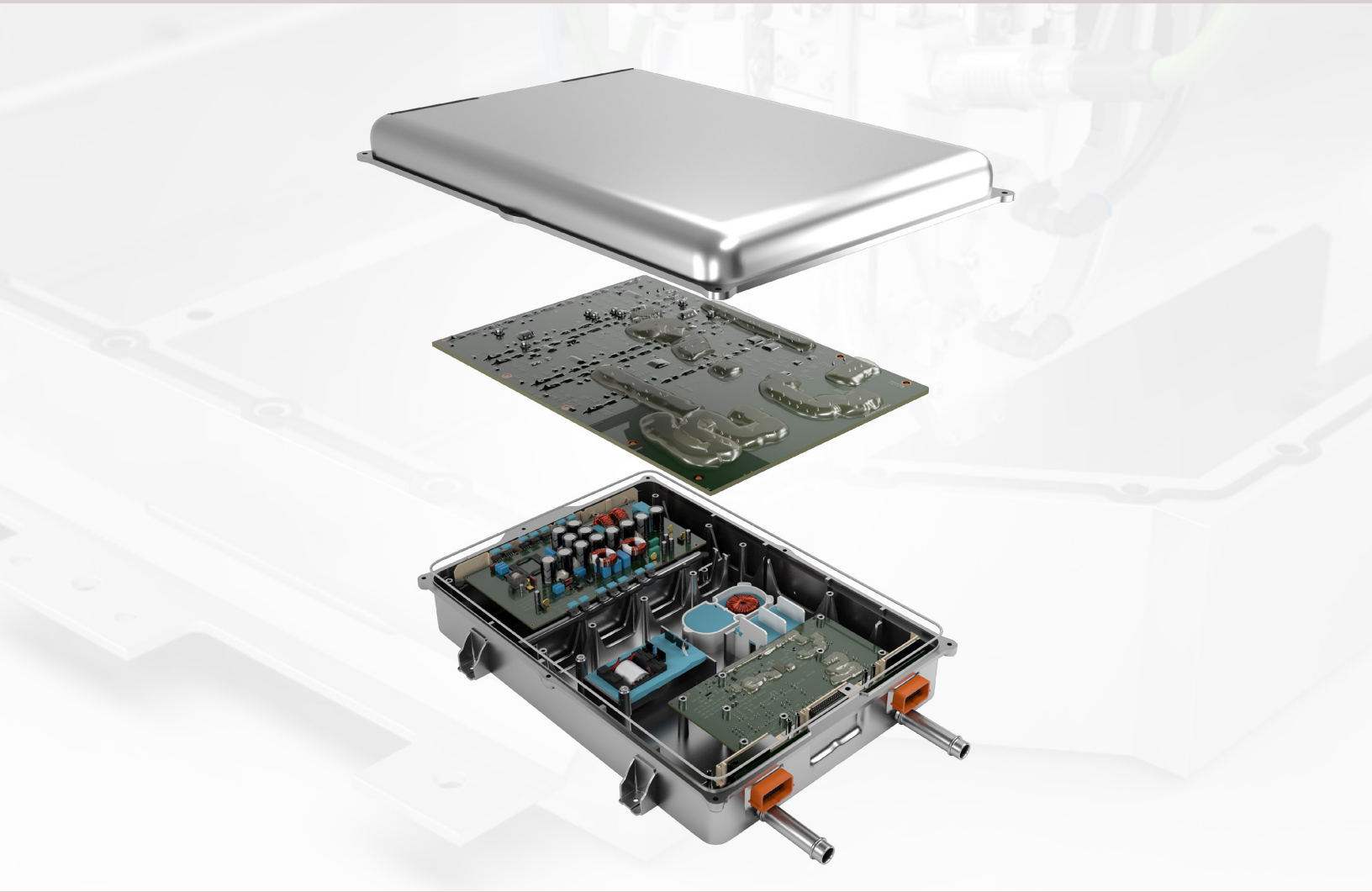

THERMAL POTTING FOR ***EV COMPONENTS***

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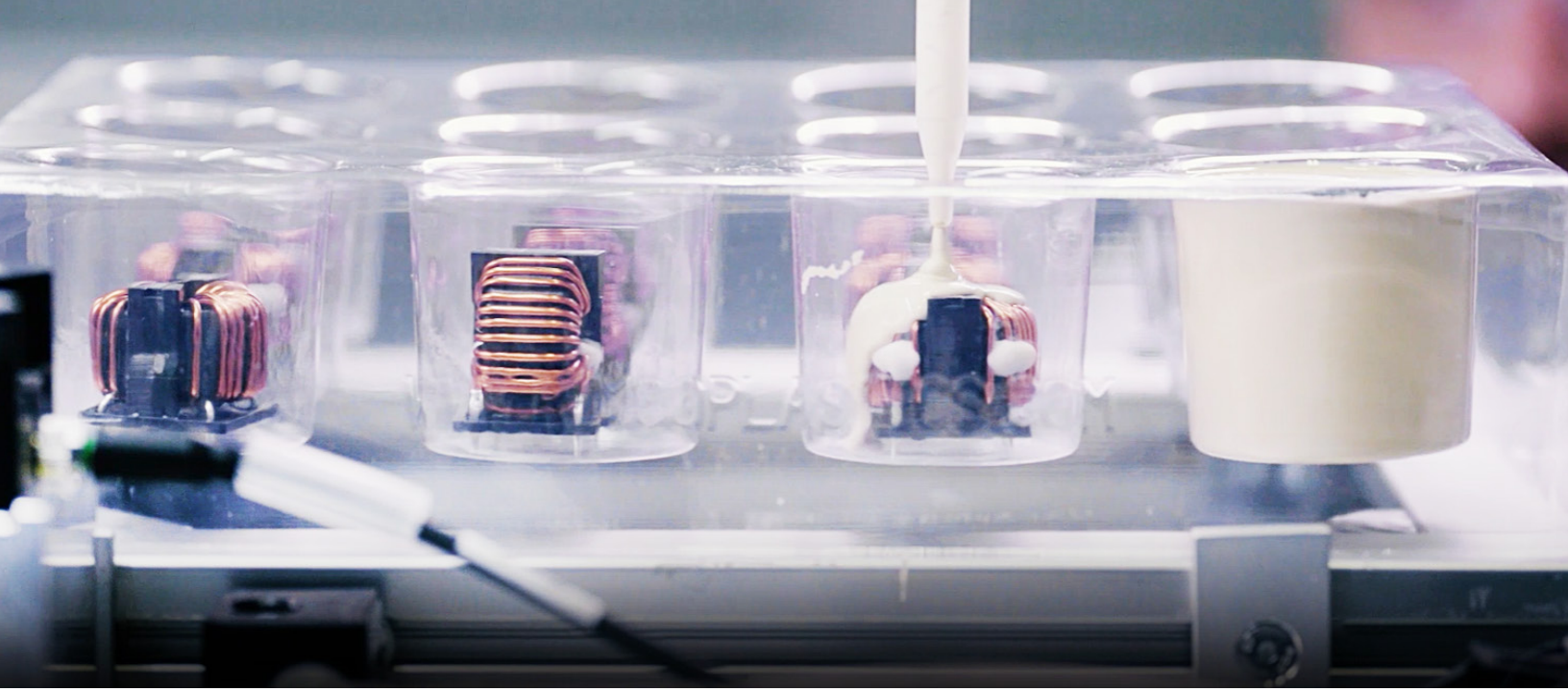
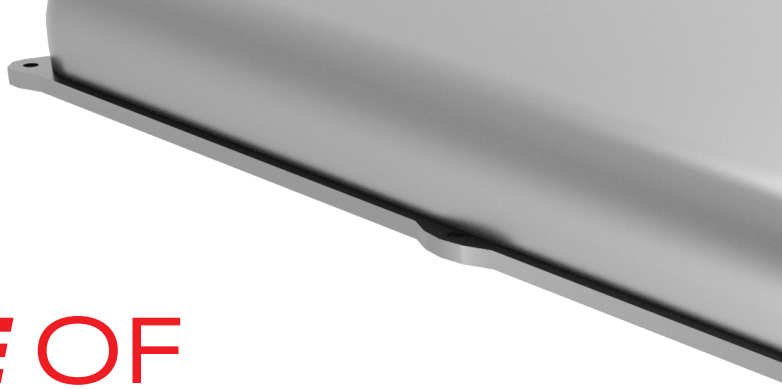


With the dramatic growth anticipated in the electric vehicle industry, manufacturers and component suppliers alike are vying for position in performance, range, cost efficiency, durability and reliability. Thermal potting materials, while often unseen, play an important role in heat management – a significant factor in achieving these objectives. As such, designers and engineers can benefit by carefully considering potting applications as they design new electric vehicle components. But not all thermal interface materials are alike. In general, thermal potting materials have unique requirements; from design, through material handling, to assembly, and even at end-of-life, it's important for engineers to partner with the right chemical supplier to meet their goals. As a leading designer of innovative adhesive solutions for EV battery components and automotive electrical and electronic devices, Henkel is well positioned to help our customers find success by navigating the complexities of thermal potting – from planning, through testing, into production and beyond.

Discover more about thermal potting compounds and how Henkel is actively developing formulations that offer superior heat transfer, excellent component protection, and long-term stability.



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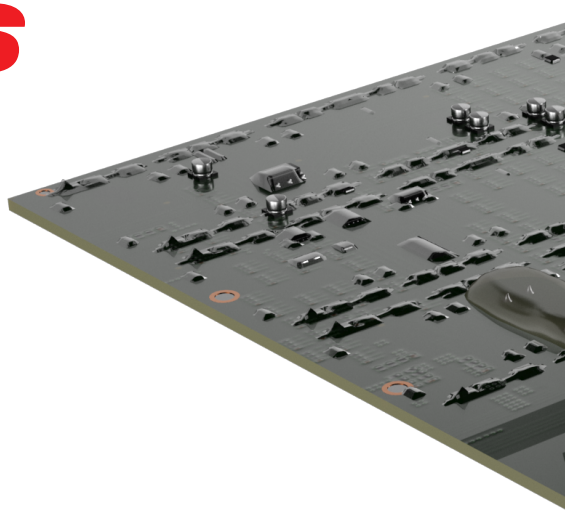
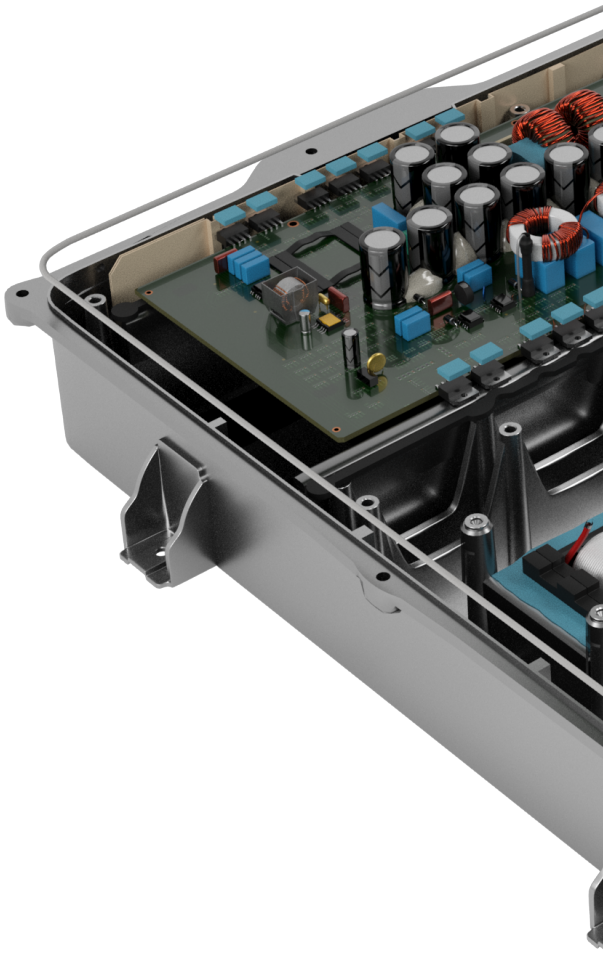




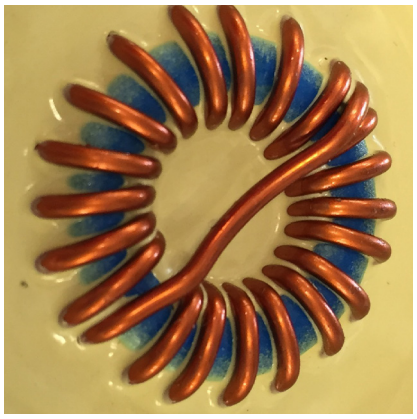
INTRODUCTION

Let's get started by looking deeper into the world of potting – not just thermal potting, but potting in general – to understand its features and benefits. Potting applications are designed to embed (or surround) and protect delicate or vulnerable components. Because potting conforms to or fills the shape of the customer's product, they offer infinite design variety, direct and full connectivity, and even unique benefits when compared to other forms of embedding.

Potting vs. Other Embedding Options

The automotive industry commonly uses three forms of embedding that offer various benefits depending on performance requirements:

- **Potting:** Filling or surrounding complex geometry or delicate componentry, or permanently affixing sensors and connectors inside a protective material
- **Encapsulation:** Covering and protecting sensitive electronic components, typically on flat surfaces requiring high dimensional stability
- **Impregnation:** Immersing heat-sensitive or heat-generating components in fluid to aid heat dissipation



Potting applications

Traditionally, potting has been used to embed and surround sensors, connectors, and electronic control units, making them impervious to harsh environmental conditions. These applications did not require heat dissipation performance, as they were often used on low-voltage components or placed in the exposed areas around the vehicle.

Over the past decade, however, emerging EV technologies have created new and more demanding high-voltage vehicle components that require not only protection but also effective heat management. Thermal potting has found a renewed purpose for EVs by simultaneously protecting and transferring heat away from sensitive components found in on-board chargers, inverters, converters, e-motors and more.

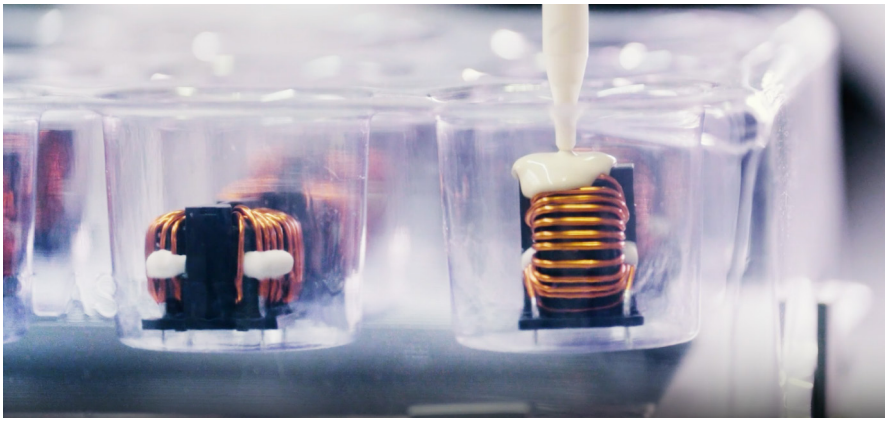
Thermal Potting Features

Thermal potting offers valuable benefits across three categories: heat management, electrical insulation and environmental protection.

- **Heat Management:** When properly formulated, dispensed, and cured, thermal potting compounds can transfer heat away from embedded electronic components effectively with long-term reliability.
- **Electrical Insulation:** When electrical insulation is required for exposed wiring or electrical conductors, thermal potting can perform a dual purpose of aiding in heat transfer while also preventing electric shocks or shorts
- **Environmental Protection:** Thermal potting compounds carry over the protective benefits of traditional potting, including:

    - Vibration/shock resistance
    - Service life resilience
    - Corrosion prevention
    - Chemical protection

Overall, a high-quality, properly applied thermal potting compound pays long-term dividends like improving the life of the electrical component, reducing warranty repairs, and improving end-user satisfaction through dependability and durability.



SELECTING A THERMAL POTTING PRODUCT

After engineers identify a component that would benefit from thermal potting, they often struggle with specifying or choosing a potting formulation. There are many considerations that go into selecting a potting product, and missing any one of those factors can mean a failed part, a lost bid, or a dissatisfied end user.

When responding to customer requirements or pursuing their own product development efforts, component engineers most often begin searching for a thermal potting solution when they encounter these key production or performance objectives:

- Improved conductivity for heat dissipation
- Higher chemical resistance
- Higher temperature resistance
- Higher voltage resistance
- Shorter production cycle time

Performance Considerations

Once a potting opportunity has been identified, engineers can begin specifying the requirements for evaluating potential solutions. But to select a suitable potting compound, the design team needs to go beyond the basic thermal potting expectations and do an in-depth evaluation of the performance parameters the potting compound will need to handle. To ensure the best possible outcome for the product evaluation process, the project team should start by answering certain questions, including:

Operating temperature:

What temperature extremes does the un-potted component reach during testing? What temperature range is acceptable for normal operation? Will the component be enclosed in a high-heat environment? What impact will the surrounding environment have on operating temperature?

Thermal properties:

Will the potting compound need to facilitate active heat transfer or only ensure operation within a specific temperature range? How quickly does the potting compound need to be able to transfer heat? Will the potted component be fully encased in another container? What are the thermal properties of the case surrounding the potted component? What other mechanisms will be attached to the component to aid heat transfer? How will temperature performance be evaluated among supplier offerings?

Electrical properties:

Is the potted component electrically insulated already, or will the potting compound need to provide electrical insulation? If insulated already, is it possible to eliminate the insulation to improve contact with the potting material's thermal capability, allowing the potting compound to provide the electrical insulation instead? What are the voltage and resistance ratings that the potting compound needs to contain? How will insulation performance be evaluated among supplier offerings?

Chemical resistance:

Will the potted component come into contact with any chemicals? If so, what chemical characteristics need to be accommodated? What is the chemical formula for the chemicals in question? How frequently will the chemicals reach the potting compound? How will chemical resistance be evaluated among supplier offerings?

Processing requirements:

Will the potting compound need to be dispensed on an existing application line? If so, what are the dispensing format and flow rate characteristics of the existing equipment? How frequently does the current line get shut down for maintenance? If no dispensing equipment currently exists, how much production space has been allocated for processing? What is the time allotted between product finishing and installation or activation? What is the air temperature/humidity range of the production facility where dispensing will take place? What storage capacity is available for chemical inventory at the production facility? What is the temperature/humidity in the storage area? What, if any, refrigerated chemical storage is available?

Regulatory considerations:

What regulatory considerations may influence the product formulation being considered? For example, are there any restrictions on silicone use that suppliers should be aware of when providing recommendations?

Business considerations:

What is the target production volume for the components? What are the product costs versus the total process costs for the potting solutions under consideration, and which has higher priority? What production efficiencies can chemical suppliers offer that may influence total process cost? What additional service and/or support do suppliers offer that may improve the likelihood of success?

Formulation Considerations

In addition to general performance and business factors, it is important to consider which formulation options may best fit the target requirements. Urethane options offer a good mix of strength and flexibility for low-range temperature applications, and they hold up well when exposed to oils, solvents and other chemicals. Epoxy options offer excellent mechanical strength for mid-range temperature applications, but in situations where flexibility and vibration dampening are important, epoxy may not be the best choice. For the greatest possible temperature range, flexibility, and vibration dampening performance, silicone formulations offer an ideal solution.

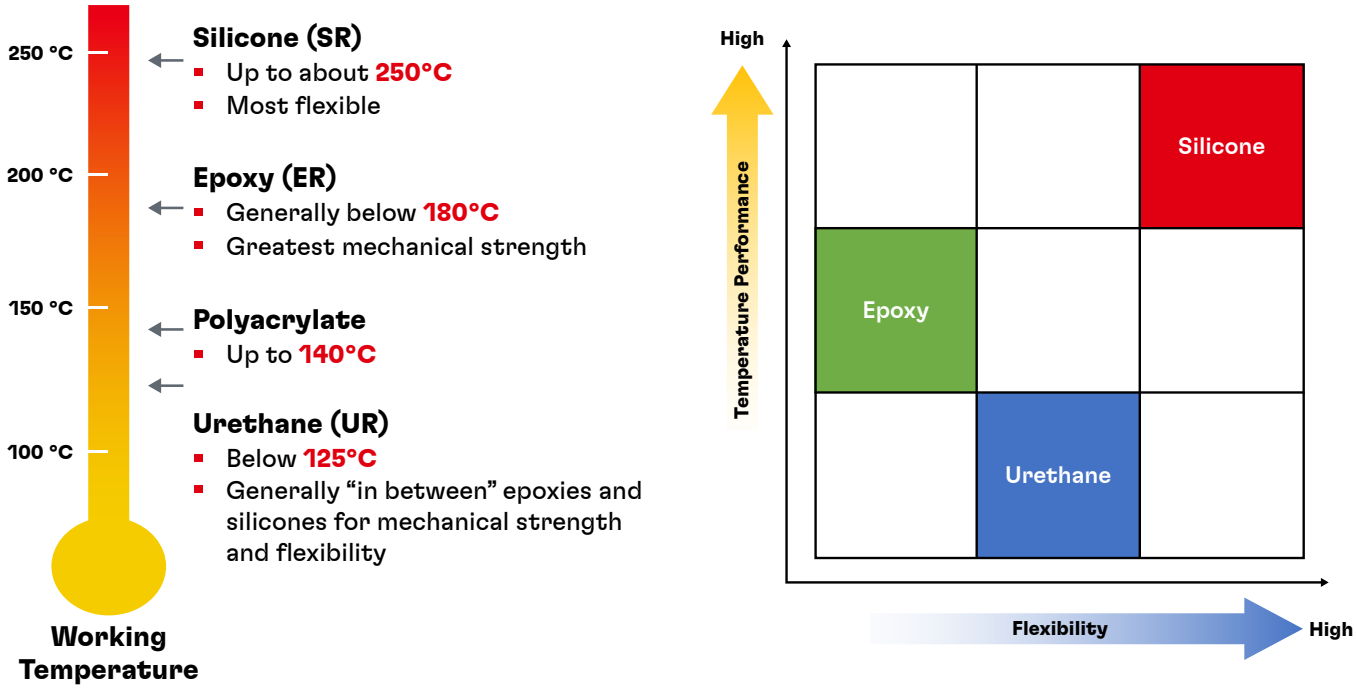


Figure 1: Formulation Features & Benefits

Working through the range of questions and considerations that affect the choice of a potting material can be overwhelming, but having clear guidelines in place when inviting and then evaluating supplier offerings will help ensure the best possible product is selected. These complexities make it even more important to focus not just on product offerings but also on choosing an experienced partner that understands how potting can integrate into a wide variety of production processes.

Henkel's knowledgeable global engineering team can provide product, process, and production insights throughout the entire selection process, even as early as the component design phase.

Design Considerations

Evaluating performance requirements and formulation options are both important prerequisites for selecting a suitable potting product, but many design variables can also impact a thermal potting compound's ability to transfer heat effectively. Engineers need to select a potting partner that can review part designs and provide insights into how a component's shape, materials, and production approach can help or hinder thermal management efforts.

When it comes to thermal management, function follows form.

Part shape:

Component manufacturers create parts in an infinite variety of shapes and sizes. Sometimes, they are seeking to differentiate themselves from competitors by the aesthetic appearance of their product, sometimes design decisions are driven by an OEM's design requirements, and sometimes designs are purely functional in nature. Regardless, the form taken by a part can actually inhibit or enhance the ultimate function of that part – by improving or reducing its ability to shed heat through thermal potting. In that sense, function follows form when it comes to thermal management. For example:

- Failing to design air outlets into the part can decrease flowability for the potting compound, creating air gaps, fissures and imperfections that prevent adequate heat transfer.
- Allowing wide tolerances in final designs, part production, or part finishing can mean even the most carefully defined specifications and requirements prove ineffective in practice.

Part materials:

Even the chemical makeup of an EV part can limit a potting compound's ability to fill and adhere to the finished part, resulting in diminished thermal performance. For example:

- Component designers occasionally introduce plasticizers to improve elasticity and durability for seals and other flexible areas of their product.
- Component designers may select metal finishes solely focused on aesthetics, durability, surface finishing, or corrosion protection.

While these considerations are valuable, they may interfere with catalysts found in thermal potting material, ultimately inhibiting its proper curing and reducing the part's long-term performance.

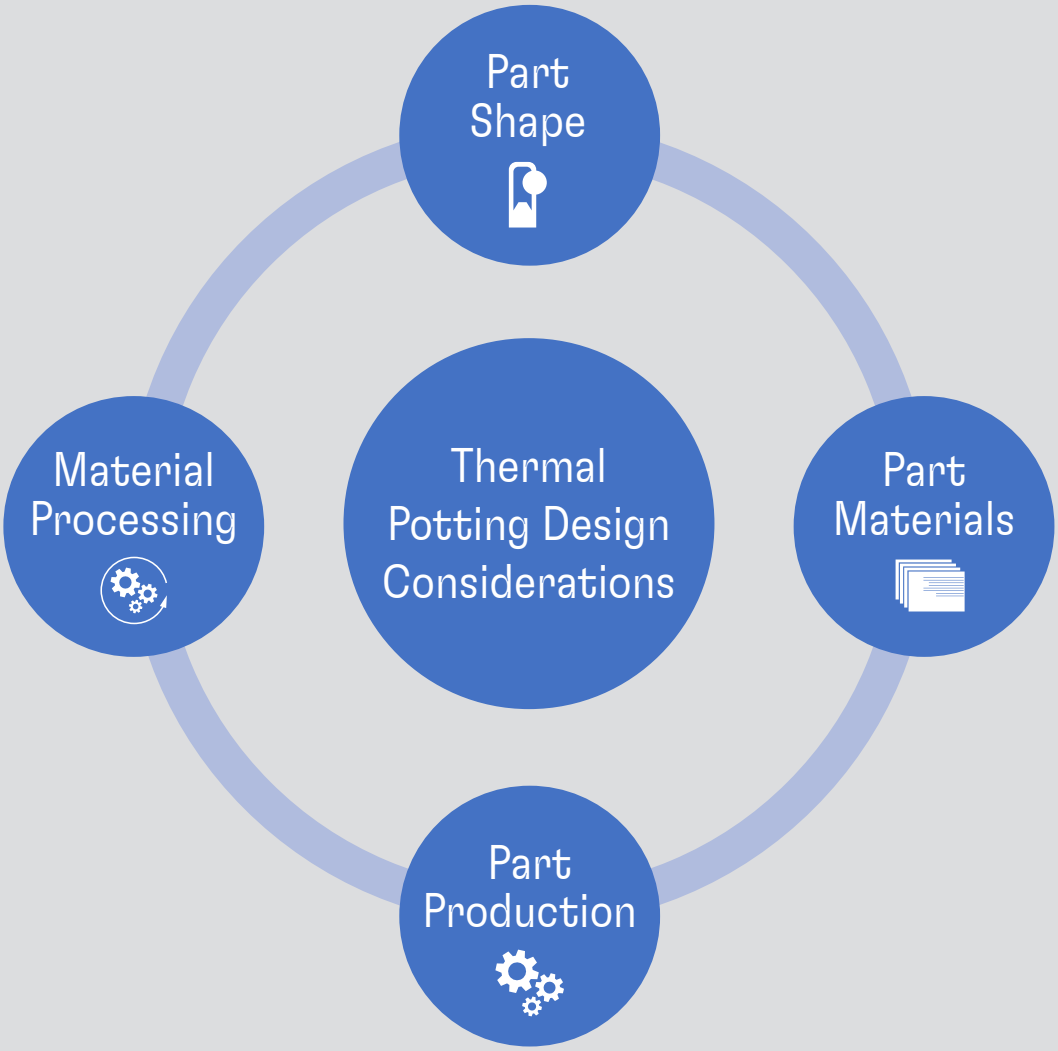
Part production:

Using flowable potting material helps reduce stresses during part assembly and finishing, but there are times when it is more effective to complete the potting prior to assembly. Ultimately, the geometry of the finished component should dictate which should come first: application or assembly.

Material processing:

Beyond the part itself, there are also potting-specific processes that need to be done properly to deliver the best possible outcome. For example:

- Mixing requirements need to be defined for chemical inventory to keep air out of the product and preventing caking over time.
- Remixing needs to be accommodated in the part production process to ensure effective dispensing and accurate metering.



Even high-quality potting compounds, while they may meet all theoretical specifications, can ultimately fail due to poor or incompatible part design, part production, or potting application. Forging good partnerships with experienced supplier partners early in the design process is essential to ensuring the final part can perform to OE expectations, prevent downstream rework, and outlast the competition.

PARTNERING FOR PRECISION & PERFORMANCE

At Henkel Adhesive technologies, we have been innovating and solving challenges in the potting space for decades. Our broad EV thermal management portfolio offers a wide range of options to our customer partners, and we make it our goal to help them find the very best solutions for their unique performance and production needs.

- **Broad portfolio:** Henkel offers approximately 400 potting solutions, of which more than 60 are thermally conductive.
- **Deep expertise:** Henkel's experienced application engineering and product development teams bring extensive material science knowledge and manufacturing know-how to help our customers work through thermal management complexities efficiently. By working closely in the design, testing and integration stages, our customers discover value far beyond chemistry.
- **Local testing capability:** With our global design teams, Henkel can collaborate with component manufacturers – wherever they may be – to define, design and test potential solutions efficiently.
- **Global manufacturing footprint:** With manufacturing facilities all over the globe, Henkel offers convenient product sourcing, localized and efficient supply chain resources, and deep connections that allow us to pivot in case of supply disruptions.
- **Strong partnerships:** Over the years, Henkel has developed partnerships with quality equipment partners. We can recommend dispensing equipment, homogenization equipment, and general material handling equipment to meet our customers' production needs.



How We Work

At Henkel, we prove our value by working closely with our customers – every day, around the globe, and across the entire value chain – to be sure they meet their objectives. Whether it's defining performance requirements, evaluating manufacturing, processing or design considerations, or meeting sustainability factors, we do everything we do to make our customers successful.

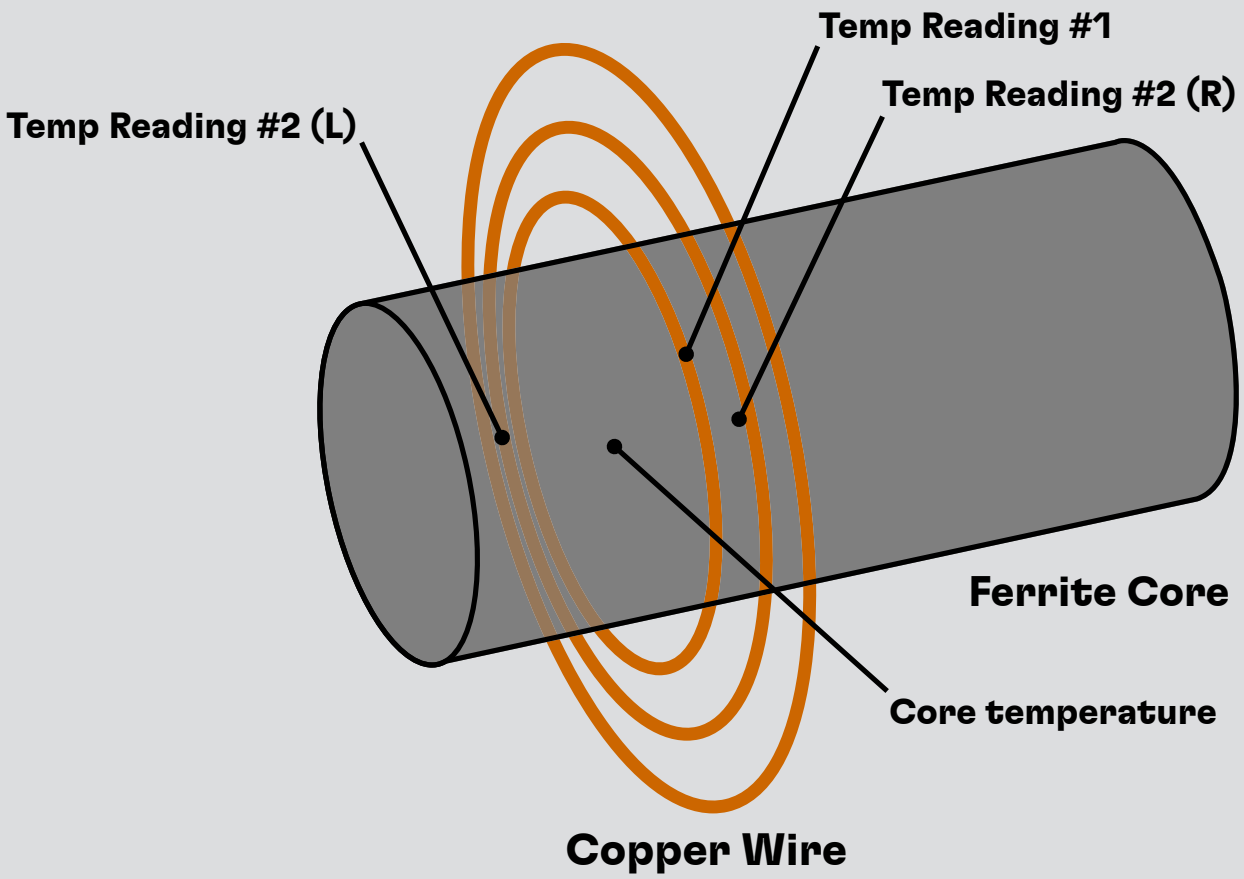
During the product selection and approval process, we work with our customers to define a seamless production and product integration strategy. Our local production capabilities allow us to support our customers as they run pilot production and then scale up into full-scale manufacturing – whether they're using an off-the-shelf or custom-designed thermal potting solution.

CUSTOMER CASE STUDY

A major automotive OEM included Henkel LOCTITE® SI 5643 thermal potting compound in a comparison test for AC/DC converter thermal management. The customer found that Henkel's offering delivered advantages over the competition in all areas of evaluation, both for thermal performance and part durability.

Test 1: AC/DC Converter Thermal Potting Performance

- **Component specifications:** 220V AC to 420V DC converter, 17A current output
- **Exposed time:** 2 hours (~30 minutes to saturation, ~90 minutes beyond saturation)
- **Temperature measurement method:** Embedded copper wire placed in concentric circles around ferrite core



A constant load was applied to the potted component and the steady state temperature was measured at the three different points. Despite a lower nominal thermal conductivity, LOCTITE SI 5643 provided both lower average temperature and better homogeneity in this applied test, which shows how it is important to look beyond the data sheet for potting applications.

Henkel LOCTITE® SI 5643 Exhibited Better Thermal Performance

Product	T.C (W/m-K)	Temp. #1	Temp. #2 (L)	Temp. #2 (R)	Wire Avg. Temp.	Core Temp.
LOCTITE® SI 5643	1.5	99.9°	96.0°	97.9°	97.9°	83.1°
Competitor A	2.2	105°	92.3°	98.8°	98.7°	84.2°

Figure 3: Temperature Test Results

Test 2: AC/DC Converter Ferrite Core Compatibility with Potting Material

- **Reliability test parameters:** Disassemble test subjects at set time periods and inspect ferrite core for cracks
  - After 1 day at 170° C
  - After 11 days: 170° C
  - After 45 days at 150° C

Henkel LOCTITE® SI 5643 Prevented Core Cracking

During durability testing, ferrite cores often crack due to thermal expansion of the surrounding material. Due to its fine particles and low modulus, Henkel's LOCTITE® SI 5643 helped limit thermal expansion, eliminating ferrite core cracking throughout the entire reliability test period.

Figure 3: Ferrite Core Remained Intact

CONCLUSION

Henkel offers EV component designers a unique blend of thermal potting innovation; design, planning and production expertise; global collaboration and manufacturing capability; and proven product performance. Engineers who choose to partner with Henkel Adhesive Technologies during early product development stages can better overcome complexities and challenges – often embracing Henkel's thermal potting solutions as their preferred solution for heat management in new EV components. Henkel's application engineering and product development teams continue to innovate and refine our thermal potting offerings to be prepared for the EV challenges of tomorrow.

WE MAKE FUTURE MOBILITY HAPPEN

Henkel holds a leading market position as an innovation and development partner to OEMs, battery manufacturers and EV component manufacturers. With a broad and diversified portfolio of advanced materials such as adhesives, sealants, battery safety materials, thermal management materials, conductive electrode coatings and dielectric coatings, supported by an extended network of partners and world-class capabilities in modeling, simulation and application technologies, Henkel stands out as a comprehensive solution partner, enabling next-generation battery design and production.

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