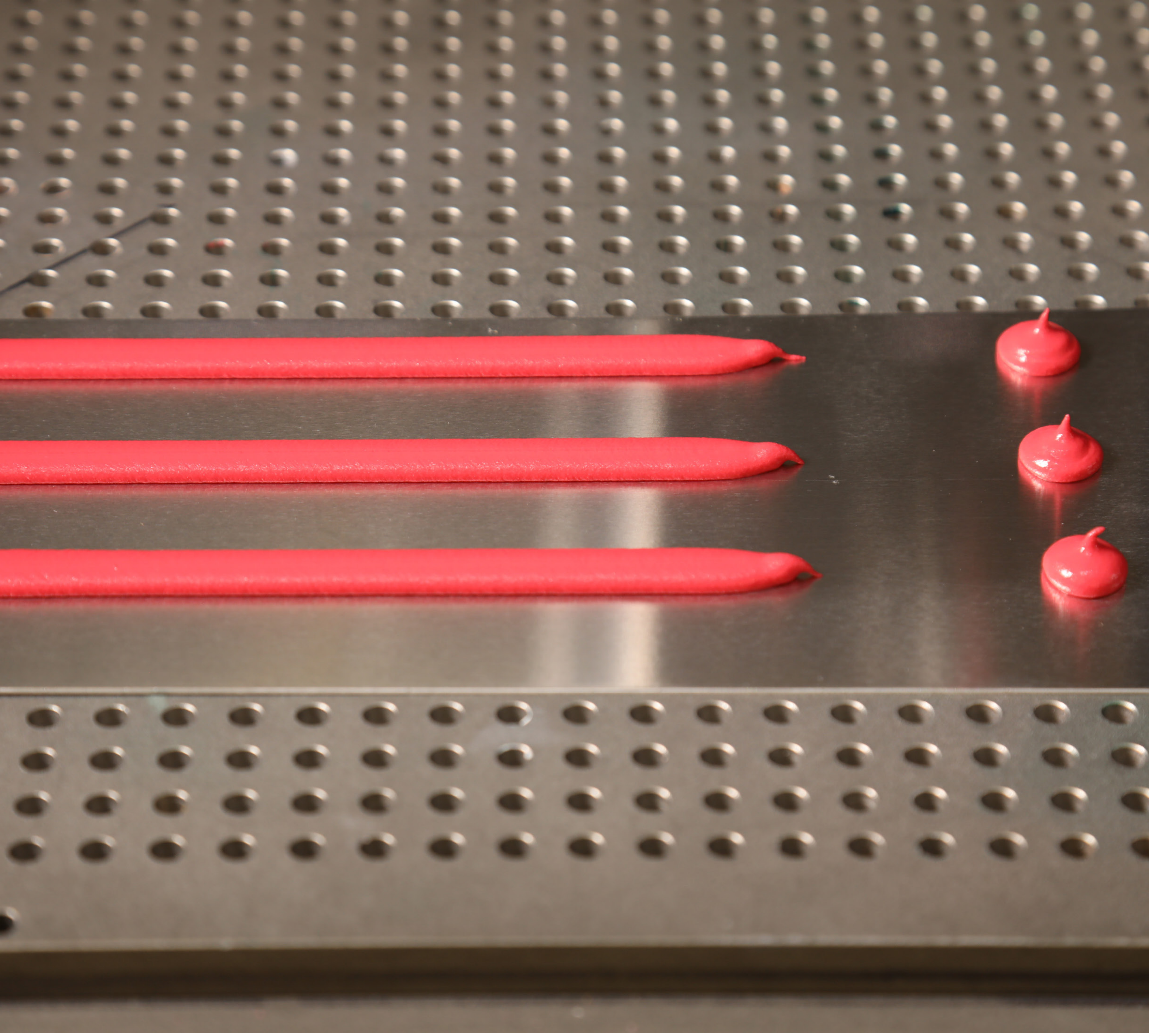

Gap Fillers for Thermal Management in Electric Vehicles

One-component (1K) or Two-component (2K)
White Paper

Parker LORD

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Gap Fillers for Thermal Management in Electric Vehicles

One-component (1K) or Two-component (2K)

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Abstract

The data shared will be valuable for Electric Vehicle (EV) battery manufacturers as well as battery module and pack designers to help them choose the right thermal interface material for their battery pack needs. The two-component (2K) gap fillers provide customers with a variety of thermal conductivities and chemistries to choose from, which provide high dispense rates, reliable cure performance and desired electrical properties. A noticeable rise in interest has been observed to reduce manufacturing complexity that comes with using 2K gap fillers. To address that need, where two-component mixing is not preferred by the end-user, a new isocyanate-free and non-silicone one-component (1K) gap filler has been developed. These new 1K gap fillers help EV OEMs by reducing manufacturing and operational complexity. The 1K solution is a low-density gap filler with excellent flow properties and low battery insertion stress.

A comparative analysis is performed between 2K and 1K gap fillers, where the advantages and trade-offs of using 1K over 2K is discussed. For a selected thermal conductivity gap filler, the comparison between 1K and 2K focuses on end-use properties of gap fillers such as density, flow characteristics, battery insertion stress, cure behavior, and environmental aging performance. As discussed in this study, the 1K gap filler helps to reduce manufacturing complexity with a trade-off of reliable cure speed that a 2K gap filler offers. In addition, the variety in the 2K gap filler chemistries offers a wider range of flexibility in designing a product to meet challenging manufacturing and design requirements.

Introduction

The thermal management in an EV battery pack is performed by a liquid-cooled metal plate commonly referred to as a cooling plate. The heat transfer from a battery to the cooling plate is aided by a thin layer of Thermal Interface Material (TIM), also referred to as a gap filler, that provides an efficient thermal pathway between the battery pack and the cooling plate.[1] Parker LORD has been very receptive of OEMs' requirements to develop tailored custom TIM solutions that arise from subtle differences in battery pack designs. The recent development of a newly formulated cell-to-pack thermal adhesive is a great example of such customer need responsiveness.[2]

Some battery pack manufacturers began by using a thermally conductive gap pad. However, they do not provide effective heat transfer and are not ideal for mass production.[1,3] As production rates increased, the industry shifted to liquid-dispensed gap fillers, where the 2K gap fillers are now widely preferred. One challenging aspect of using a gap filler is reworkability of battery modules, which has been constantly addressed with improved design and next generation gap fillers.[4] As the industry is optimizing battery pack designs to improve thermal management, there is an additional push to increase the manufacturing throughput and reduce complexities that arise from using a 2K gap filler.

The main sources of complexities arise during the application process of 2K gap fillers. The illustration in Figure 1 highlights the sources of complexities. First, a precise control is needed in dispensing the two components to ensure that the final mix is at the optimum ratio, otherwise material performance can be compromised. Second, no need for mixing elements in 1K allows for lower pressure to dispense the material at the same flow rate as

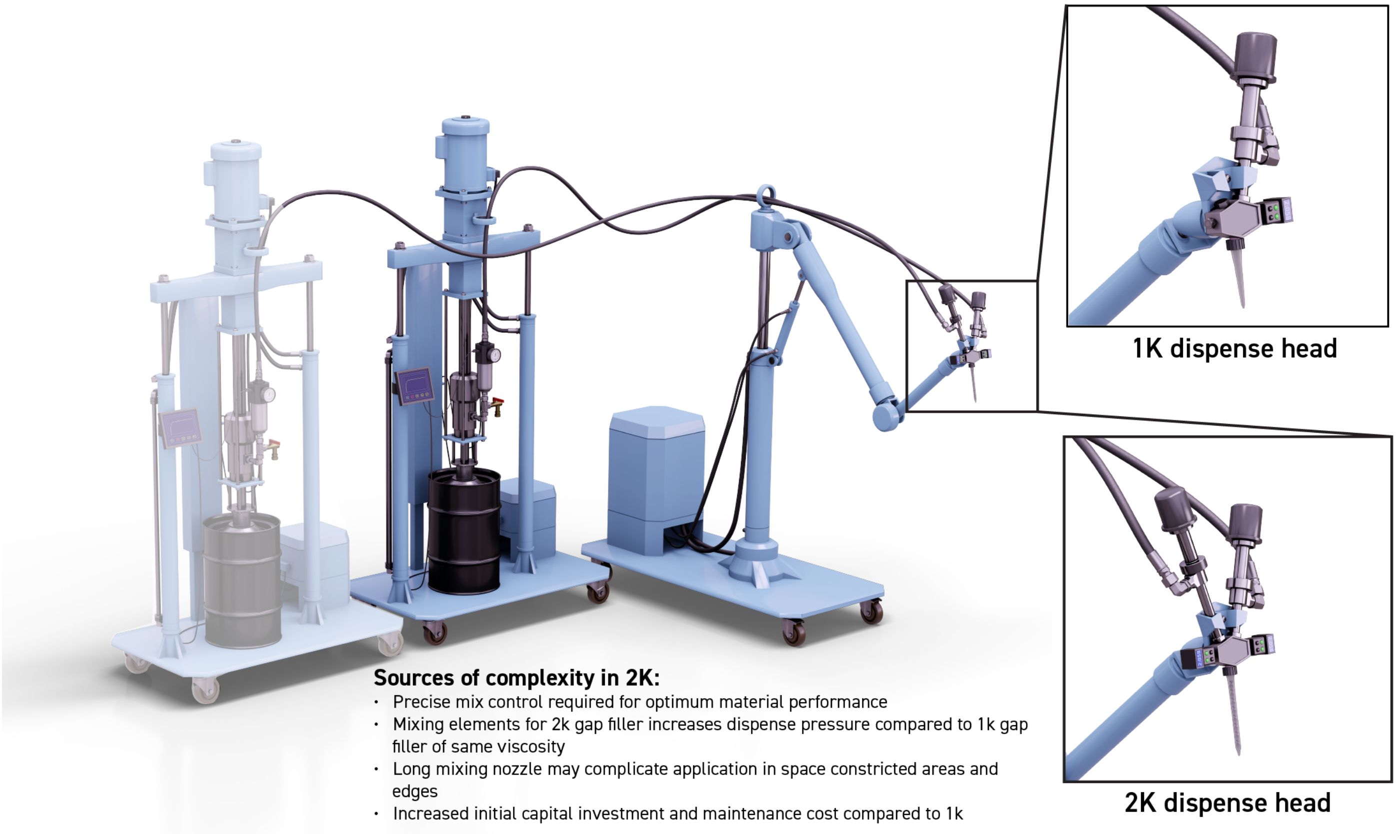


Figure 1: Sources of complexities illustrated during application of a 2K gap filler from a meter-mix dispense system.

in 2K. Additionally, no mixing elements in 1K also eases material application in space-constricted corners and edges, where it can be difficult for a 2K gap filler to apply due to a long mixing nozzle. Furthermore, the dispense system requirements for 2K gap fillers, such as pumps and shot meters, are twice as much as for 1K gap fillers and will increase initial capital investment.[5]

These manufacturing and operational complexities can be addressed by a one-component gap filler. However, the manufacturing ease of 1K gap filler comes with a few trade-offs as depicted qualitatively on a slider chart in Figure 2. The biggest trade-off is the dependence of 1K gap filler chemistry on not only environmental conditions for its cure performance but also on the bondline geometry, whereas cure performance of most of the 2K gap filler chemistries is less dependent of environmental conditions and not at all dependent on bondline geometry. While a 2K gap filler provides a formulator with multiple approaches to tune its cure speed, a 1K gap filler has limited knobs in its toolbox to do the same. Additionally, chemistry selection diversity and market availability of 1K gap fillers is limited.

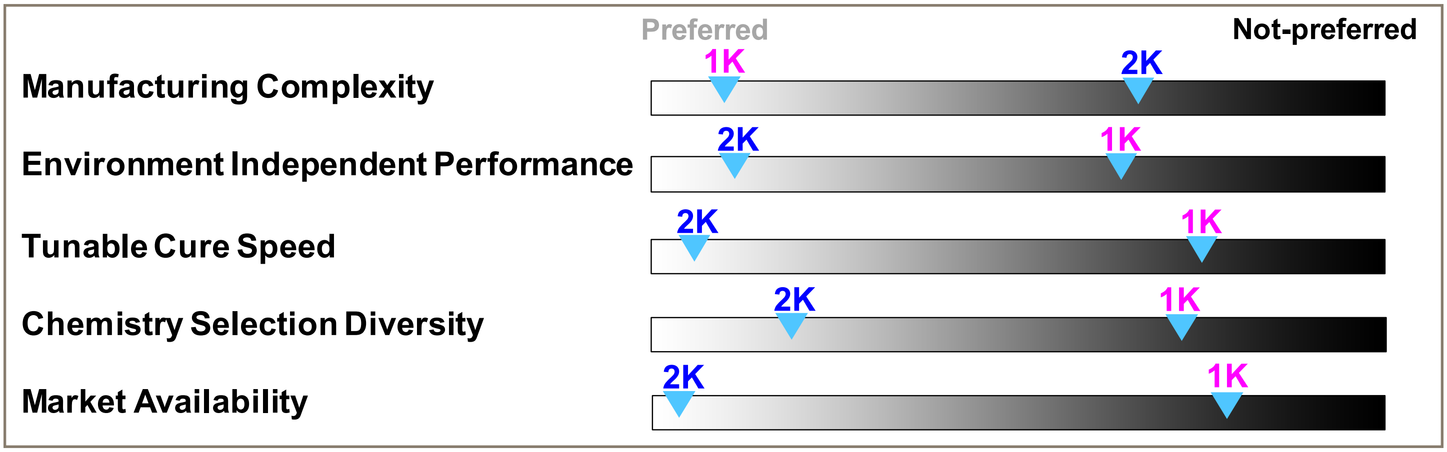


Figure 2: Qualitative comparison of one-component (1K) and two-component (2K) gap fillers in electric vehicle application for selected properties. Preference for 1K or 2K gap filler is indicated on a gray scale, where light indicates preferred and dark indicates not preferred.

There are a variety of 1K TIMs available in the market that are called thermal grease, thermal paste or thermal compound. They are largely thermoplastic or pre-gelled TIMs. Parker LORD itself has an extensive portfolio of such thermal greases that can be found on our website (Thermally Conductive Greases | Parker NA). For further understanding of different types of TIMs, the reader is referred to the *Realizing Possibilities: Thermal Management of Electric Vehicles and Electronics.*[6]

For the purposes of this white paper, a 1K gap filler is defined as a thermally conductive thermoset. Parker LORD has developed a 1K gap filler from a modified silane (MS-polymer) chemistry referred to hereon as MS-1K. This prototype has no volatile silicones and hazardous isocyanates. It is a low density (2.0 g/cc) gap filler with a thermal conductivity of 2.0 W/m·K. In this paper, a comprehensive comparison is performed between 2K and 1K gap fillers chosen from Parker LORD's CoolTherm® portfolio, with a goal to assist OEMs and battery pack designers in making an informed decision when choosing the type of gap filler for their battery pack designs.

Gap Fillers Chosen for Comparison

The three types of gap filler chemistries chosen for this comparison are polysiloxanes, polyurethanes, and modified silane (MS) polymer, as listed in Table 1. All selected gap fillers have a density of 2.0 g/cc and thermal conductivity of 2.0 W/m·K.

The material properties shown in this paper are from limited pilot scale batches and are subjected to change. Most of these properties can be tailored based on battery pack design requirements.

Flow Behavior

The three most desirable flow properties for a gap filler are:

1. High dispense rate to allow for faster manufacturing throughput,
2. Good sag resistance to prevent material dripping or sliding until it is cured in place,
3. Low battery insertion stress to prevent any damage to the cooling plate or cell.

Figure 3 compares the flow rate and sag resistance of the gap fillers. Flow rate was measured by dispensing through a 3.1 mm diameter and 51 mm long nozzle at a pressure of 80 psi in accordance with SAE J1524 test method. Vertical sag test images are shown in the inset of Figure 3. Vertical sag test was performed in accordance with ASTM D2202, where a fixed volume of gap filler was held vertically for 30 minutes at room temperature. The travel distance of material was recorded at specified intervals for a maximum of 30 minutes. PU-2K performed worst on the test with drip of 100 mm in less than 5 minutes. MS-2K has the best sag resistance of the three. MS-1K has high flow rate

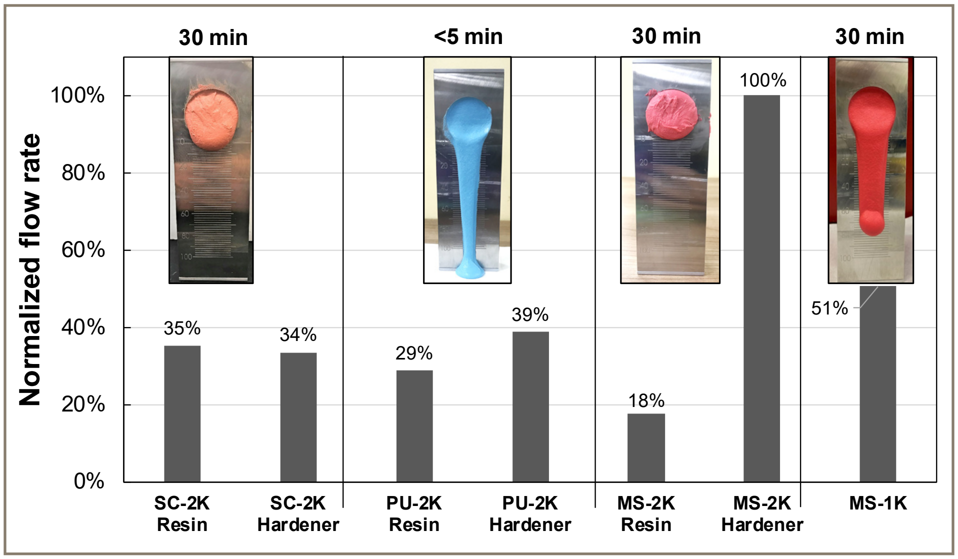


Figure 3: Flow rate normalized with MS-2K hardener and sag resistance of the gap fillers.

Table 1: Materials chosen for the study from Parker LORD CoolTherm® portfolio. All materials listed have a density of 2.0 g/cc and thermal conductivity of 2.0 W/m·K.

Material	Color	Chemistry	Volume Mix Ratio	Number of Components
SC-2K	Orange	Polysiloxane	1:1	2
PU-2K	Blue	Polyurethane	1:1	2
MS-2K	Pink	MS-Polymer	1:1	2
MS-1K	Pink	MS-Polymer	N/A	1

and reasonably good sag resistance with drip of 80 mm in 30 minutes. The sag resistance of these gap fillers can be tailored according to production requirements.

Battery insertion stress, also commonly referred as compression squeeze force, is defined as pressure experienced by the cooling plate when the battery module compresses the gap filler to its final bond gap. The battery insertion stress is of interest to EV manufacturers because depending on the design of a battery pack, the cell components or a thin cooling plate can get damaged during battery insertion if battery insertion stress is high. It should be noted that battery insertion stress does not only depend on the material but also the rate at which the battery module is inserted and the surface area of the battery module. To increase the manufacturing throughput, the highest possible rate of battery module insertion is preferred by EV manufacturers. The battery insertion stress is tested by pressing the material between two parallel plates and recording the pressure exerted at a desired gap height, 1 mm in this case. All gap fillers selected for this study are engineered for a low battery insertion stress as shown in Figure 4; the MS-1K has the lowest battery insertion stress of the gap fillers tested.

Cure Behavior

The cure behavior of 2K gap filler from polysiloxanes (SC-2K), polyurethanes (PU-2K) and MS-polymer (MS-2K) is not dependent on bond geometry and is less dependent on environmental conditions. Figure 5a displays the % cure measured at 5 and 15 hours at 25°C & 40-50% RH, where close to 90% cure is achieved within 5 hours for SC-2K. The PU-2K and MS-2K chosen in this study are designed for slow cure. However, PU-2K and MS-2K reach their full cure within 15 hours and 7 days respectively. MS-2K reaches handling strength, i.e., 40-50% cure, within 15 hours. On the contrary, the cure speed of 1K prototype (MS-1K) is dependent on both the bond geometry and the environment conditions. As seen from Figure 5b, at 25°C & 90% RH, the MS-1K achieves 62% cure within 15 hours. At 40°C & 90% RH, full cure is achieved within 15 hours.

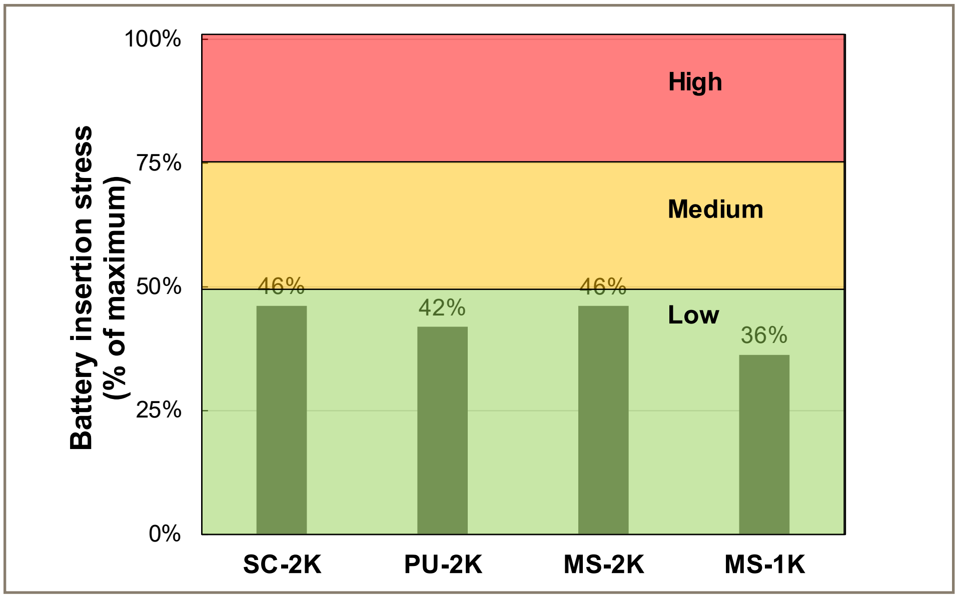


Figure 4: Qualitative comparison for battery insertion stress. The maximum is defined by the values that are generally unacceptable by OEMs. All these materials are designed for low battery insertion stress and among those, MS-1K has the lowest insertion stress.

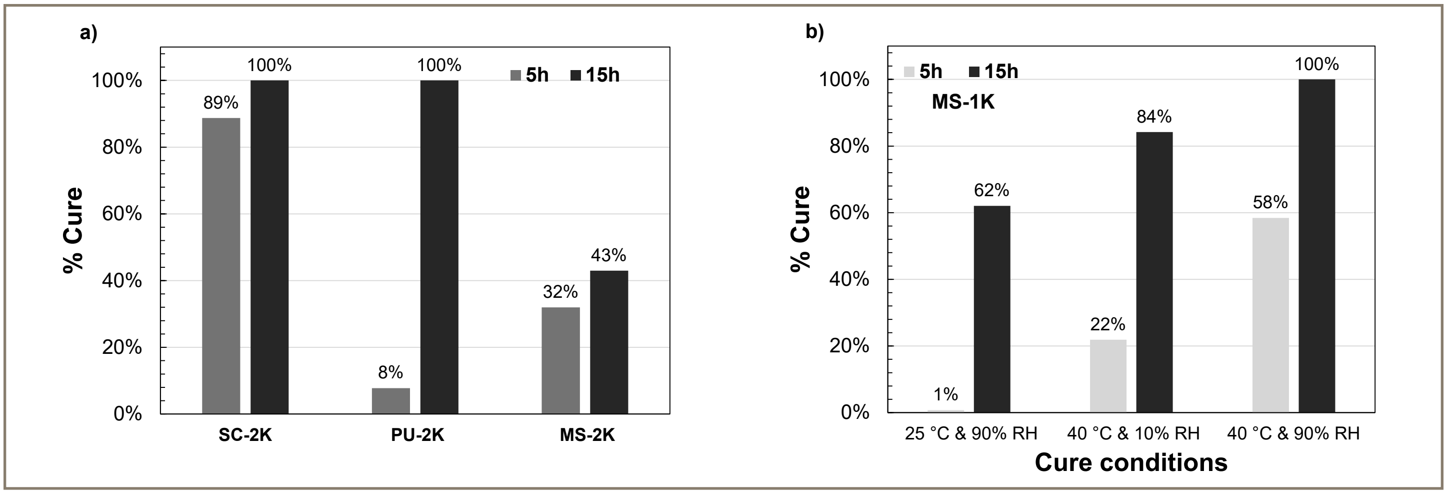


Figure 5: Percentage cure achieved for a) 2K chemistries after 5 and 15 hours of cure at 25 °C and 40-50 % RH, and b) MS-1K at different cure conditions after 5 and 15 hours of cure.

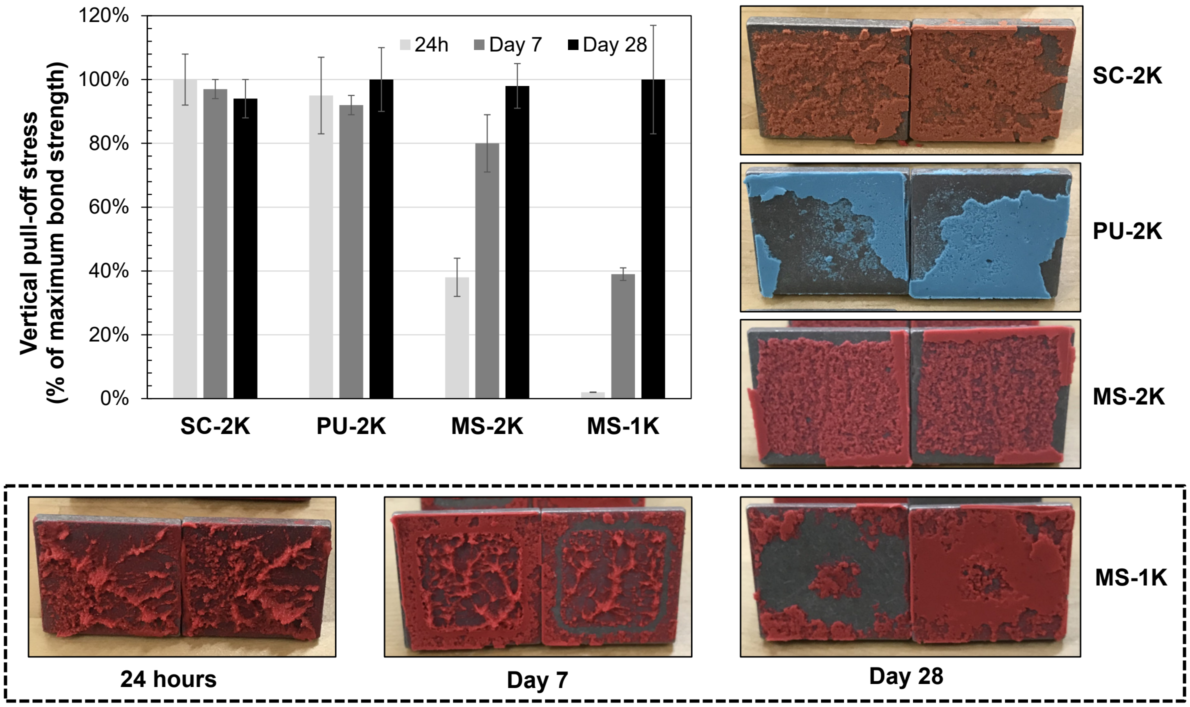


Figure 6: Vertical pull-off stress as the gap filler ages at room temperature, 40-50% RH. Images exhibit the surface failure, all of them are cohesive.

Because of the environment and time dependence on the cure of MS-1K gap filler, the cure properties such as adhesion varies with time. The normalized values of vertical pull-off stress are shown in Figure 6, measured as it ages at room temperature and 40-50% RH. The MS-1K exhibits a strong time dependence on vertical pull-off stress. Depending on when the measurement is done, MS-1K can be classified as either reworkable or high adhesion. If measured within a week of applying, the pull-off stress is low enough to call it a reworkable gap filler. Conversely, if the measurement is done after a month of application the vertical pull-off adhesion may become too high for rework. A larger volume of MS-1K will take even longer to fully cure and develop adhesion strength. Therefore, it is recommended to carefully design the test methods to measure cure properties while working with 1K gap fillers. In contrast, the adhesion values for SC-2K and PU-2K do not change significantly after 24 hours of cure at room temperature. The MS-2K gap filler takes a week to fully develop the full adhesion strength. The failure mode for all the 2K gap fillers remains cohesive throughout the period of testing.

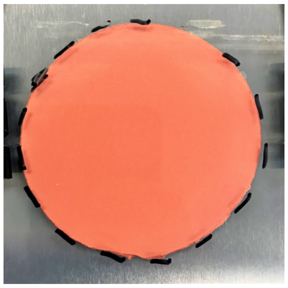
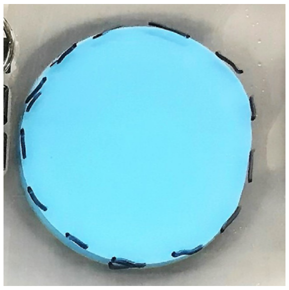
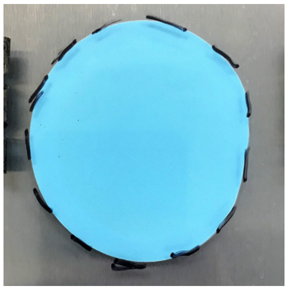
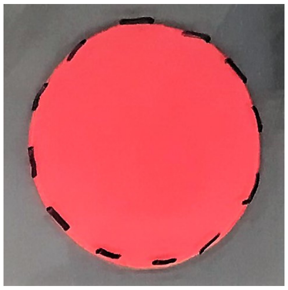
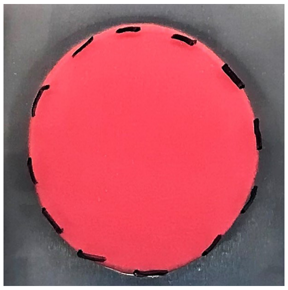
Similar trends are observed for other cure performance parameters such as mechanical properties, lap shear adhesion, hardness, and others. The cure performance parameters for MS-1K are not only environment and time dependent, but also dependent on the bondline geometry of the application.

Environmental Aging

With delayed cure, one common concern is material performance upon subjection to harsh climate conditions. The standard approach to test such performance is by placing the material vertically in a thermocycling chamber while sandwiched between two materials of different thermal expansion coefficient, usually aluminum and glass. Any change in material appearance, material sliding, sagging, dripping, cracking, or pinholes is an indication of material failure.

The test samples were prepared at a 3 mm thickness between aluminum and glass sheets. The samples were cured for the specified interval at room temperature in the horizontal state. The cured perimeter was marked with a dotted line prior to placing them vertically in a thermocycling chamber. The chamber cycled between -40 to 80°C, at a rate of 1°C/min with holds at each extreme temperature for 4 hours. Therefore, each cycle was 10 hours. The sample was aged for 100 cycles or 1000 hours.

All gap filler samples were cured for 24 hours at room temperature prior to placing them in the chamber. An additional sample was made for the 1K prototype that was also cured for 7 days. As seen from images in Figure 7, the 2K gap fillers exhibit no material change after 1000 hours of aging. The 1K gap filler prototype, however, must be cured for at least 7 days before subjecting it to thermocycling, as shown in the images of Figure 8. After 7 days of cure, 1K gap filler can reliably pass thermocycling test for 1000 hours without showing any signs of slipping, cracking, or discoloration.

Material & Cure Conditions	Initial	1000 h @ -40 to 80 °C thermocycling
SC-2K Cure: 24 h, RT, 40-50 %RH		
PU-2K Cure: 24 h, RT, 40-50 %RH		
MS-2K Cure: 24 h, RT, 40-50 %RH		

- Sample: 3 mm thick, sandwiched between aluminum and glass
- Sample placed vertically

After 1000 h of thermocycling

- No sag or dripping
- No cracks
- No discoloration

Figure 7: Images of vertically placed samples of SC-2K, PU-2K, and MS-2K in thermocycling chamber, cycling between -40 to 80°C.

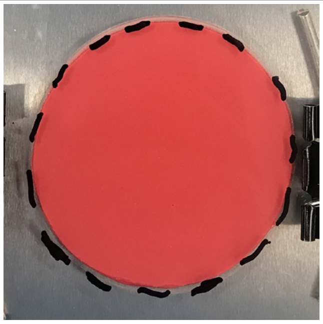
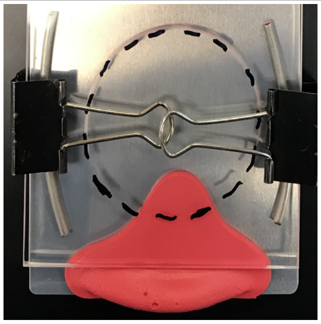
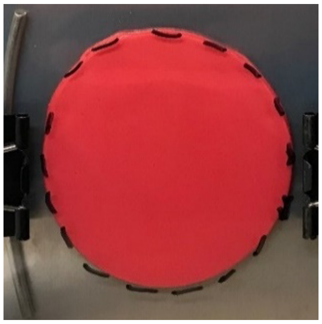
Material & Cure Conditions	Initial	1000 h @ -40 to 80 °C thermocycling
MS-1K Cure: 24 h, RT, 40-50 %RH		
MS-1K Cure: 7 days, RT, 40-50 %RH		

Figure 8: Images of vertically placed samples of MS-1K in thermocycling chamber, cycling between -40 to 80°C. The material needs to cure for at least 7 days at RT and 40-50% RH for it to pass thermocycling.

Qualitative Comparison of Chemistries

To summarize, a qualitative comparison of the 3 chemistries, silicone, urethane, and MS-Polymer, is provided in Figure 9. This comparison is limited to highly-filled thermal interface materials or gap fillers.

2K or 1K Gap Filler: How to Choose?

With the data presented, it is evident that, both 2K and 1K gap fillers have their own advantages and limitations. The choice primarily depends on the specific needs of the battery pack design and the production process.
If simplifying manufacturing complexity is the primary goal and the process can handle environmental dependent cure, then a 1K gap filler may be a good choice. A 2K gap filler is a better choice if the material cure speed is the priority. Even with their manufacturing complexities, the cure speed of a 2K gap filler does not depend on bondline geometry and is much less dependent on environmental conditions. The variety of 2K gap filler chemistries also offers a wider range of flexibility in designing a product to meet challenging manufacturing and design requirements. To help decide between gap fillers chemistries, the reader is referred to the following article[7].

Properties	Silicone Wide temp range, protects fragile electronics	Urethane Low temp silicone alternative, good moisture barrier	MS Polymer Low temp silicone alternative, EHS friendly
Temperature range	●	◑	◑
Delicate electronics	●	●	●
Moisture barrier	◑	●	◕
Adhesive strength	◔	◕	◑
Processing	◕	◕	●
Chemical resistance	◔	●	◕
Electrical insulation	●	●	◕
Repairability	●	◑	◕
Hardness	Low	Medium	Medium

● = Excellent
◑ = Moderate
○ = Poor

Values are applicable for our thermally conductive materials.

Figure 9: Qualitative comparison of the three gap filler chemistries offered in the CoolTherm® portfolio.

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