THE RIGHT AMOUNT OF STRESS

Reworkability of Gap Fillers in EV Battery Packs
White Paper

Parker Lord

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Reworkability of Gap Fillers in EV Battery Packs

Abstract

The fast-growing Electric Vehicle (EV) market demands robust and efficient thermal management solutions for battery packs, such as gap fillers and thermal pads. Gap fillers can outperform thermal pads to achieve lower thermal impedance, as the gap fillers conform to surface roughness before curing.[1,2] This allows gap fillers to adhere well to surfaces and provide mechanical support during normal operation.

However, this also poses a challenge during repair and re-manufacturing. To keep costs down, OEMs are interested in removing and replacing individual modules. The tight assembly of batteries in their housing does not allow easy access for removal, such as peeling the battery from an edge, and vertically pulling the battery generally damages the cooling plate, thus, destroying the entire assembly.

Currently, there is no set standard for quantifying reworkability. In this paper, we will discuss how to quantify reworkability by testing and measuring vertical pull-off stress. The effect of factors such as surface properties (roughness, coating), material properties (silicones vs. polyurethanes) and the testing conditions (pull rate, bondline thickness) is evaluated on the vertical pull-off stress.

Introduction

The design of the battery pack may vary among manufacturers but commonly, the battery is attached to the cooling plate not only with fasteners but also thermally conductive polymeric materials called gap fillers. Gap fillers can outperform thermal pads to achieve lower thermal impedance, as the gap fillers conform to surface roughness before curing.[1,2]

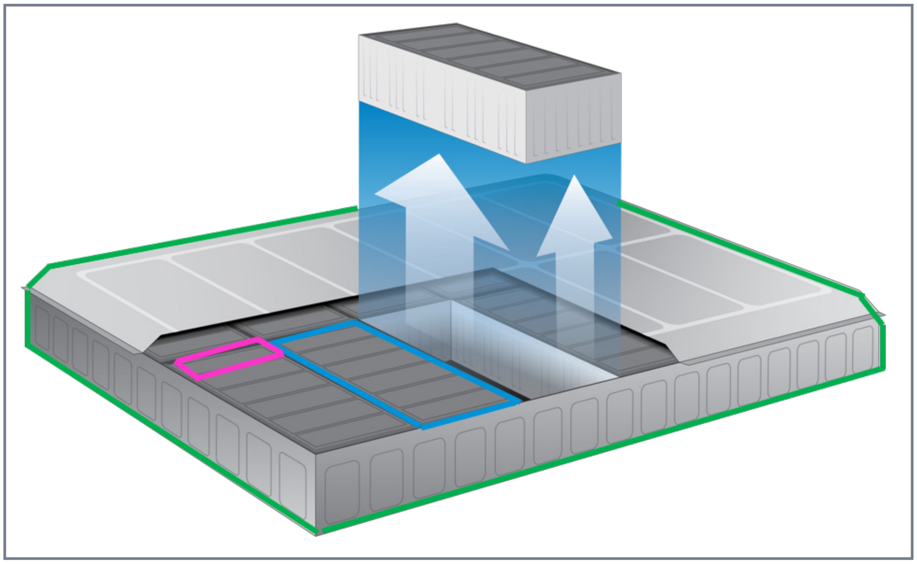

Figure 1. A generic illustration of battery cells, modules, and battery pack in a battery housing.

This allows gap fillers to adhere well to surfaces, provide mechanical support during normal operation, and pass strict reliability standards of OEMs.

However, the high adhesion values also pose a challenge if the battery needs to be disassembled. A general design of the battery pack is shown in Figure 1 where battery modules are tightly packed together to maximize space and energy density. Such tight assembly of batteries in their housing does not allow easy access for removal, such as peeling the battery from an edge, and vertically pulling the battery generally deforms the cooling plate, thus, destroying the entire assembly.

The reworkability of a battery pack entails removing and replacing the defective battery module without destroying the other modules or cooling plate. The stress required to remove a battery module depends on the adhesive strength of the gap filler, which in turn depends on the surface properties, mechanical strength of the gap filler and battery removal conditions.

One may ask the importance of reworkability in the EV market. Apart from a clear environmental impact of a reworkable battery pack that allows reuse and recycle to reduce waste and encourage sustainability, there are real economic impacts. The most expensive part of an EV is the battery pack which accounts for 25 to 40% of the cost of an electric vehicle.[3] If we approximate a 1% failure rate of battery packs for 2.1 million EVs[4], the difference in cost of changing an entire battery pack versus one module comes out at approximately $200 million per year. Additionally, emerging markets like India and China, where charging stations are limited, are experimenting with swappable batteries. Such markets need an easily removable battery module.

In this report, we talk about 1) vertical pull-off testing method, 2) surface effects, 3) effect of pull rate and, 4) effect of bondline thickness on vertical pull-off. We highlight Parker Lord's efforts to 5) tailor pull-off stress for our gap fillers and we close the study with 6) industry consideration in design of battery packs.

1. Vertical Pull-off Testing Method

This paper covers typical CoolTherm® products in our thermal management portfolio including silicones and polyurethanes. Information on such products can be found at https://www.parker.com/cooltherm. A few materials selected for this study are listed in Table 1 along with general properties. CoolTherm-A gap filler was used for test development purposes. The T-bar assembly shown in Figure 2 was tested according to modified ASTM D897-08. A total of 7 to 10 measurements were performed for each sample.

2. Surface Effects on Pull-off Stress

In the box plots shown henceforth, the arrows indicate an increase (red) or decrease (green) in the mean pull-off stress when moving from left to right sample. A paired t-test for sample means is performed with alpha of 0.05 to evaluate if the difference in pull-off stress means is statistically significant. The failure modes are shown through a representative image. The failure modes are defined as follows:

a. *Cohesive (coh)*: distinct failure in the bulk of the gap filler, both substrates have gap filler present.
b. *Adhesive (adh)*: failure at the interface between the substrate and gap filler, gap filler present only on one surface.
c. *Mixed (mix)*: a mix of adhesive and cohesive failure where some part of substrate is clean of any gap filler.

A *cohesive (coh)* material failure is preferred by some OEMs from a thermal transport perspective.

Table 1. Materials tested for pull-off stress and their common properties

Material	Thermal Conductivity, W/m·K (ISO 22007-2)	Density, g/cm^3 (ASTM D1475-13)	Hardness, Shore OO (ASTM D2240)	Cyclic Siloxane Content (ASTM F2466)
CoolTherm-A	3.5	3.30	80	<100
CoolTherm-B	3.0	2.38	70	<100
CoolTherm-C	2.0	2.90	80	<200
CoolTherm-D	2.0	1.97	60	<100
CoolTherm-E	2.0	2.65	75	N/A

However, an *adhesive (adh)* failure is easy to clean. As we will see below, failure mode of a gap filler is not only a material property but also a result of the substrate surface.

To evaluate the effect of rough surface on the pull-off stress, the T-bar surface was sand blasted. The surface roughness was measured using a surface roughness tester (Mitutoyo, SurftestSJ-210) as per ISO1997. The average roughness (Ra) for the clean aluminum surface was recorded as 0.35 ± 0.05 µm, whereas for the sand blasted surface the Ra was recorded as 4.66 ± 0.30 µm. The surface roughness after sand blasting is roughly 10 times higher than the original surface. The vertical pull-off stress for fresh aluminum (fresh Al) and sand blasted is shown in Figure 3, where a 17% increase in the mean pull-off stress is observed for the sand blasted surface. The difference in mean values is statistically significant. The failure mode also

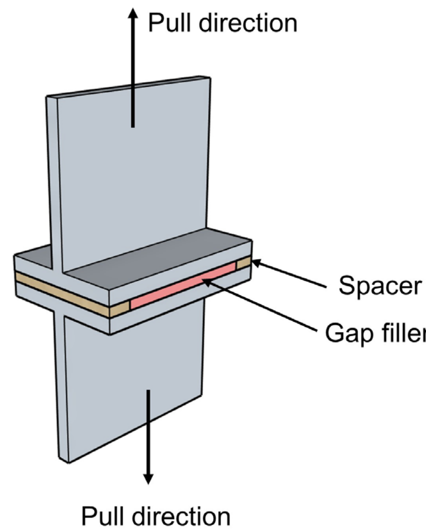

Figure 2. Illustration showing assembly for vertical pull-off testing using T-bars. The spacers of appropriate thickness are placed to achieve required bondline thickness.

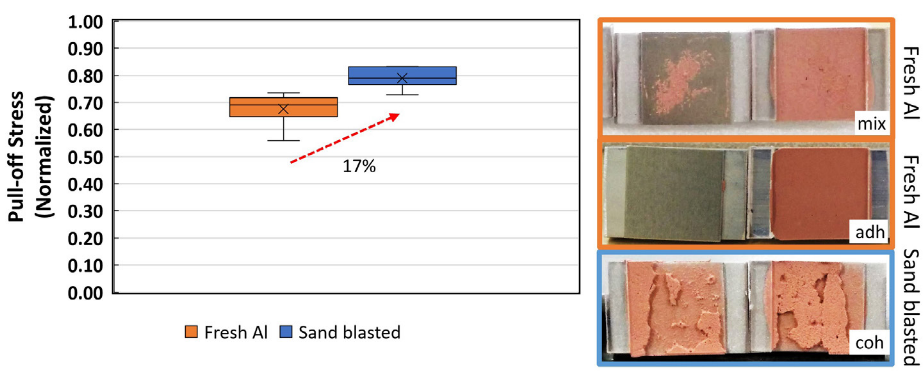

Figure 3. A statistically significant increase of 17% in mean pull-off stress is noticed for rough surface made by sand blasting. The failure mode switches from *adhesive/mixed (adh/mix)* for fresh Al to *cohesive (coh)* for sand blasted surface as shown through representative images of samples.

switches from *adhesive/mixed (adh/mix)* for fresh Al surface to *cohesive (coh)* for sand blasted surface as seen from the images in Figure 3. The result highlights the importance of defining substrate surface roughness while testing the vertical pull-off for reworkable gap fillers.

In a practical scenario of replacing a battery module, the cooling plate must be cleaned of existing gap filler before fresh gap filler is applied. The procedure was simulated on T-bars that were previously tested. The surface was cleaned of the cured gap filler manually with a dry paper towel and fresh gap filler was applied (Second-use). The assembly was cured for 72 hours at room temperature prior to testing. As seen in Figure 4, the pull-off stress in the Second-use T-bar assembly was not significantly different from the First-use. The failure mode switches from *adhesive/mixed (adh/mix)* for First-use to completely *mixed (mix)* for Second-use surface. It is noteworthy that no chemical or harsh mechanical cleaning was needed to remove CoolTherm-A. In a practical scenario, simply wiping the gap filler with a dry paper towel should suffice without any change in pull-off values after second use. However, a drastic change in the substrate surface during cleaning may change the pull-off values as seen for the rough surface.

To further study surface effects, both fresh aluminum surfaces were E-coated. A small statistically insignificant increase in the mean pull-off stress was noticed as shown in Figure 5. The failure mode is mainly *cohesive (coh)*.

3. Effect of Pull-rate

With the viscoelastic behavior of polymers in mind, the effect of pull-rate (strain-rate) on the pull-off stress was measured and the result is shown in Figure 6. The bond gap is kept constant at 1 mm. Clearly, the pull-off stress increases as the pull-rate increases. However, after 12 mm/min a less significant increase in pull-off stress is noticed for CoolTherm-A. A noticeable difference in the failure mode is evident. At 1 mm/min, failure mode was *cohesive (coh)*. At and above 12 mm/min, the failure mode was mostly *adhesive (adh)* with occasional *mixed (mix)*. The representative images of the failure modes are shown in Figure 6.

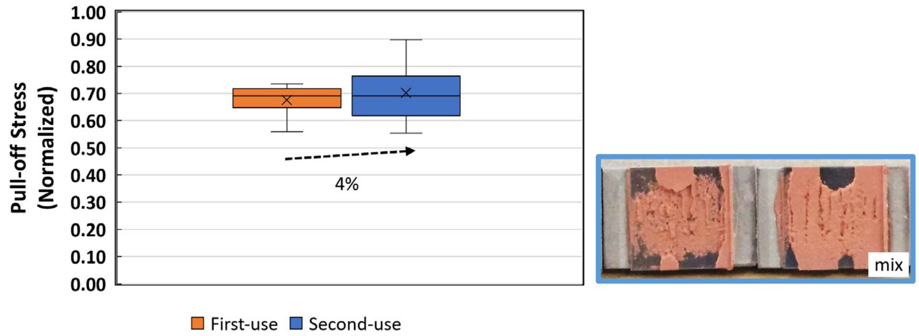

Figure 4. The comparison of pull-off stress between fresh aluminum (First-use) and reusing the same substrates after it was wiped with dry paper tissue (Second-use). A statistically insignificant change in pull-off stress is noticed. The failure mode however, switched from *adhesive/mixed (adh/mix)* for First-use surface to *mixed (mix)* for Second-use surface.

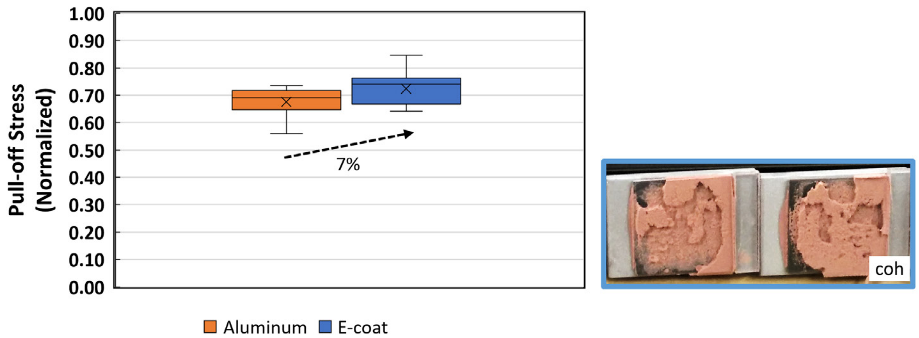

Figure 5. A statistically insignificant increase in the mean pull-off stress noticed from Aluminum to E-coat surface. The failure mode is *cohesive (coh)* for E-coat surface.

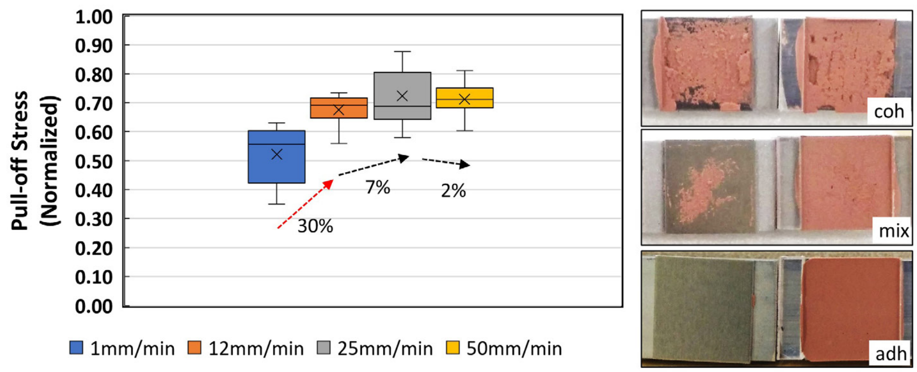

Figure 6. The effect of pull-rate on the pull-off stress is demonstrated. A representative image of three failure modes is shown in the right. At 1 mm/min, the failure mode was a *cohesive (coh)*. At and above 12 mm/min, *adhesive (adh)* with occasional *mixed (mix)* failure was observed.

4. Effect of Bondline Thickness

The next variable we investigated was the effect of bondline thickness on the pull-off stress (Figure 7). The pull-off stress decreases as the bond gap is increased from 1 mm to 3 mm. The failure mode switched from *adhesive/mixed (adh/mix)* at 1 mm to completely *adhesive (adh)* for 2 and 3 mm bond gap. The representative images of failure modes are shown in Figure 6.

5. Tailoring Pull-off Stress

Parker Lord understands the economic and environmental impact of reworkable battery packs. To assist our customers in realizing their goals of sustainability we have developed a portfolio of silicone and non-silicone reworkable gap fillers. We can tailor the pull-off stress, thermal conductivity, dispense rate, and other properties to fit the needs of your application. The vertical pull-off stress for the CoolTherm products are compared in Figure 8.

CoolTherm-B exhibits 31% lower mean pull-off stress than CoolTherm-A, while CoolTherm-D exhibits 59% lower mean pull-off stress than CoolTherm-C. The failure mode in both CoolTherm-B and CoolTherm-D is *mixed (mix)*, which may allow for easy cleaning of cooling plate. It is noteworthy, that the lower pull-off stress was achieved while also reducing the density of CoolTherm-B and CoolTherm-D by 28% and 32% respectively.

For applications that cannot use a silicone gap filler, we also offer a low pull-off stress polyurethane gap filler, CoolTherm-E. This gap filler has relatively low pull-off stress and exhibits *cohesive (coh)* failure.

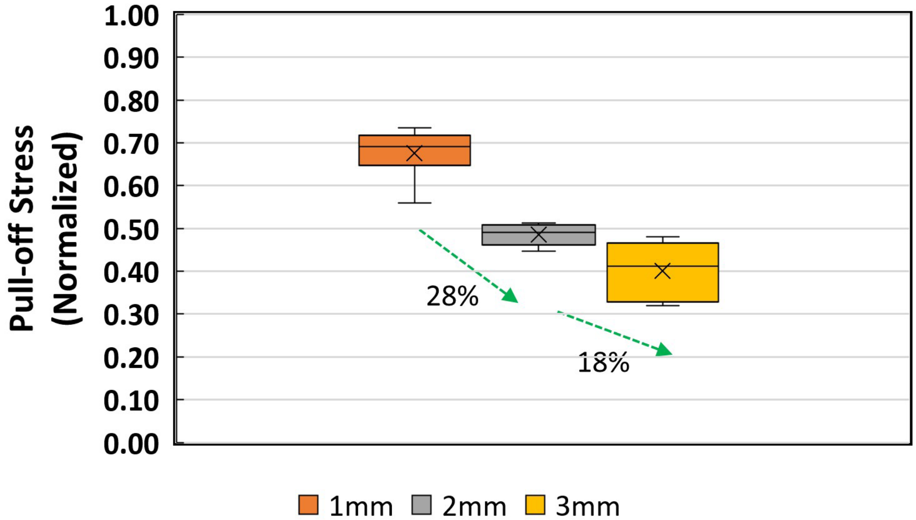

Figure 7. The effect of bond gap on the pull-off stress is demonstrated. At 1 mm, the failure mode was *adhesive/mixed (adh/mix)*. At and above 2 mm, *adhesive (adh)* failure mode was observed.

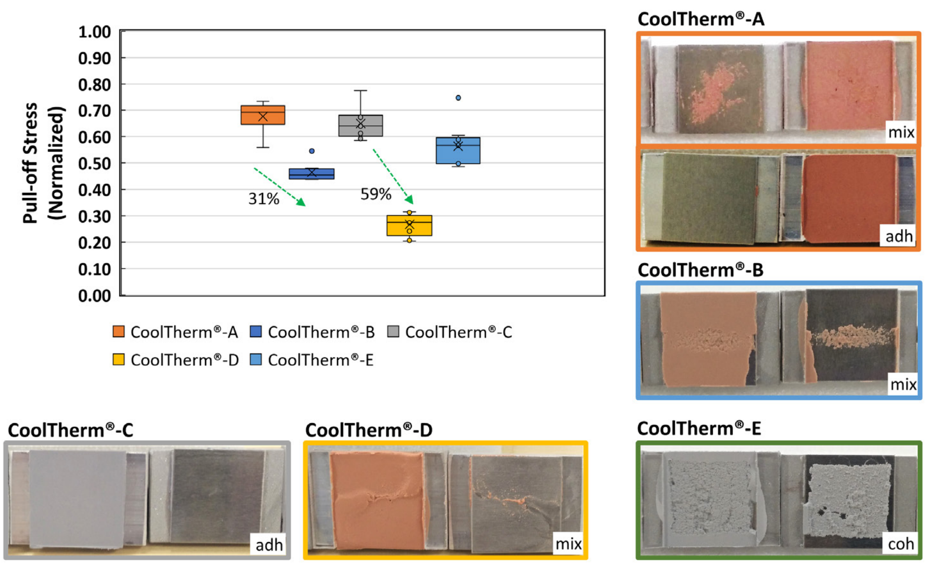

Figure 8. Comparing pull-off stress for Parker Lord gap fillers. The measurement was performed on aluminum surface with bondline thickness of 1 mm at pull-rate of 12 mm/min.

6. Industry Consideration

If a battery can be pulled vertically from an edge, it may provide more than 50% reduction in the pull-off stress as compared to force being evenly applied from the center (Figure 9). The failure mode for CoolTherm-A was completely *adhesive (adh)* when pulling from an edge versus *adhesive/mixed (adh/mix)* when pulling from the center as seen in Figure 8.

The tight assembly of battery modules may not allow for the peeling of the module from an edge. But, is a complete peeling from an edge required?

The average displacement of the edge before joint failure was only 0.6 mm when pulling from the edge That equates to the angle of 1.4 degrees. If that angle of 1.4 degrees is applied to a battery module of usual size (40 cm x 20 cm), it results in the need for a 4 to 5 mm clearance between modules to allow for easier removal.

This could reduce the required force by more than 50% as compared to lifting from the center or applying equal force across the surface of the module. This would significantly reduce the chance of damaging the cooling plate.

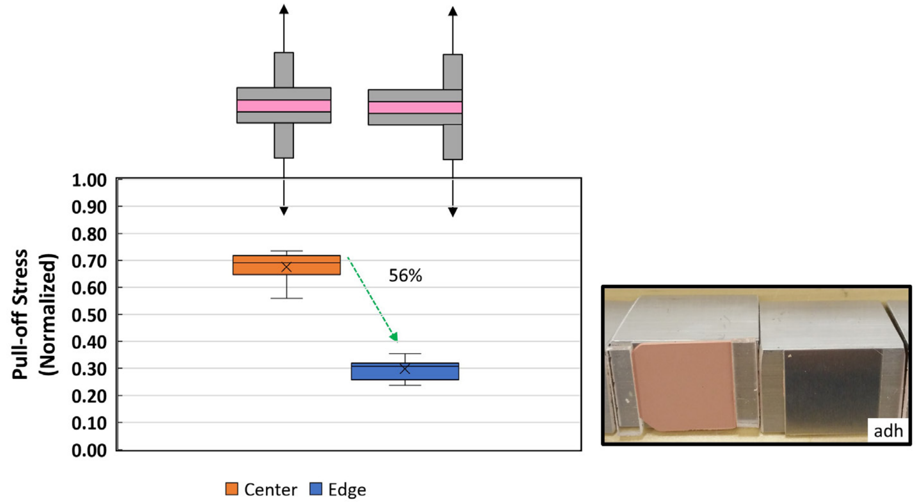

Figure 9. The mean pull-off force lowers by 56% when pulling from an edge as compared to center for CoolTherm-A. The failure mode is *adhesive (adh)*.

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