Thermally conductive gap filler for the Electric Vehicle (EV) battery assembly

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Battery Assembly Materials

- Rapid expansion of EV market has led to new material challenges to address the EV performance
- Battery assembly materials help OEMs address some key challenges
  - Thermal management
  - Safety and reliability
  - Enabling simplicity and lightweighting
  - Servicing and end of life
- Thermally conductive gap fillers & adhesives, sealing materials, foams etc. → Highly formulated multi component systems

Prismatic

Pouch

Cylindrical

TC Gap fillers
TC adhesives
Non-TC adhesives

Potting materials
TC adhesives
Non-TC adhesives
Batteries generate heat during use and charge/discharge cycle
Thermal management is a key for safety, range and reliability of electric vehicles
Most batteries are cooled using a cooling plate with active coolant
Good thermal contact between the battery and cooling plate is critical for efficient thermal management
Temperature variations across the pack need to be minimized
THERMALLY CONDUCTIVE GAP FILLERS

- Thermal Interface Materials (TIMs)
- Two-part curable paste with very high loading of fillers
- Polymers have low thermal conductivity & high loading of fillers is needed to achieve high thermal conductivity
- Material is applied in paste form and conforms well to the interface
- Material gets cured after application to form a soft solid

\[
R_{th} = \frac{\Delta T}{Q} = \frac{\Delta x}{\lambda_{eff} A}
\]

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal Conductivity [W/m.K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.026</td>
</tr>
<tr>
<td>Water</td>
<td>0.60</td>
</tr>
<tr>
<td>Polymers</td>
<td>0.1-0.6</td>
</tr>
<tr>
<td>TIMs</td>
<td>1-10</td>
</tr>
<tr>
<td>Ceramic fillers</td>
<td>10-400</td>
</tr>
<tr>
<td>Copper</td>
<td>400</td>
</tr>
<tr>
<td>Diamond</td>
<td>~1000</td>
</tr>
</tbody>
</table>
KEY PERFORMANCE REQUIREMENTS

In-process
- Easy spreading/low squeeze force
- Open time
- High dispense
- Low abrasion
- Safe handling/EH&S

In Use
- Thermal Conductivity
- Low density
- Mechanical properties
- Durability

After use
- Re-workability/easy debonding
- Easy clean-off

- Molecular scale engineering of polymer properties play a key role in achieving the performance targets
- Often involves balancing conflicting properties
Managing viscosity/processability at high filler loading is a key challenge

Strong dependence of viscosity on filler loading makes formulating TCC highly challenging

Filler selection and matrix filler interaction is key to achieve low viscosity/processability along with high TC
IN PROCESS PERFORMANCE: SQUEEZE FORCE & RHEOLOGY

- Ability to quickly press-in the material is critical for fast assembly and productivity → Low squeeze force
- Rheology
  - High viscosity at low shear rate/yield stress → bead stability/settling stability
  - Low viscosity at high shear rate → easy processing during application
- Long open time ~ 60 minutes

![Graphs showing rheological properties and squeezing force](image-url)
Fillers can be hard and abrasive and can cause damage to the pump and other equipment over time.

- Critical to have fillers with low abrasion
- Aluminum nozzle test: <1% weight loss after 20 Liters → Low abrasion
- Material is dispensed through drums using a mix-meter-dispense unit
- Ability to dispense material quickly is critical for high productivity at OEM
- High dispense rate ~60cc/sec at room temperature

### IN PROCESS PERFORMANCE: ABRASION & DISPENSE

<table>
<thead>
<tr>
<th>Material</th>
<th>Mohs Hardness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diamond</td>
<td>10</td>
</tr>
<tr>
<td>Alumina</td>
<td>9</td>
</tr>
<tr>
<td>Silica</td>
<td>6-7</td>
</tr>
<tr>
<td>Aluminum hydroxide</td>
<td>3</td>
</tr>
<tr>
<td>Talc</td>
<td>1</td>
</tr>
</tbody>
</table>

Before abrasion test

After abrasion test

Mohs hardness scale for different materials:

- Diamond: 10
- Alumina: 9
- Silica: 6-7
- Aluminum hydroxide: 3
- Talc: 1
IN-USE PERFORMANCE

- Thermal conductivity → key for effective thermal management
  - >2 W/m.K, ASTM-D-5470

- Low density → lightweighting
  - ~2.0 gm/cc at 2 W/m.K

- Mechanical properties → soft and pliable material for good contact, hardness 65-75 Shore OO

- Flame resistance → battery safety, UL-94 V0

- Thermal-mechanical stability → durability
  - Accelerated ageing stability (tested at 500 hours exposure @ 90°C)
  - Retention of hardness and thermal conductivity
Battery modules may need to be removed and replaced during the lifetime of the vehicle.

Low adhesion is typically needed to ensure serviceability while ensuring a good thermal interface.

Pulling from the middle vs. side can make a significant difference.

Substrates can play an important role.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Pull force [MPa]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal</td>
<td>0.19</td>
</tr>
<tr>
<td>Plastic</td>
<td>0.13</td>
</tr>
</tbody>
</table>

Cohesive Adhesive
- CFD analysis to predict application relevant properties such as squeeze and dispense.
MODELING THE EFFECT OF BEAD PLACEMENT

- Placement pattern of beads can have a significant effect on squeeze force.
- Predicted squeeze force showed excellent agreements with experimental results.
- Beads placement can have a significant impact on squeeze force.

Battery Module Scale CFD

Test 1

Baseline

Normalized Force [N]

0.00

0.50

1.00

1.50

Exp

CFD

Baseline Case 2 Case 3 Case 4 Case 5 Case 6

Time = 0.05 sec

Exp

CFD
Thermally conductive gap filler for efficient assembly, light weighting, & end use performance

**VORATRON™**

- Two-part system
- 1:1 mix ratio
- Room temperature curing
- Thermal conductivity 2-3 W/m.K
- Low density
- Low squeeze force
- Low abrasion
- High dispense rate
- Room temperature dispense
- Low pull-off force
Dow Mobility Science
Dow booth # 10-B20
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