Silicone adhesives for lifetime performance in vehicle electrification and autonomy

DOWSIL™ Mobility and Transportation Electronic Adhesives
MobilityScience™

How we’re driving change in the transportation industry together
Definitions

Mobility

- Construction & optimization
- Power
- Utilization
- Control

Science

- Silicones
- Polyolefin Elastomers
- Polyurethanes
- Acrylics
- Specialty chemicals
Our global transportation capability

**Building blocks**
- Advanced back-integration
  - Acrylics
  - Propylene oxide
  - Ethylene oxide
  - Polyolefin elastomers
  - Silicones

**Capabilities**
- World-class science and engineering capabilities
  - High-throughput research
  - Catalyst discovery and ligand synthesis
  - Polymer science
  - Materials science
  - Formulation expertise
  - Process engineering
  - High-performance computer modeling
  - Application development
  - Product safety

**Scale**
- Global reach
  - Performance Materials & Coatings
  - Packaging & Specialty Plastics
  - Industrial Intermediates & Infrastructure
  - LA
  - APAC
  - EMEA
  - NA
How can we collaborate?

One Dow
Cross-business team providing easy access to the breadth and depth of Dow

Leading technology
World leading integrated material science portfolio

Customized development
Mobility specific innovation

Global reach
Reliable global supplier at scale

Expertise & support
Decades of industry experience and expertise

Sustainability
Holistic approach to material and vehicle life cycle
What trends can we explore as partners?

- E-mobility
- Autonomous
- Acoustics
- Lightweighting
- Connectivity
- Safety
- Comfort

All underpinned by Sustainability
Dow solutions for transportation electronics

Polyurethane
- Under-the-hood components
  EPDM for A/C hose, water hose, battery heating hose, molded parts, and NVH.
- Hood-liner, engine cover and engine encapsulation
  Polyurethane materials offer acoustic powertrain efficiency, thermal management and improved sound insulation.
- Foam gasket & sealant
  Efficient sealing for power units and control units.
- Sealant, thermal, and low viscosity impregnation materials
  Exceptional protection for the electric motor.
- Silicone gel
  High temperature-resistant potting solution for IGBT and control units.
- Silicone elastomers
  High performance materials for connector, damping, or protection parts for high voltage electric cable, valve caps, etc.
- Adhesives & thermal materials
  Strong bonding and heat management in the on-board charger.
- Sealant, thermal, and low viscosity impregnation materials
  Exceptional protection for the electric motor.
- EMI shielding materials
  Help increase safety and reliability of battery pack.
- Conformal coatings
  Thin films/membranes for protection against moisture, dust, static, etc.
- Adhesives & foam sealants
  Excellent adhesion/sealing performance in battery pack, power and control units.
- Thermally conductive gap fillers
  For thermal management of PCB, modules, and battery pack (cells and cooling plate). Also used in power and control units.

Silicone
- Under-the-hood components
  EPDM for A/C hose, water hose, battery heating hose, molded parts, and NVH.
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Use silicone for performance that lasts!

**Durable Performance**
- Temperature extremes - -45-200 °C
- UV exposure
- High heat and humidity
- Water immersion
- Stress relaxing

**Protect electronics**
- Water impermeable
- Prevent metal corrosion

**Stress relief & Light weighting**
- Long term elasticity and flexibility
- Vibration damping
- Eliminate mechanical fasteners

**Ease of Processing**
- Tunable hardness, cure chemistries, cure speed
- Low toxicity and low abrasion fillers
- Simple mix ratios

Lifetime performance in challenging conditions
Use DOWSIL™ silicone to durably protect electronics

<table>
<thead>
<tr>
<th>MobilityScience™</th>
<th>Cameras</th>
<th>RADAR</th>
<th>LiDAR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Si Encapsulants or gels</strong>&lt;br&gt;To protect the electronics units and sensors</td>
<td><strong>Si Thermally conductive silicones</strong>&lt;br&gt;To dissipate the heat generated by the PCB</td>
<td><strong>Si Conformal Coatings</strong>&lt;br&gt;To protect PCB boards</td>
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Use DOWSIL™ silicone to durably protect electronics

Advantages of silicone in joint

- Water proof
- Permanent flexibility
- Elastic
- Fast and simple assembly
- Consistent performance
- Vibration damping
- Eliminate physical fasteners
Use DOWSIL™ silicone to durably protect electronics

E-mobility silicone applications

- Converter
- Inverter
- Autonomous steering controller
- RADAR/LiDAR
- Cameras
- Battery control units
- Thermal management
- Electromagnetic shielding

durable protection
**Mobility Science™**

Specialty DOWSIL™ products for best in class performance in mobility solutions

- silicone polymers
  - formulate for performance
- viscous fluid silicone product
  - cure
- high performance silicone elastomer
  - transportation electronics

**Leading technology**
- World leading integrated material science portfolio

**Expertise & support**
- Decades of industry experience and expertise

**Customized development**
- Mobility specific innovation
Room temperature cure DOWSIL™ adhesives

**Advantages**
- Excellent adhesion to metals, glass, ceramics and some plastics
- No curing equipment such as ovens or lamps are required

**Points to consider**
- Environmental conditions such as dry winter air can affect cure
- Can limit throughput on part testing, handling, and shipping

**Innovative Trend**
- Shorter cure times – minutes/hours vs. days

**Example of adhesive joint**
- **Cure condition**: 40-80% RH
- **Cure mode**: outside - in
- **Typical cure time**: hrs/days based on thickness

**DOWSIL™ EA-3838** that cures and builds bond strength in 5 min at room temperature
Heat cure DOWSIL™ adhesives

**Advantages**
- Excellent adhesion to metals, glass, and broader range of plastics
- Parts can be tested, handled, and shipped immediately after cool down

**Points to consider**
- Must reach required temperature at actual bondline
- Some electronics or substrates require lower temp or time at high temp

**Innovative Trend**
- Faster cure at high temp and cure at lower temp (80 vs 100 C)

**Example of adhesive joint**
- **Cure condition**: 130-150 °C
- **Cure mode**: all at once
- **Typical cure time**: 30-60 minutes

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**Graph**
- DOWSIL™ EA-7100 5 min cure & adhesion
  - Compared to common 30-60 min cure & adhesion

**Legend**
- DOWSIL heat cure adhesive
- Silicone heat cure adhesive

**Curve**
- Degree of Cure (%)
- Time (min)
  - 125 °C cure
UV cure DOWSIL™ products

Advantages
- Cure in seconds
- Minimal energy input - sustainable

Points to consider
- Insufficient cure in deep sections or shadowed regions
- Low energy input can limit adhesion on some plastics

Innovative Trend
- Addition of secondary cure mechanisms to address shadow cure

Example of adhesive joint
- Cure condition: UV light exposure
- Cure mode: line of sight
- Typical cure time: seconds to minutes
- Note: secondary cure for shadow regions

DOWSIL™ CC-8030 that cures in seconds in UV exposure and cures in deep sections or shadowed area over time
Reactive hot melt DOWSIL™ adhesives

Advantages
• Snap assembly – instant green strength upon cooling
• Minimal energy input - sustainable

Points to consider
• Requires automated hot dispensing capability
• Balance pot life at high temperature with working time

Innovative Trend
• Addition of secondary cure mechanisms to build strength

Example of adhesive joint
• Cure condition: 90-140 °C to dispense
• Cure mode: cools in place
• Typical cure time: instant green strength
Reactive hot melt DOWSIL™ adhesives

Advantages
- Snap assembly – instant green strength upon cooling
- Minimal energy input - sustainable

Points to consider
- Requires automated hot dispensing capability
- Balance pot life at high temperature with working time

Innovative Trend
- Addition of secondary cure mechanisms to build strength

DOWSIL™ EA-5151 reactive silicone hot melt adhesive dispensed hot then cools for instant green strength

Example of adhesive joint

Dispense melted silicone hot melt on parts -> Assemble parts with silicone hot melt immediately after dispensing (Apply fixture pressure) -> Hot melt will cool immediately achieving instant adhesion or green strength -> Strength builds over time
Choosing the right material for your application

- Identify cure type that meets performance and supply chain needs
- Collaborate with Dow early to go beyond the technical data sheet
- Focus on application-specific testing

Adhesives often compared based on “adhesion” or “lap shear” strength
A common method to evaluate adhesives

Basic description of lap shear test
- Select adhesive
- Glue two surfaces together
- Pull apart and measure force

example single lap joint test
Align material selection to application specific testing

Common reasons for lap joint use
• Simple
• Inexpensive
• Gives some information on adhesion

To consider
• High force over seconds to minutes
• Provides no information on durability

Requirements for actual module in the field
• Years to decades of life
• Constant low or repeated forces
• Changing conditions
  • Thermal cycling
  • Humidity differences
  • Vibrations
Align material selection to application specific testing

**Testing modules**
- Required for validation and final steps

**To consider**
- Costly
- Small sample sets
- Screening challenge
  - Many adhesives
  - Multiple substrates
  - Surface treatments

**Dow durability testing**
- Test samples that match the application
- Expose to environmental stresses
- Correlate to lifetime performance
- Maximize performance for “in field” conditions
- Modified wedge specimen (ASTM D3762)

![Diagram of wedge specimen](image)
Build “actual” adhesive joint and run through durability testing

Dow durability sample leveraged from aerospace industry

Key Points
- **Mimic joint** - better representation of adhesion in the application than the lap shear test
- **Consistent defined stress** - maintain mechanical stress on joint
- **Exposure** - combine mechanical stress (strain) and environmental exposure (e.g. water, salt)
- **Inexpensive** - low cost compared to testing many electronic modules
- **Statistical power** - build large sample sets
Evaluating durability samples after environmental exposure

sample after desired exposure aging

vice

substrate of interest

pull open joint and inspect for adhesive failure

permanent substrate

actual test substrate

No adhesive failure if adhesive is in same place as imposed defect
Evaluating durability samples after environmental exposure

**Good – no adhesive failure**
Durable to stress + exposure

- Surface that cured on top of Teflon tape
- Wedge insertion line
- Defined edge at pre-crack. No change in crack length. No adhesive failure

**Bad – adhesive failure**
Not durable to stress + exposure

- Adhesive failure
Adhesions durability – 150 °C accelerated aging

Silicone transportation adhesives

Lower is better and zero is best

No crack growth – Good → No Failures

Replicates - 3 replicates each adhesive, ea substrate, ea time point – 210 total; Substrates – 30% GF PBT and Aluminum alloy; Data shown – Aluminum substrate
Measure adhesion durability to correlate to lifetime performance

<table>
<thead>
<tr>
<th>Lap Shear</th>
<th>150 °C</th>
<th>-40-125°C</th>
<th>85 °C 85% RH</th>
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<tbody>
<tr>
<td>560 psi</td>
<td>✓</td>
<td></td>
<td></td>
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<td>550 psi</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>335 psi</td>
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Adhesive A

Adhesive B

Adhesive C
Adhesion durability – -40-125 °C cycling accelerated aging

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<td>560 psi</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
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</tr>
<tr>
<td>550 psi</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
<td>✓</td>
</tr>
<tr>
<td>335 psi</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
<td>✓</td>
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Adhesion durability – 85 °C 85% relative humidity aging

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<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
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</table>

- All 3 adhesives pass 150 °C aging and -40-125 °C aging without failures
- Only one adhesive passes combined exposure of heat + water + mechanical stress
- Lap shear did not predict performance durability
Exposing durability samples to salt spray conditions

**Dow durability samples in salt spray chamber**

**Statistical power** – Large sample sets for statistical strength

**Automotive tests** - Run same environmental exposure cycles as required by automotive industry

**Predictive screening** - Test many adhesives, substrates, and surface treatments
Automotive salt spray cycle steps
1. Mist atomized 1% mixed salt solution over samples
2. Ambient stage: 25 ± 3 °C 45% RH – 8 hrs
3. Humid stage: 49 ± 2 °C 100% RH – 8 hrs
4. Dry stage: 60 ± 2 °C < 30% RH – 8 hrs
5. Repeat daily for desired number of cycles

Run durability samples through E-module validation type tests

<table>
<thead>
<tr>
<th>Material</th>
<th>Duration</th>
<th>Total samples</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adhesive C</td>
<td>91 days</td>
<td>65</td>
<td>0</td>
</tr>
<tr>
<td>Adhesive D</td>
<td>84 days</td>
<td>60</td>
<td>7</td>
</tr>
</tbody>
</table>

Match durability testing to standard validation tests
Match durability testing to standard validation tests

Automotive salt spray cycle steps
1. Mount e-module at intended final orientation
2. Soak in chamber at 70 °C for 1 hr. Then adjust to 35 °C.
3. Spray with 5 wt% salt solution for 1 hr. Turn off spray
4. Allow chamber to cool to RT for 1 hr
5. Repeat steps 2-4 three times for a total of 9 hr
6. 15 hr at RT. Humidity uncontrolled. No salt spray.
7. 24 hr sequence repeated for desired cycles

All modules passed initial leak tests before exposure
Placed into salt spray cycle
Durability testing predicted performance in actual E-module testing

<table>
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<th>Salt Spray Exposure (days)</th>
<th>Pass Leak Test?</th>
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<td>60</td>
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</tr>
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Adhesive A
Adhesive C
Salt Spray Exposure (days)
Match durability testing to standard validation tests

- All modules passed initial leak tests before exposure
- Placed into salt spray cycle
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<td>X</td>
<td>N</td>
<td>N</td>
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<tr>
<td>Adhesive C</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
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- Winner? → Adhesive C!
- No failures in all durability tests
- Lowest “adhesion” value on TDS
Partner with Dow for application expertise in addition to materials science know-how

Key Points
- Customer worked with Dow to address a failure
- Separation during thermal cycle testing from -40 to 125 °C
- Dow provided application analysis
- Leverage Dow technology and application expertise to design solutions and innovate

adhesive joint in actual module

- Adhesive failure
- Cohesive failure
- Plastic lid
- Aluminum housing
- Adhesive under compression
- Adhesive under tension
- Deformation during thermal cycling
Dow recommendations to resolve customer issue

- Smaller overall lid size to reduce movement during thermal cycling
- Larger starting adhesive bondline to reduce strain (~35%)
- Softer and higher elongation adhesive to reduce stress on interface
- Higher adhesive strength to plastic
- Higher cohesive strength to prevent tears
- Compressive strain prevented additional tearing that would lead to water exposure
Go beyond the technical data sheet for application specific performance

Dow application frame to precisely control strain at a defect

Application testing
- Test at expected strains in module
- Determine if cure cycle effects performance (such as shrinkage stress)
- Cycling and fatigue testing
- Goes beyond lap shear or peel testing to predict performance in application
Go beyond the technical data sheet for application specific performance

Dow application frame to precisely control strain at a defect

Adhesive C
60% strain at defect
plastic substrate
aluminum substrate

Adhesive B
60% strain at defect
plastic substrate
aluminum substrate

No adhesive or cohesive failure
Adhesive C
60% strain at defect
plastic substrate
Dramatic shifts in the industry require strategic innovation

Partner with Dow to define material requirements and produce technical solutions that meet emerging market needs
Let's collaborate!

Partner with Dow to get access to:
• A world-leading R&D organization and deep chemistry toolbox
• Materials that meet high performance product lifetime needs
• Global reach
  • Excellent technical and application expertise
  • Strong regional manufacturing footprint
  • Local support and sourcing

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