



Emerging Silicone-Based Solutions for Thermal Management and Application Test Method Developments in Aerospace Technologies

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Use Silicone for Superior Performance that Lasts!

Silicone for Durable Performance

- Stable over decades of exposure
- Temperature extremes (-45 to 200°C)
- High heat and humidity



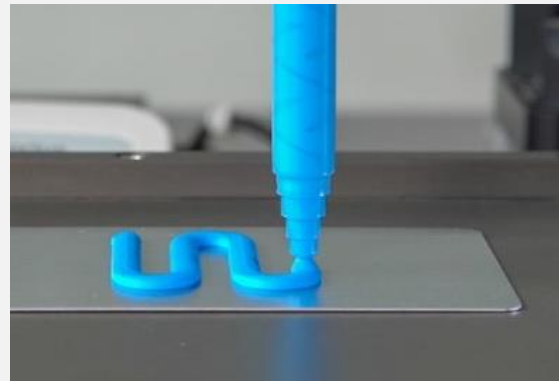
Stress relief & lightweighting

- Vibration damping
- Long-term elasticity and flexibility
- Eliminate mechanical fasteners



Ease of processing

- Smooth dispense; simple mix ratios
- Tunable hardness, cure type and cure speed
- Low toxicity



Protect electronics

- Water impermeable
- Stress relaxing
- Helps prevent metal corrosion



Dow's thermally conductive commercial product family

Gap fillers

*Soft & Stress-Relieving
For Large bond line thicknesses*

- Higher thermal conductivity: 10-15 W/mK
- Lower density
- High heat resistance
- Low volatility



Gels

*Soft & Stress-Relieving
Designed for variable gaps*

- Higher TC: 8-15 W/mK
- Thin bond line
- High heat resistance
- Low volatility



Adhesives

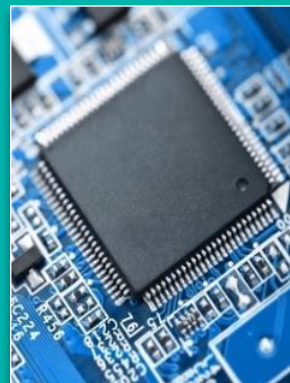
*Replace mechanical fixation.
Insulating or electrically conductive*



- Tunable cure speed and type
- Higher thermal conductivity: >5 W/mK
- Stable over lifetime
- Mechanically robust

Compounds (greases)

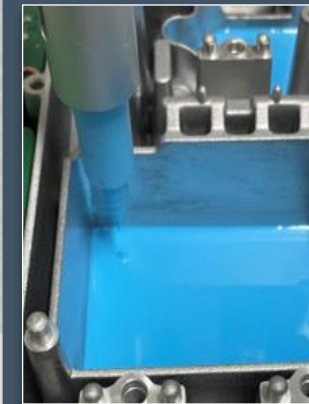
*Low thermal resistance and pump-out resistance
For thin bond lines*



- Increased pump-out resistance
- Low thermal resistance
- Improved stability in aging
- Two-part; curable

Encapsulants (pottants)

*Environmental protection and stress-relieving
Flowable & self-leveling*



- Easy to re-homogenize
- High flow; low viscosity
- Stable at high temperature
- Cost-effective

NEW: Dow and CARBICE Partner to Advance Thermal Interface Materials

Partnership combines Dow's silicone thermal management expertise and Carbice's carbon nanotube (CNT) technology to offer a full TIM solution portfolio, addressing various thermal management challenges.

- #1 Silicone Global Leader
- Industry recognized technical team with an 80-year history in silicone science
- Silicone leader liquid TIM portfolio
- Customer intimacy globally
- Leading brand reputation and quality



Pioneering Nanotube Interfaces Together



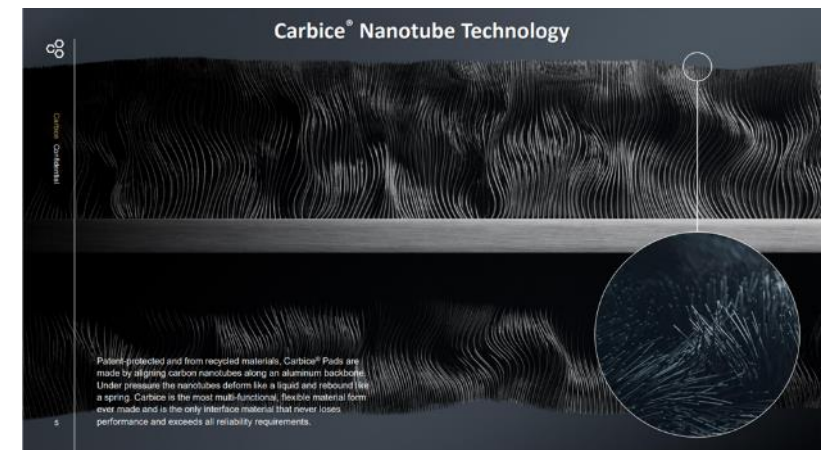
- CNT industry leader
- CNT world's only high volume aligned CNT manufacturing facility
- Carbice lab: simulation, innovation capabilities
- Proven solutions Space Pad
- Industry experienced leadership team

Why it matters

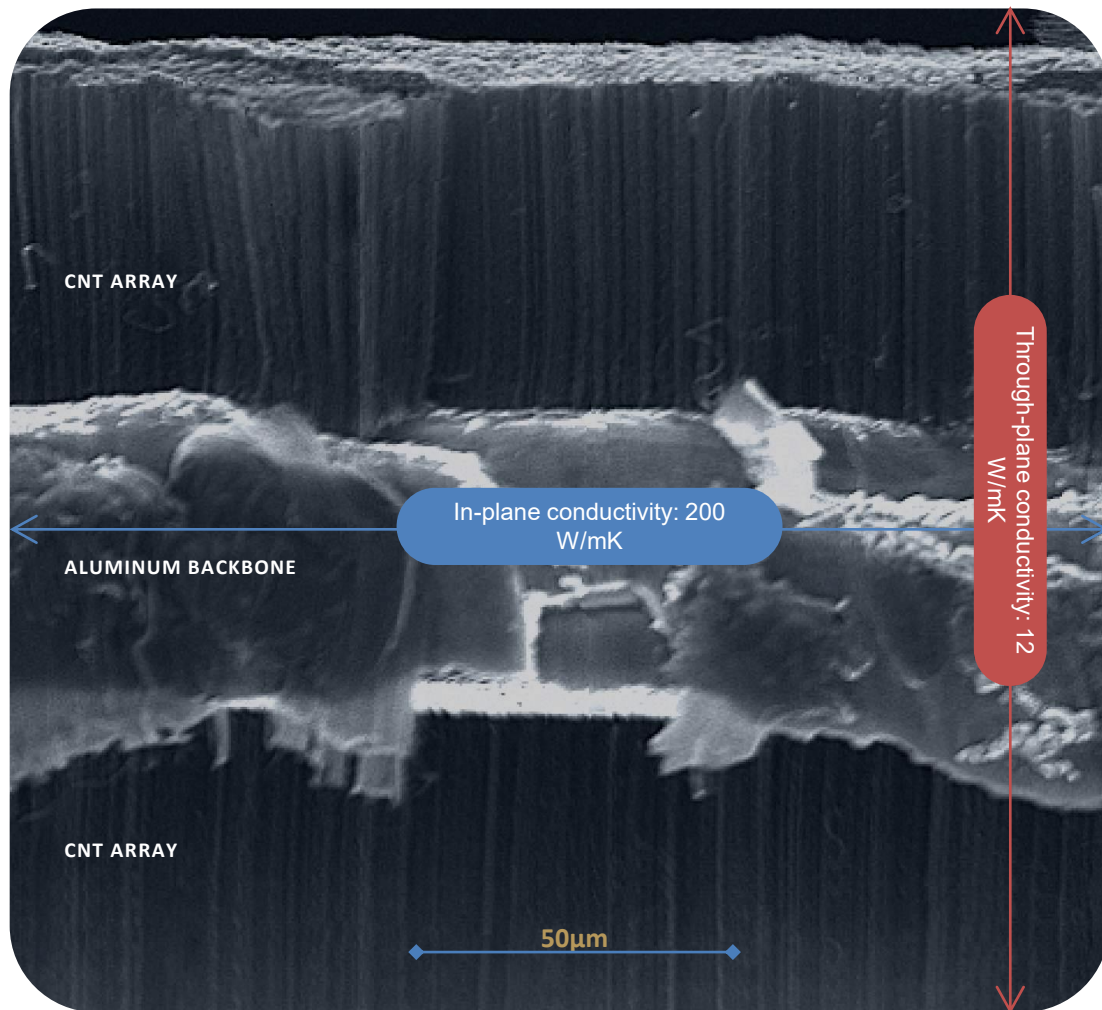
- The growth of TIMs in Electronics markets, increased power demands from electronics and data is creating a need for high-performance thermal management.

How it works

- Billions of vertically aligned CNTs are grown in situ from a gaseous precursor onto a recycled aluminum backing sheet to create a TIM product with both liquid-like and solid properties.
- Current products sold Space Pad™

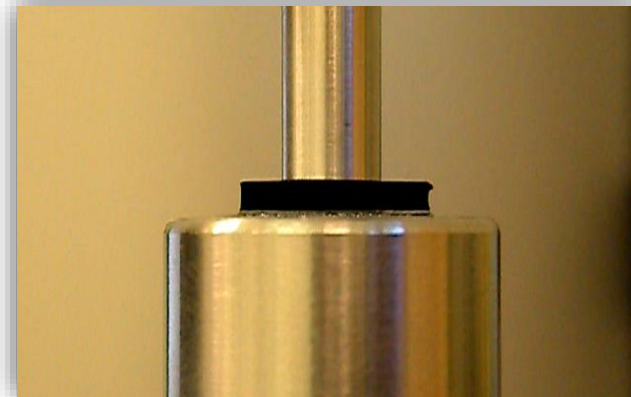


NEW: CARBICE Technology – Vertically Aligned Carbon Nanotubes (CNT)



Fast Facts

- Vertically aligned carbon nanotubes grown from aluminum foil substrate
- Through plane conductivity – 12 W/mK
- Aluminum x-y plane – 200 W/mK
- CNT infiltrated with polymeric binder to stabilize the structure and provide wetting

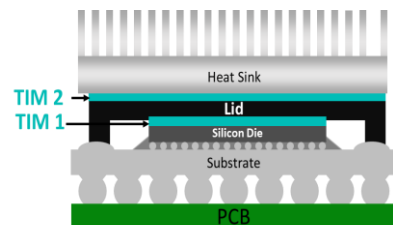


Aligned CNTs enhance compressibility compared to other carbon-based solutions

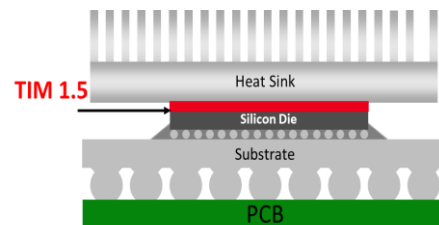
NEW: CARBICE Technology – Overcoming challenges for electronics

Challenge

- **Thermal Interface Materials (TIM)** play a critical role in the thermal management of electronic devices that are increasingly **compact** and **powerful**, and which **generate high level of heat**.
- **High Power Devices** → SiC power electronics driving higher temperatures and need for better thermal management
- **Consolidation of Modules** → Multi-functional power modules are increasing in size and power density
- **Fast assembly and sustainability needs growing** → fast assembly needs to improve productivity and sustainability solutions along life cycle

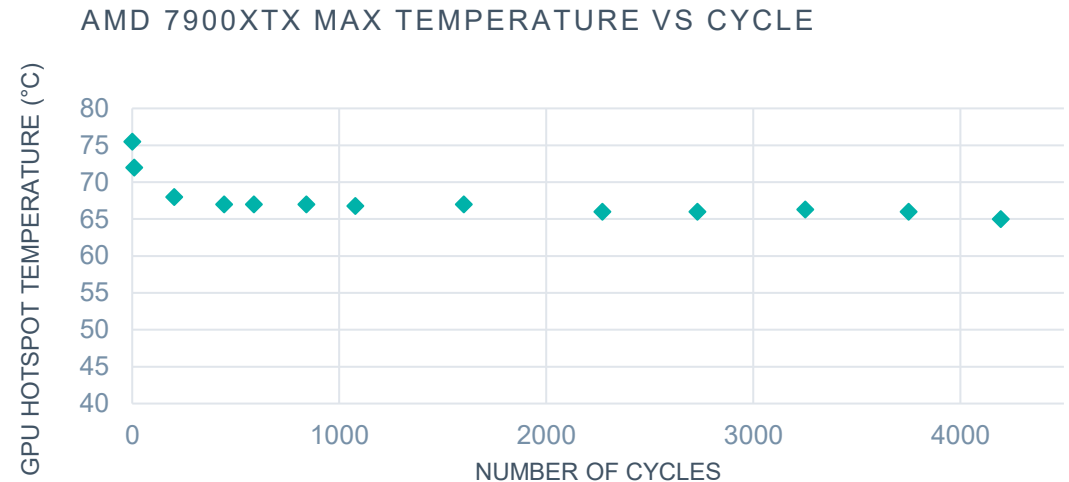


Lidded Package



Bare Die Package

Power cycling in TIM1.5 Bare Die Application with Consumer GPU – provided by Carbice



Hot spot performance visualization



Time – disperses heat in-plane

Application testing completed with Caribce® SW-90

Path Forward with Dow – Customer Centric Testing

ASTM E595

Thermally Conductive Materials

- Gap Fillers
 - DOWSIL™ TC-5533 (3W)
 - DOWSIL™ TC-4060 (6W)

- Adhesive

- DOWSIL™ TC-2035

Electrically Conductive Materials

- Adhesive

- DOWSIL™ EC-6484
 - DOWSIL™ EC-6601

Encapsulants

- DOWSIL™ 93-500 Space Grade Encapsulant

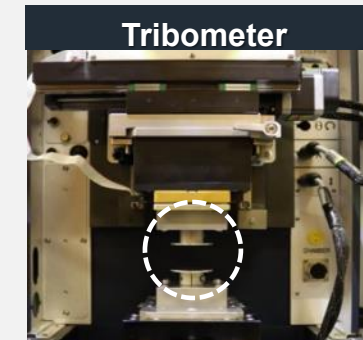


Customer Centric Application Test Method Development

Fatigue testing of thermal compounds

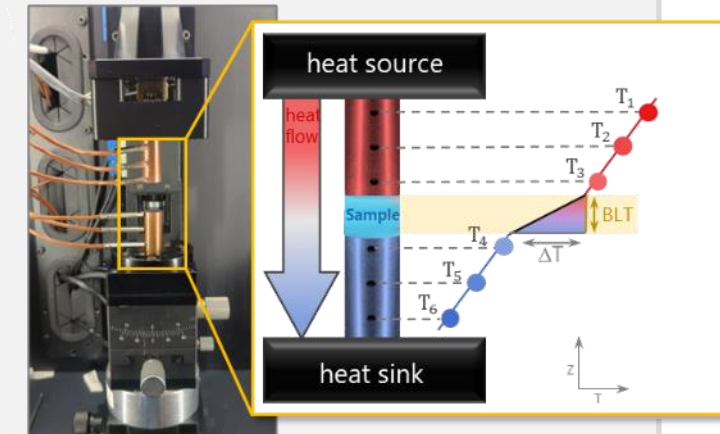
Thermal grease pump-out:

- Mimic temperature cycles and movement that cause pump-out



Measuring bulk thermal conductivity under thermal and mechanical stress:

- Mimic thermal and mechanical cycles and relating to the bulk properties of the material



ASTM D5470

Customer Centric Testing – Fatigue testing of thermal compounds

Thermal Grease Pump-Out

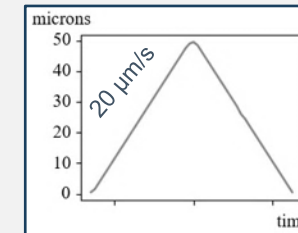
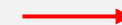
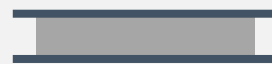


- Temperature cycles cause assembly warpage
- Resultant squeeze flows drive grease in & out of the assembly

Tribometer:

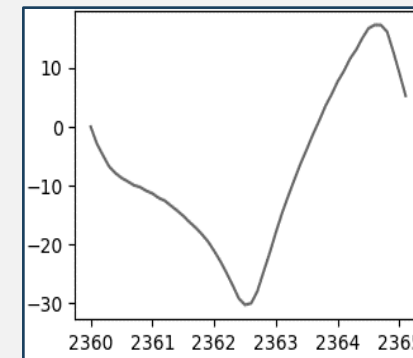
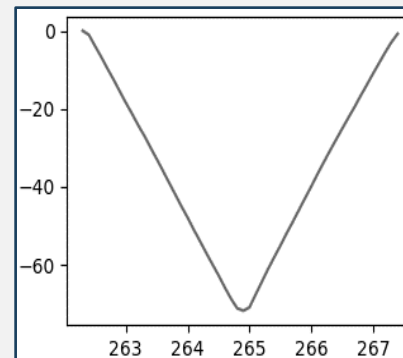


Fix max gap to 200 μm and set min gap to 150 μm (as example)



Sets amplitude to 50 μm

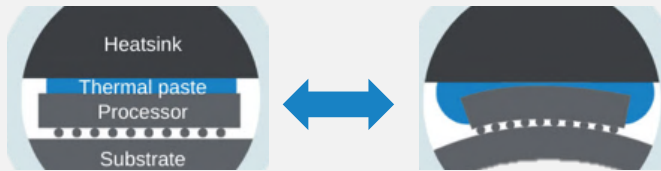
- Isolate the mechanical stress from the thermal changes
- Subject thermal grease to cyclic squeeze flows at micron-scale gaps
- Variables
 - Amplitude
 - Oscillation
 - Temperature



Visible pump-out

Customer Centric Testing – Fatigue testing of thermal compounds

Thermal Grease Pump-Out



- Temperature cycles cause assembly warpage
- Resultant squeeze flows drive grease in & out of the assembly

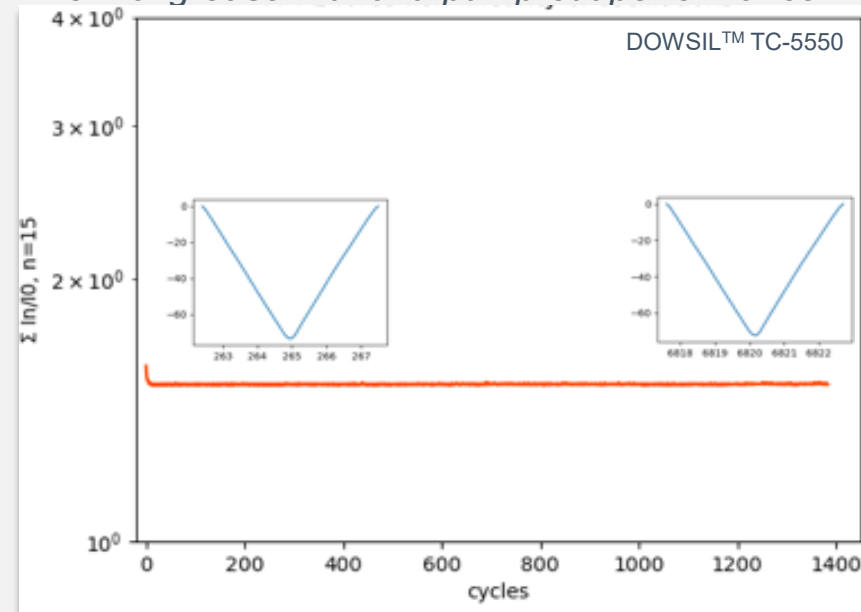
Tribometer:



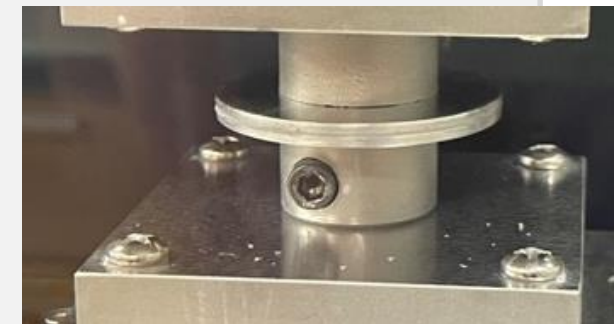
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Fix max gap to 200 μm and set min gap to 150 μm (as example)

Thermal grease with anti-pump-out performance

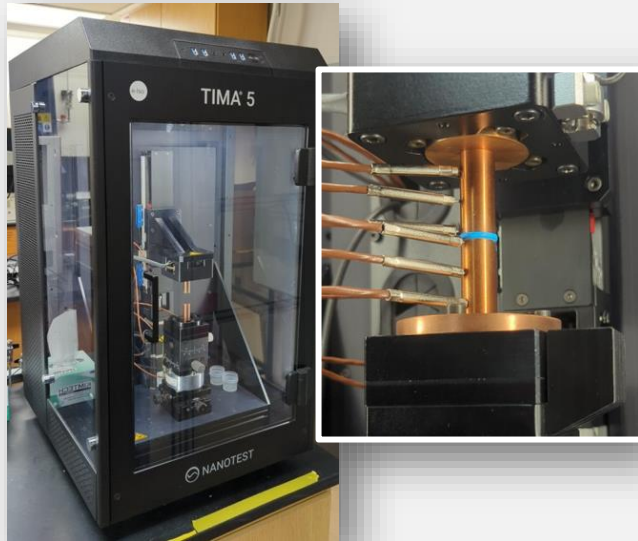


FFT analysis:
Linear response persists through the entire test



Customer Centric Testing – Fatigue testing of thermal compounds

Modified ASTM D5470



Variables

- Temperature
- Thickness
- Probe size
- Probe composition

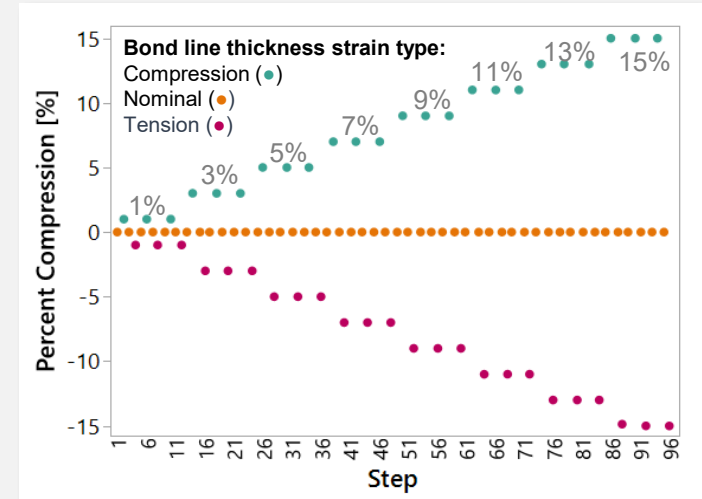
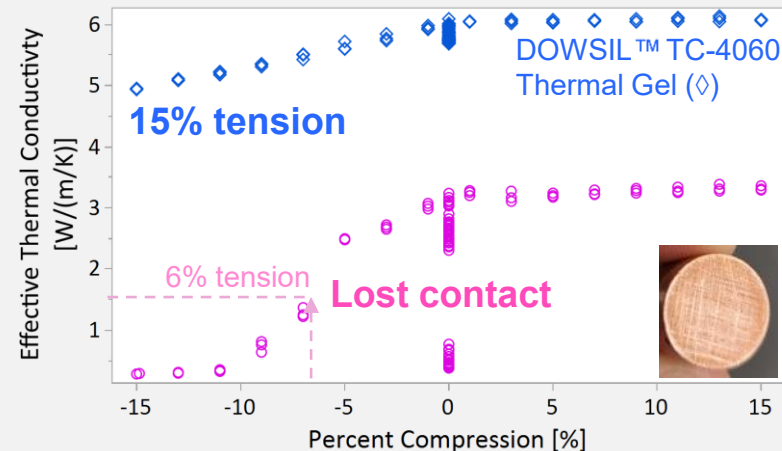
Cycling

- Thermal
- Mechanical

Sawtooth pattern

Developed to understand materials performance under compression and tension cycling.

- Allows for thermal performance measurement in tension and compression
- Evaluate mechanical deformation under thermal gradient

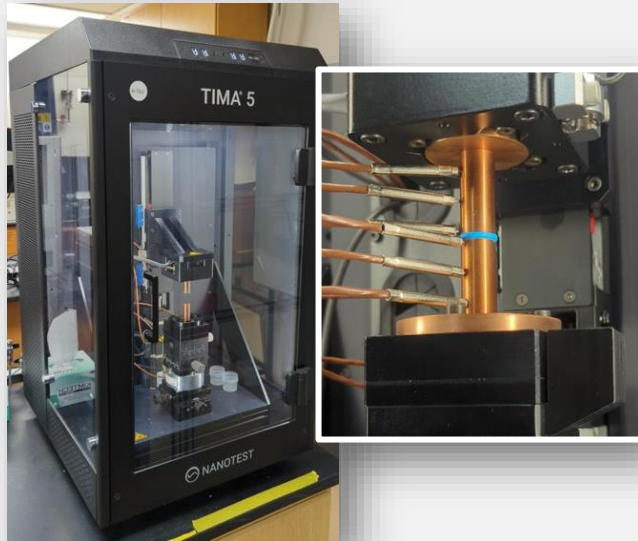


Visual inspection



Customer Centric Testing – Fatigue testing of thermal compounds

Modified ASTM D5470



Variables

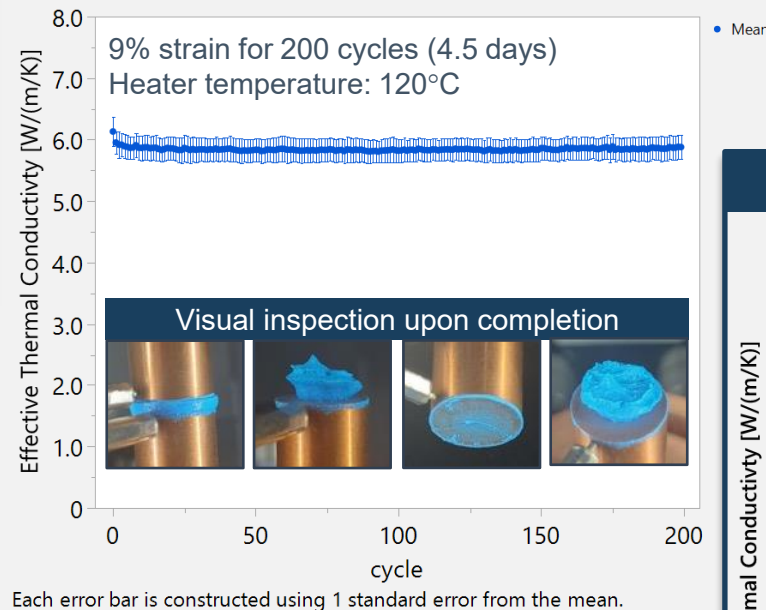
- Temperature
- Thickness
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Cycling

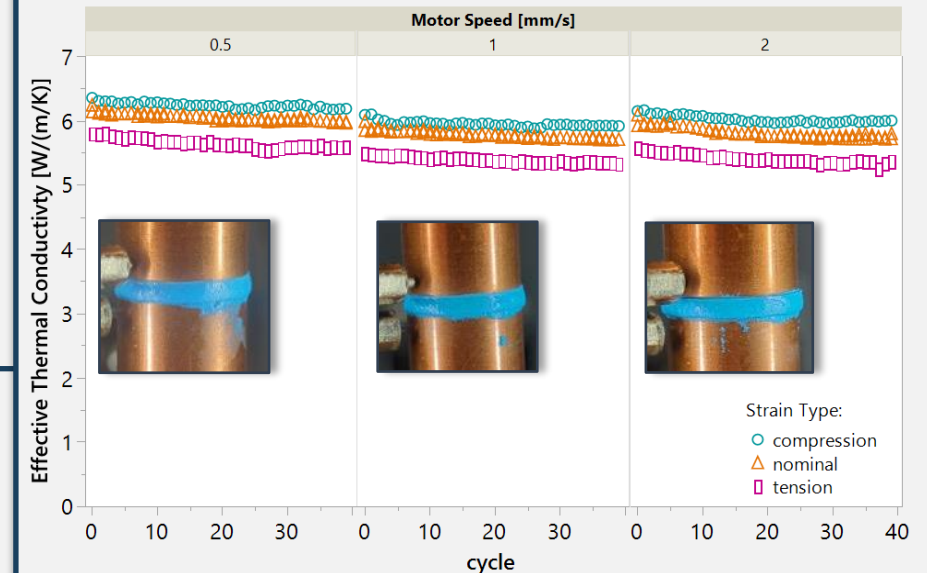
- Thermal
- Mechanical

Mechanical cycling of thermal gap filler & varied strain rates

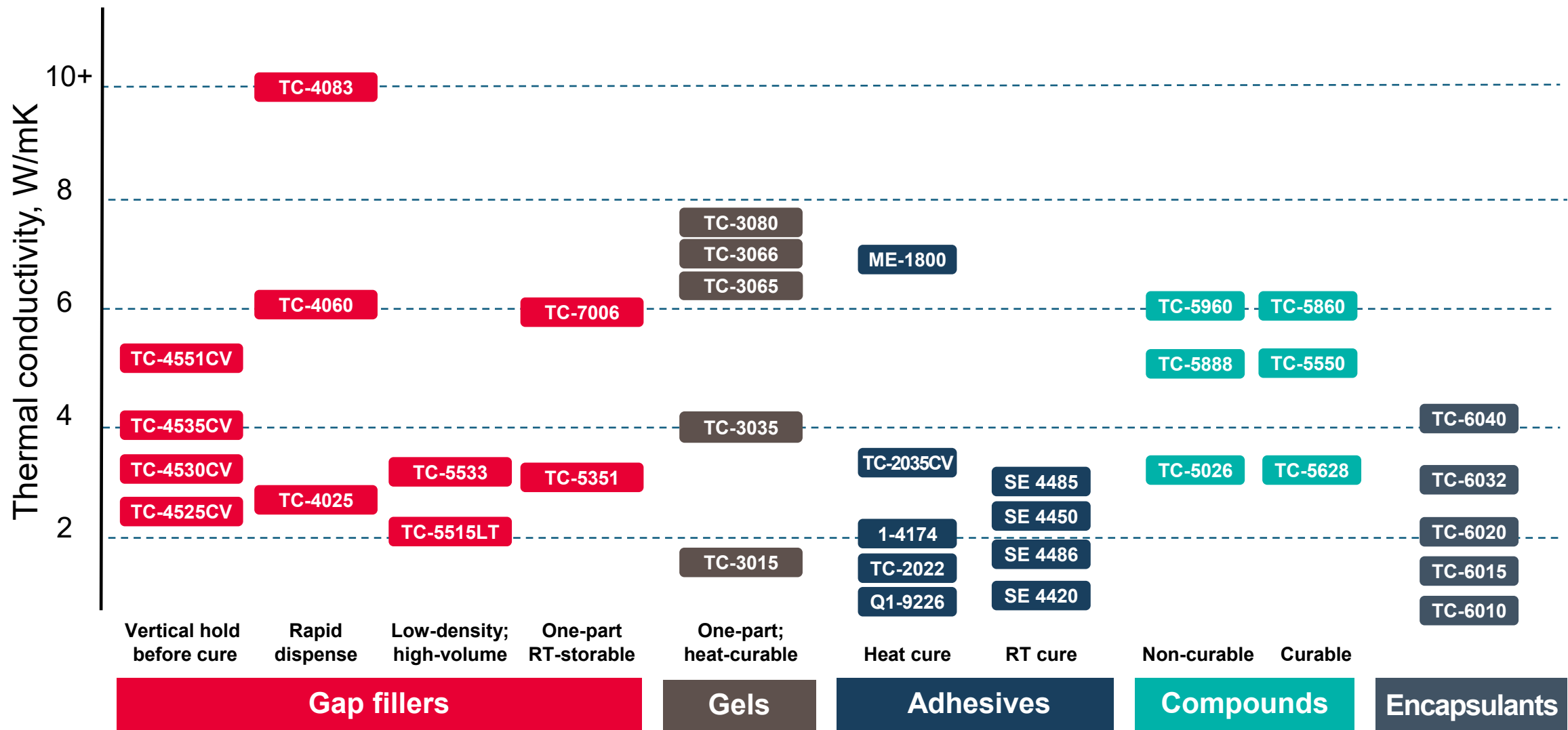
DOWSIL™ TC-4060 Thermal Gel



Varied strain rates (motor speeds)



SELECT DOWSIL™ THERMALLY CONDUCTIVE PRODUCTS



*These are typical properties, not to be construed as specifications.



Thank you

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