SAND2022-14861C

Die Attach Epoxy Characterization for Electronic Assemblies

Debbie Hagen, Sara Dickens, Mark Dimke, Elliott Fowler

October 31-November 3, 2022

Die Attach Epoxy

Thunderbirds 2011
Sandia photographer Randy Montoya captured these photos of the US Air Force's Thunderbirds

Great things are done by a series of small things brought together

Vincent Van Gogh

Outline

- Functionality of die attach
- System requirements drive die attach requirements
- Properties measurements
- Conclusions
- Acknowledgements
- Q & A

Die Attach Functionality

- Semiconductor chips are often attached to substrates, leadframes, ceramics or printed wiring boards with die attach adhesives
- This presentation will cover wire bonded products (no flip chip) and A stage vs B stage die attach materials
- Die attach adhesives are typically **polymer-based composites with non-polymer fillers**
- **Adheres** the silicon to either organic or metal surfaces (Solder mask, Cu, Au, etc.)
- **Accommodates thermal expansion mismatches** between silicon and substrate or leadframe
- Provides a **thermal path**
- Provides **electrical conductivity** per device needs
- Does so **without harming** or contaminating the circuit

System Requirements Drive Die Attach Requirements

System Requirements	**Die Attach Derived Requirements**
Reliability	Mechanical properties, Strength and adhesion to interfaces, Contamination (Outgassing, Resin bleed, Ionics) Voiding, Moisture diffusivity, Thermal stability, and Cure parameters
Electrical Performance	Electrical resistivity, Filler, Thermal conductivity and diffusivity, Heat capacity, Adhesion strength, Voiding
Manufacturability	Dispensability & consistency (Viscosity, Thixotropy), Cure conditions, Voiding, Resin bleed, Thermal stability

System and sub-system requirements are diverse – no single material fits all needs

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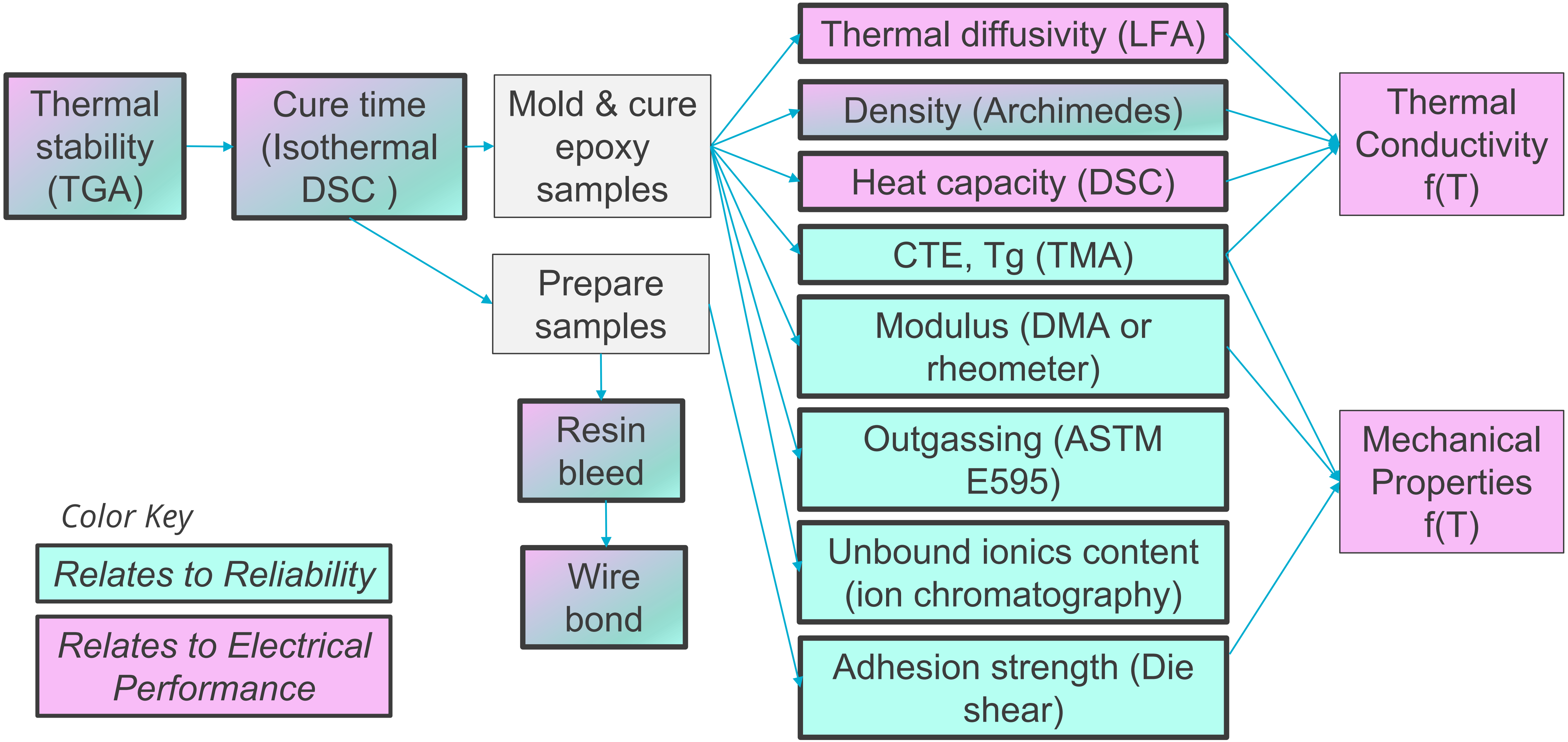
Die Attach Materials Characterization



Thermal stability (TGA)

Cure time (Isothermal DSC)

Mold & cure epoxy samples

Prepare samples

Resin bleed

Wire bond

Thermal diffusivity (LFA)

Density (Archimedes)

Heat capacity (DSC)

CTE, Tg (TMA)

Modulus (DMA or rheometer)

Outgassing (ASTM E595)

Unbound ionics content (ion chromatography)

Adhesion strength (Die shear)

Thermal Conductivity f(T)

Mechanical Properties f(T)

Color Key

Relates to Reliability

Relates to Electrical Performance

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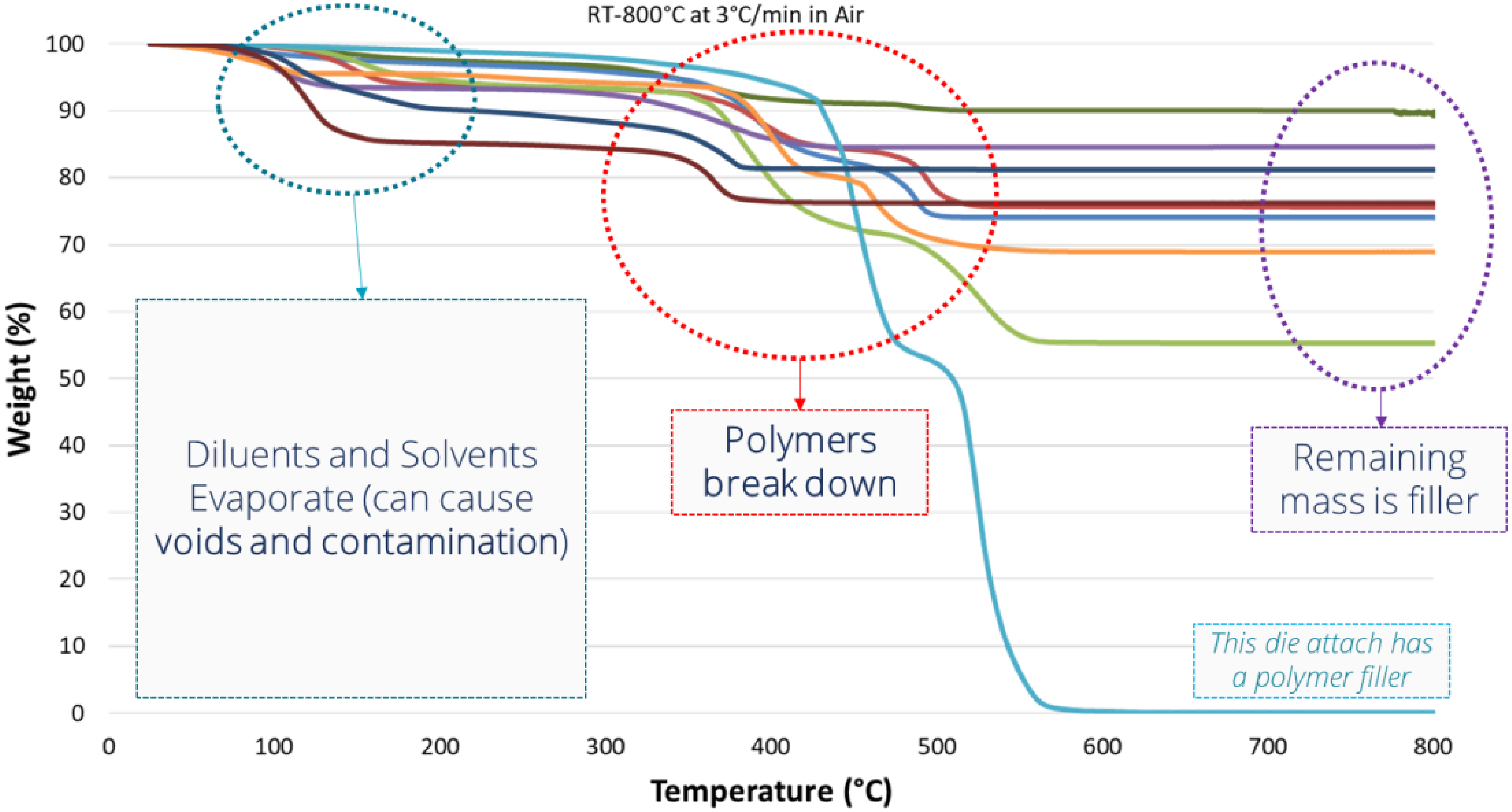
Thermal Stability

Measured by thermal gravimetric analysis (TGA)

- TGA Q5000
- Heating rate of 3°C/min under air
- Jamie Kropka and Catherine Groves
- bleed


RT-800°C at 3°C/min in Air

Diluents and Solvents Evaporate (can cause voids and contamination)

Polymers break down

Remaining mass is filler

This die attach has a polymer filler

How do high temperatures affect die attach materials, possibly impacting device reliability and performance?

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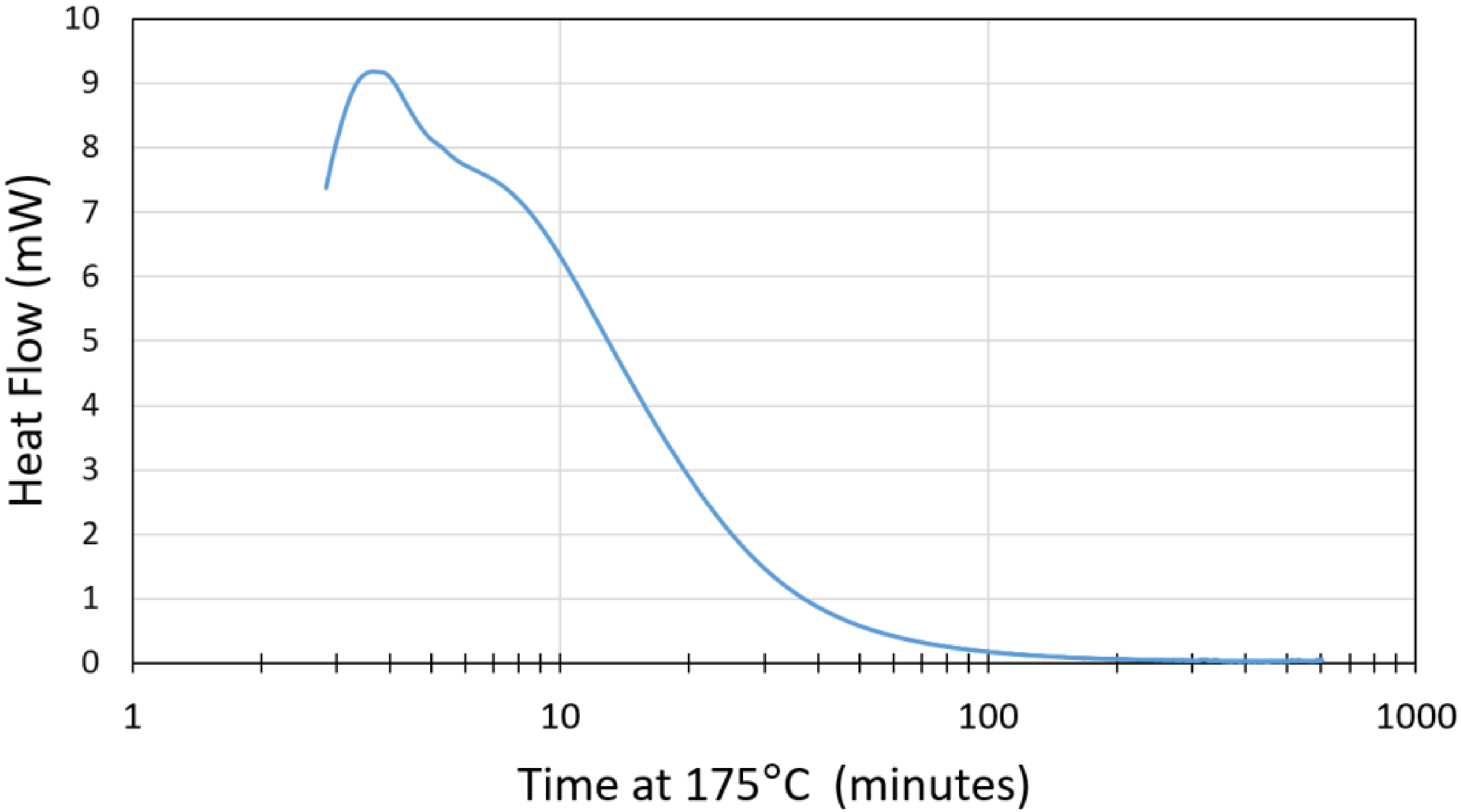
Cure Time at Temperature

- Isothermal hold at the supplier's recommended cure temperature
- Exotherm is evidence of chemical reaction
- Measured by Differential Scanning Calorimetry (DSC)



TA Instruments Q2000 series DSC
Jamie Kropka and Catherine Groves

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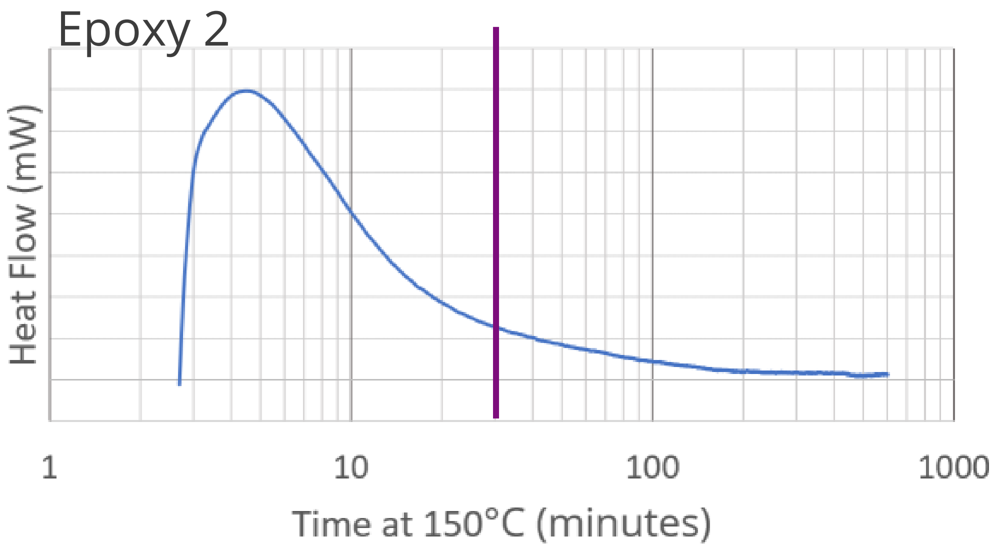
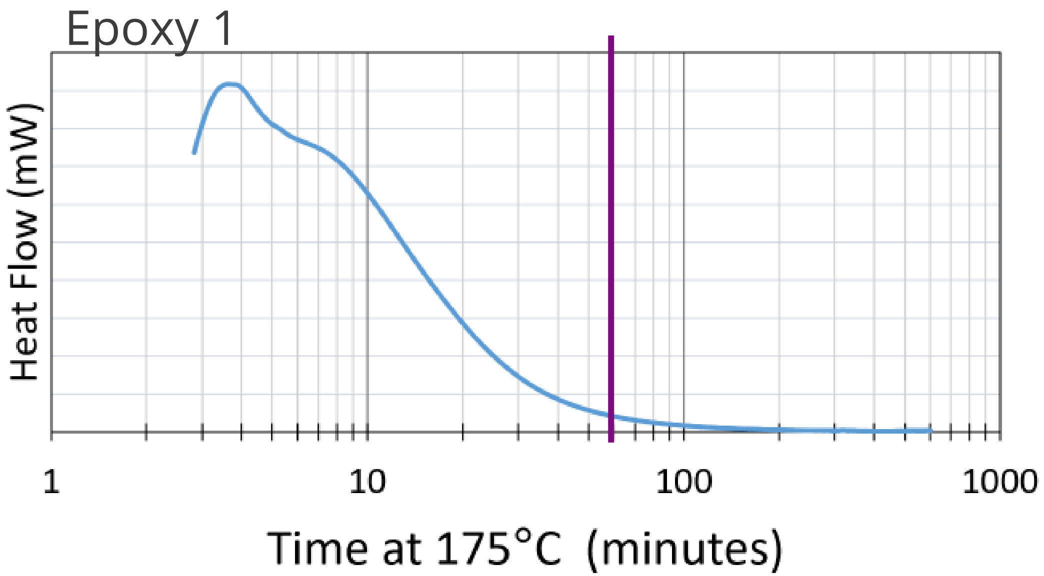
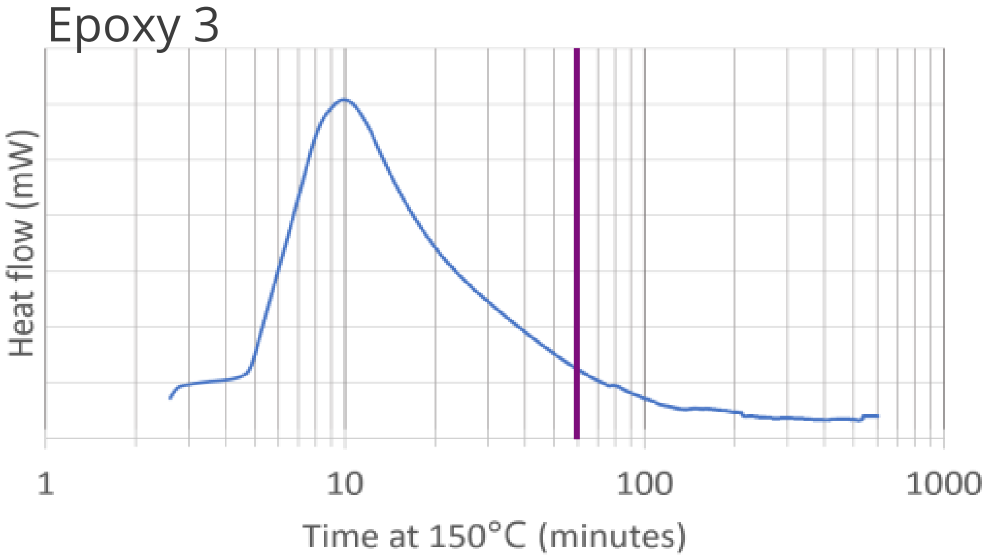
Cure Time– Data Sheet vs Complete Cure

- Data sheet cure time recommendations often under-cure the epoxy
- Data sheet recommended cure times are shown with purple lines







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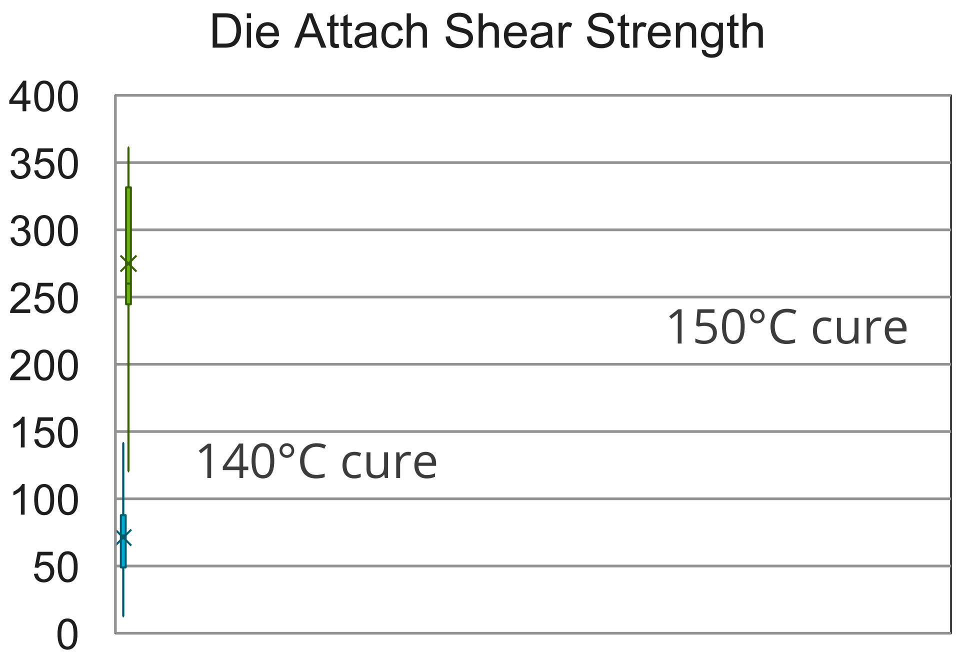
Cure Conditions Can Affect Properties

Outgassing performance can improve with higher cure temperature

Cure Temperature	Total Mass Loss (Outgassing ASTM E595)
60 C	1.18
71 C	0.91
80 C	0.8

Thermal conductivity of silver-filled die attach often will increase as cure temperature increases

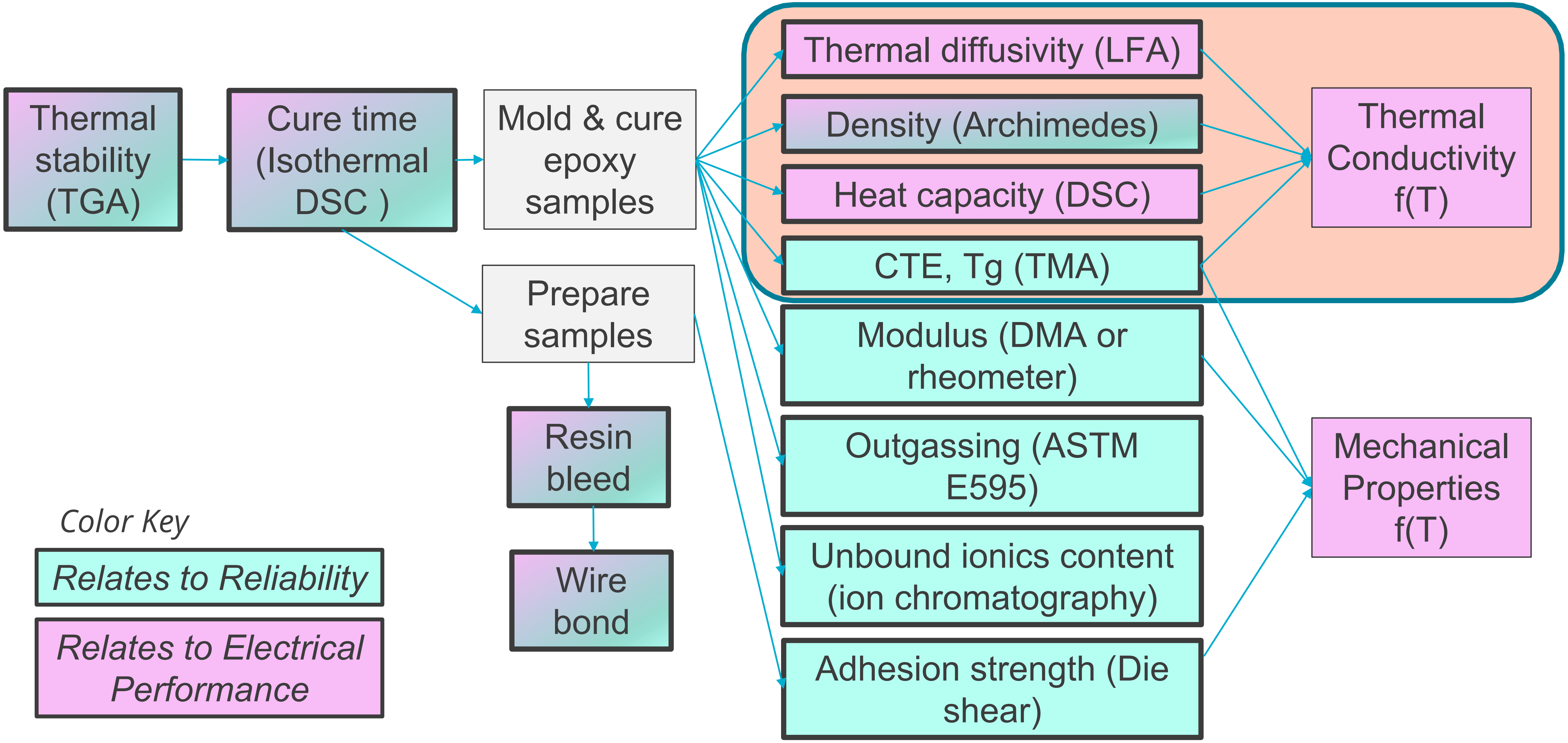
Same epoxy – Different cure



Connor Healey, Dage 4000 die shear tester

Die attach properties can depend on the cure process

Die Attach Materials Characterization



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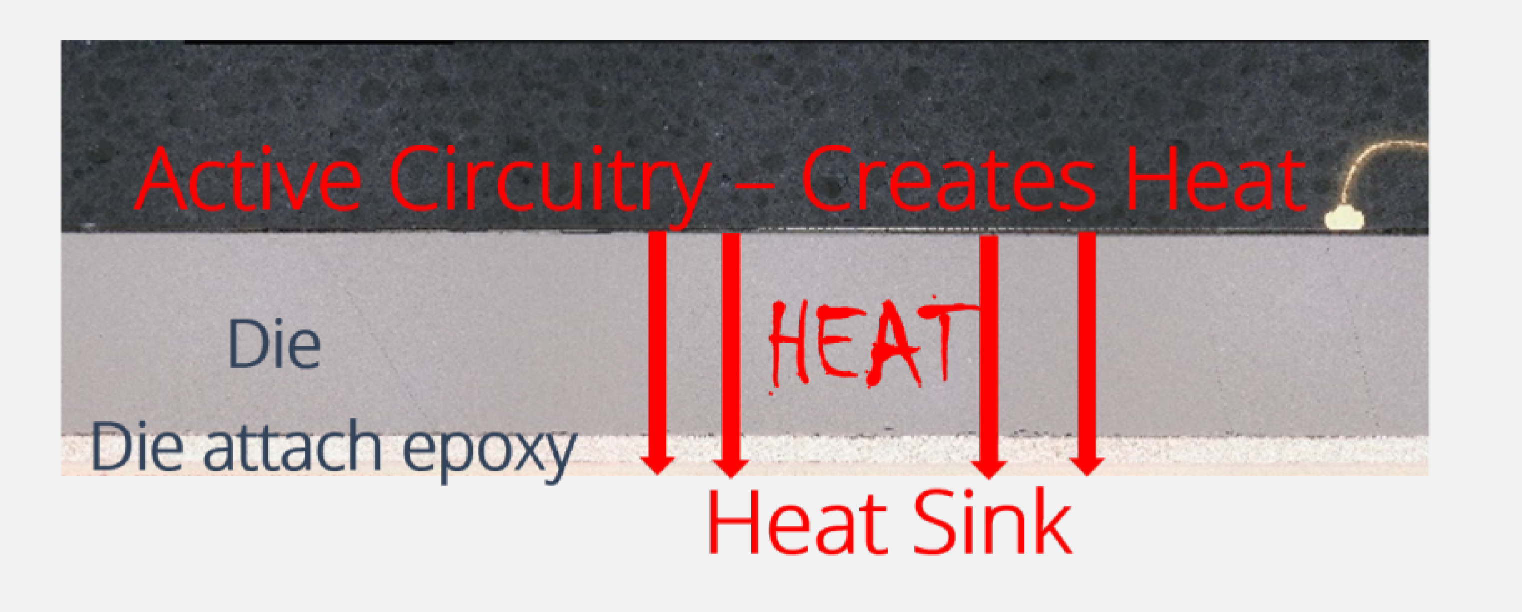
Thermal Conductivity

- Heat generated by the active circuitry of the die can transfer through the die attach



Thermally conductive die attach can remove excess heat and lowers junction temperatures

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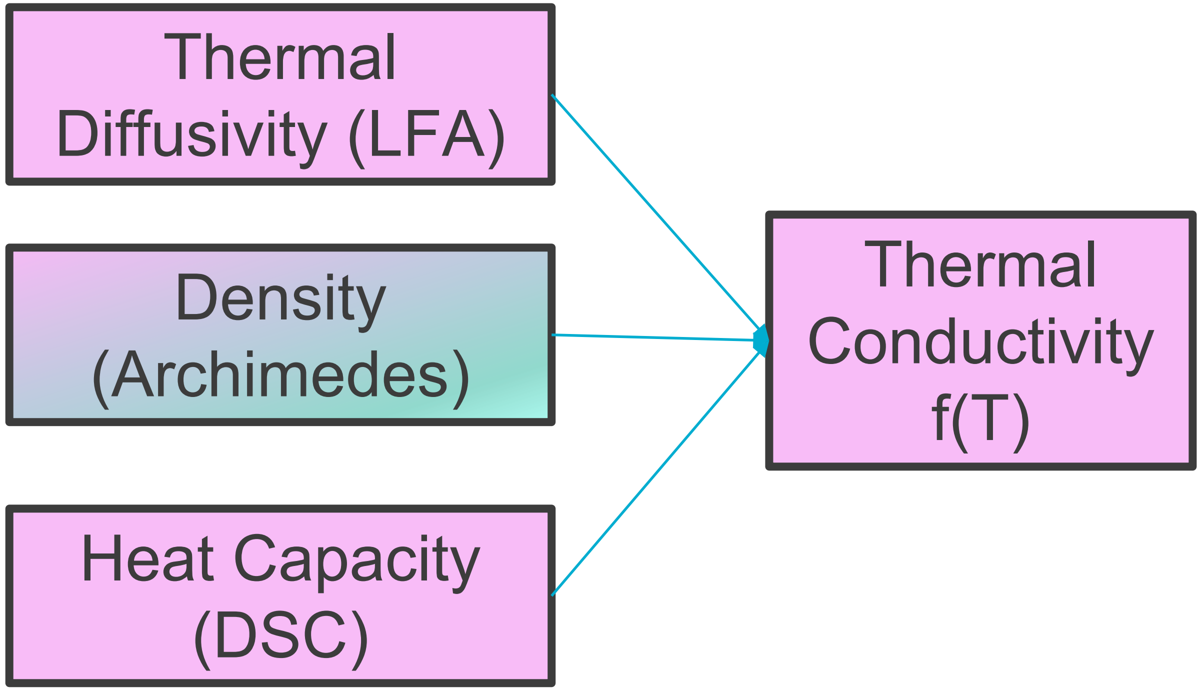
Thermal Conductivity Measurement

$$\lambda = \alpha \, C_p \, \rho$$

λ	Thermal conductivity
α	Thermal diffusivity
Cp	Specific Heat Capacity
ρ	Density



Thermal Diffusivity (LFA)

Density (Archimedes)

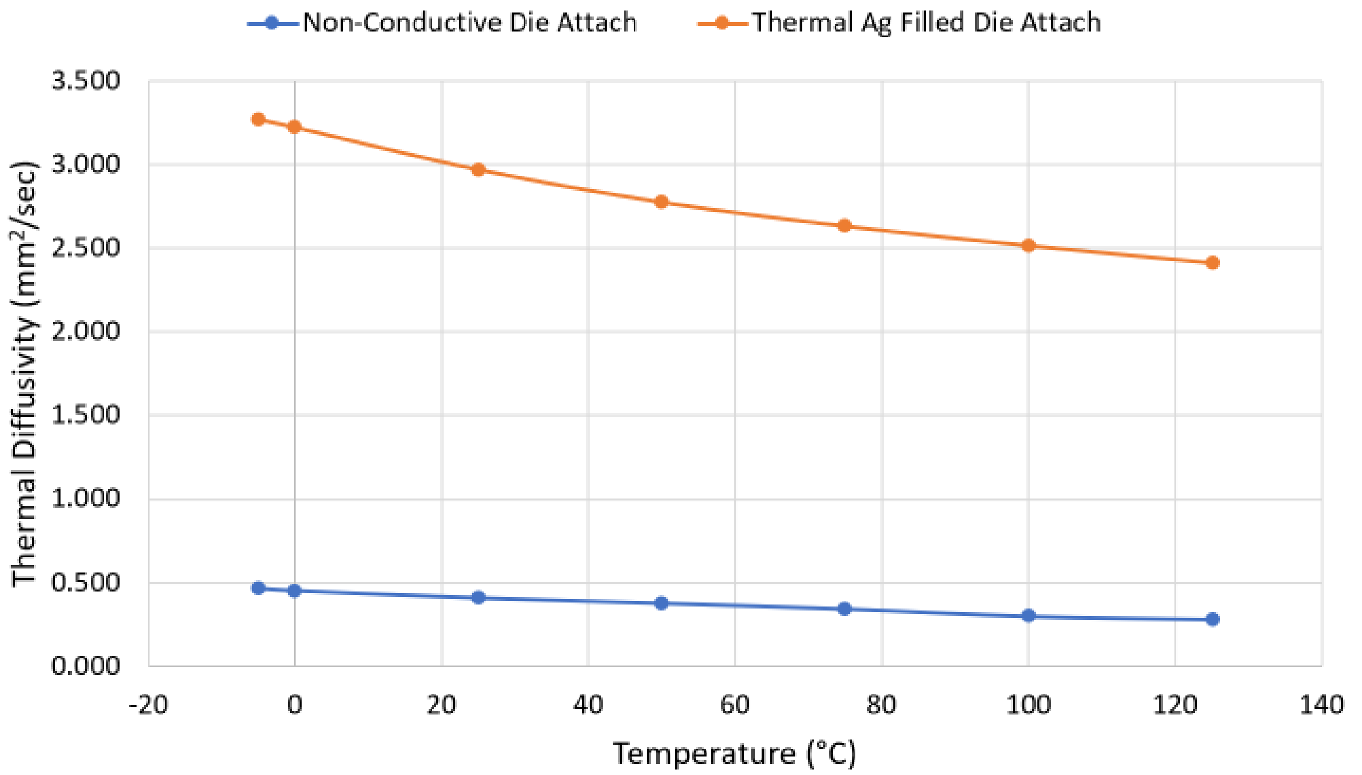
Heat Capacity (DSC)

Thermal Conductivity f(T)

Thermal Diffusivity Measurement

$$\lambda = \alpha \, Cp \, \rho$$

α Thermal diffusivity



Netzsch LFA 467 Hyperflash
Pin Yang and Mia Blea

Designation: E1461 – 13 (Reapproved 2022)

Standard Test Method for
Thermal Diffusivity by the Flash Method[1]

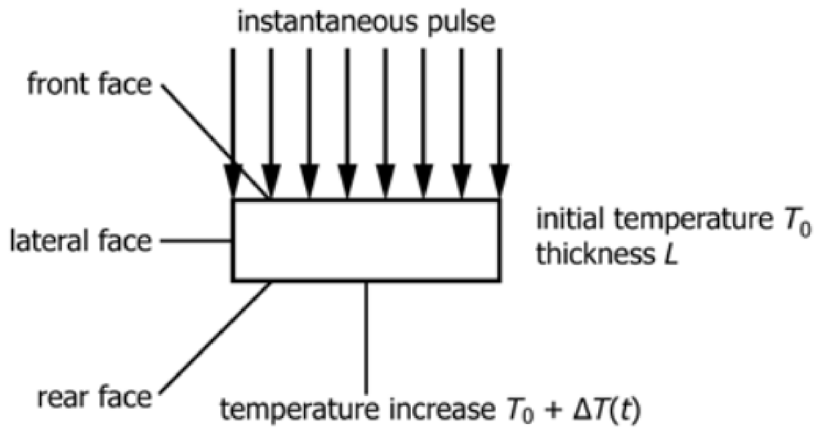


FIG. 2 Schematic of the Flash Method

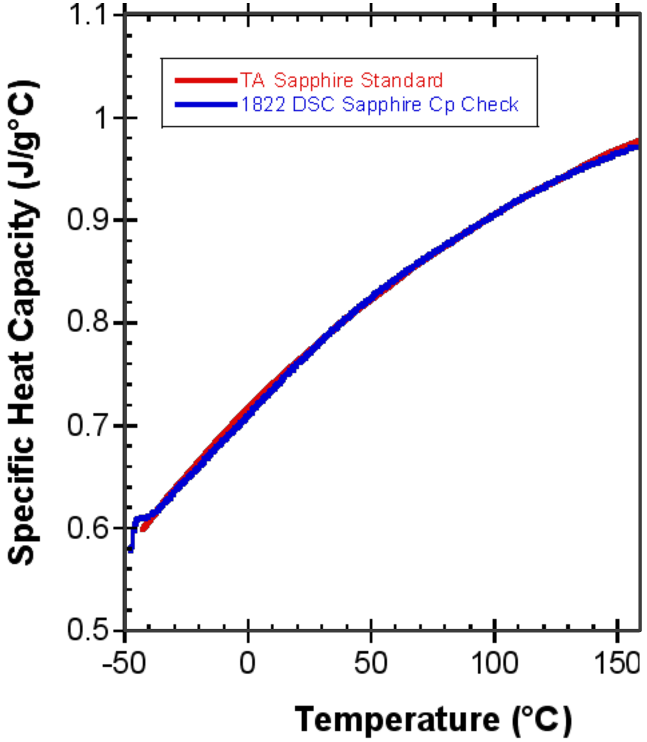
Presented at SMTA International 2022

Specific Heat Measurement

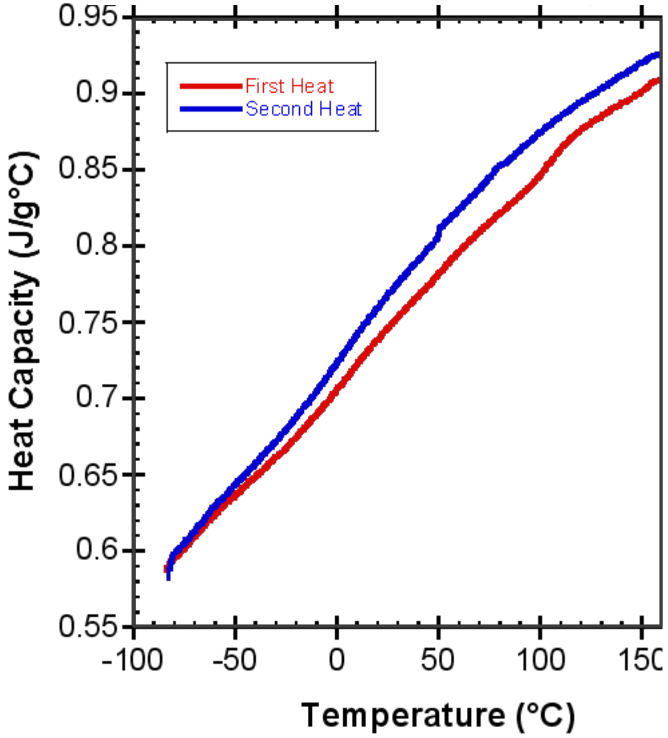
$$\lambda = \alpha \, C_p \, \rho$$

C_p Specific Heat Capacity

Calibration



Die attach sample



Designation: E1269 – 11 (Reapproved 2018)

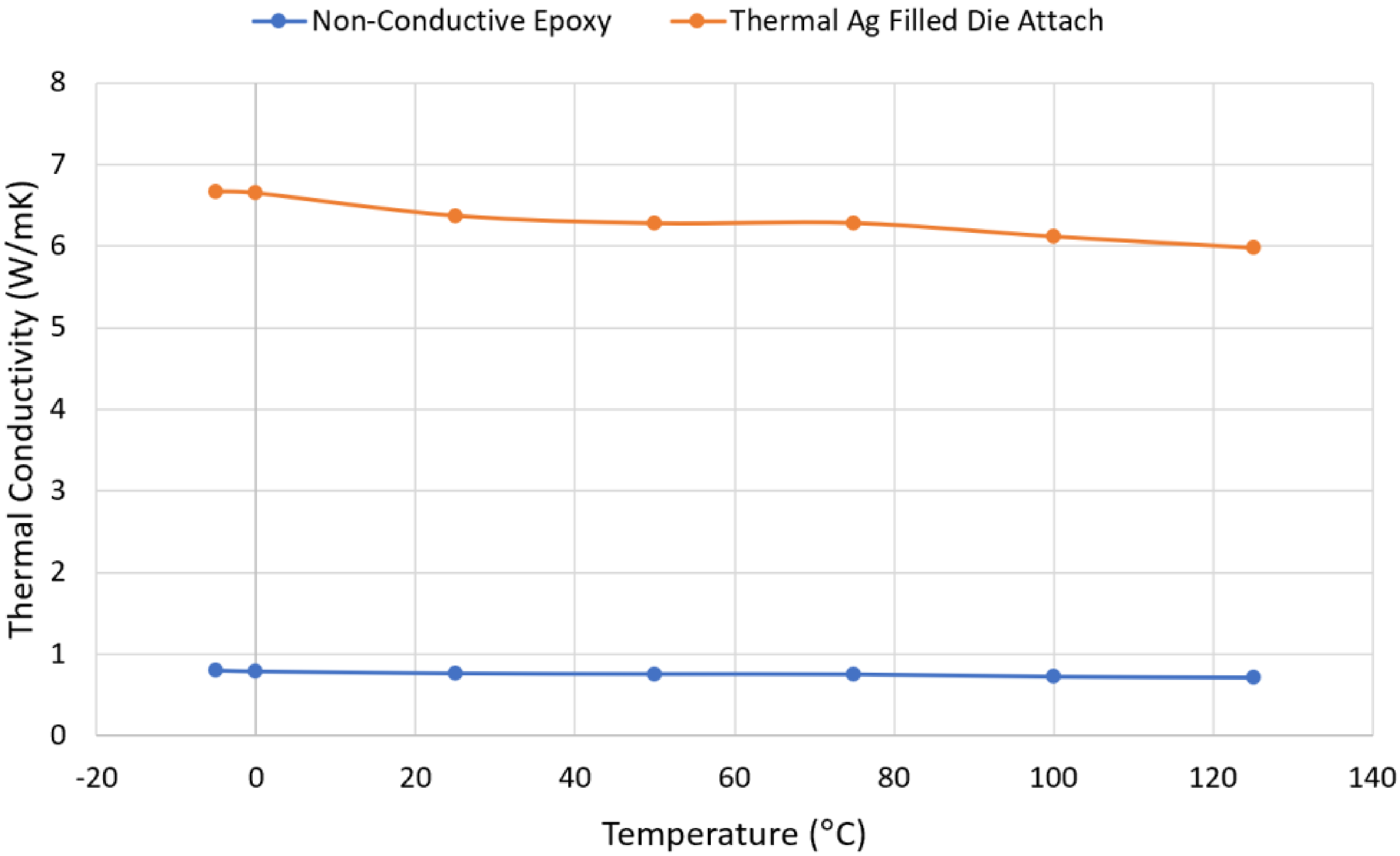
Standard Test Method for
Determining Specific Heat Capacity by Differential Scanning Calorimetry[1]

- TA Instruments Q2000 series DSC
- Performed with nitrogen sealed hermetic pans
- Jamie Kropka and Catherine Groves

Thermal Conductivity

$\lambda = \alpha \, C_p \, \rho$

λ Thermal conductivity



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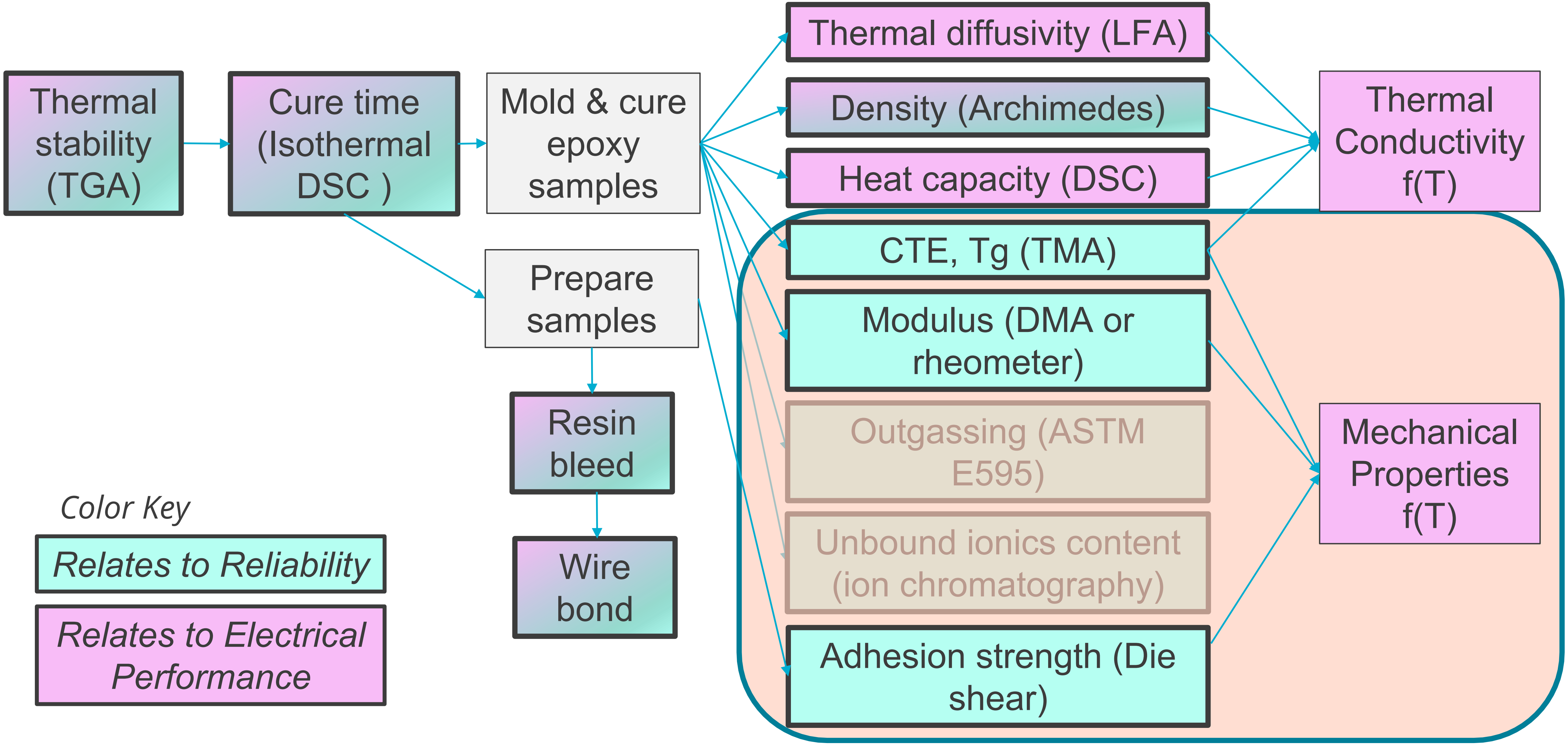
Die Attach Materials Characterization



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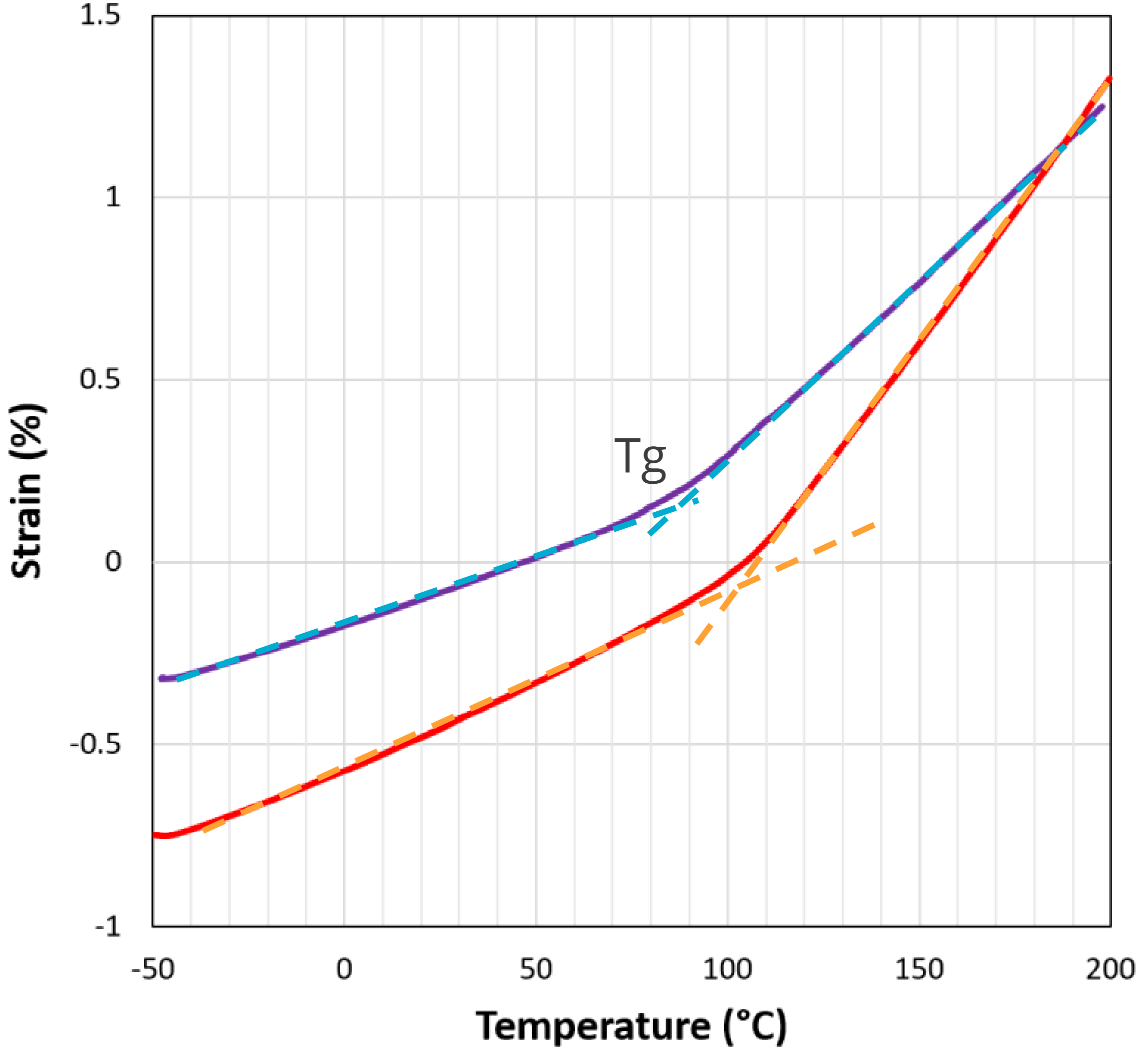
Mechanical Properties – Coefficient of Thermal Expansion

Thermal Mechanical Analysis (TMA)

- Measures the sample during heating and cooling
- Thermal expansion coefficient (slope)
- Glass transition temperature (Tg) (inflection point)
- Shrinkage due to additional thermal excursions after cure



Jamie Kropka and Catherine Groves
Heating rate of 1°C/min in nitrogen

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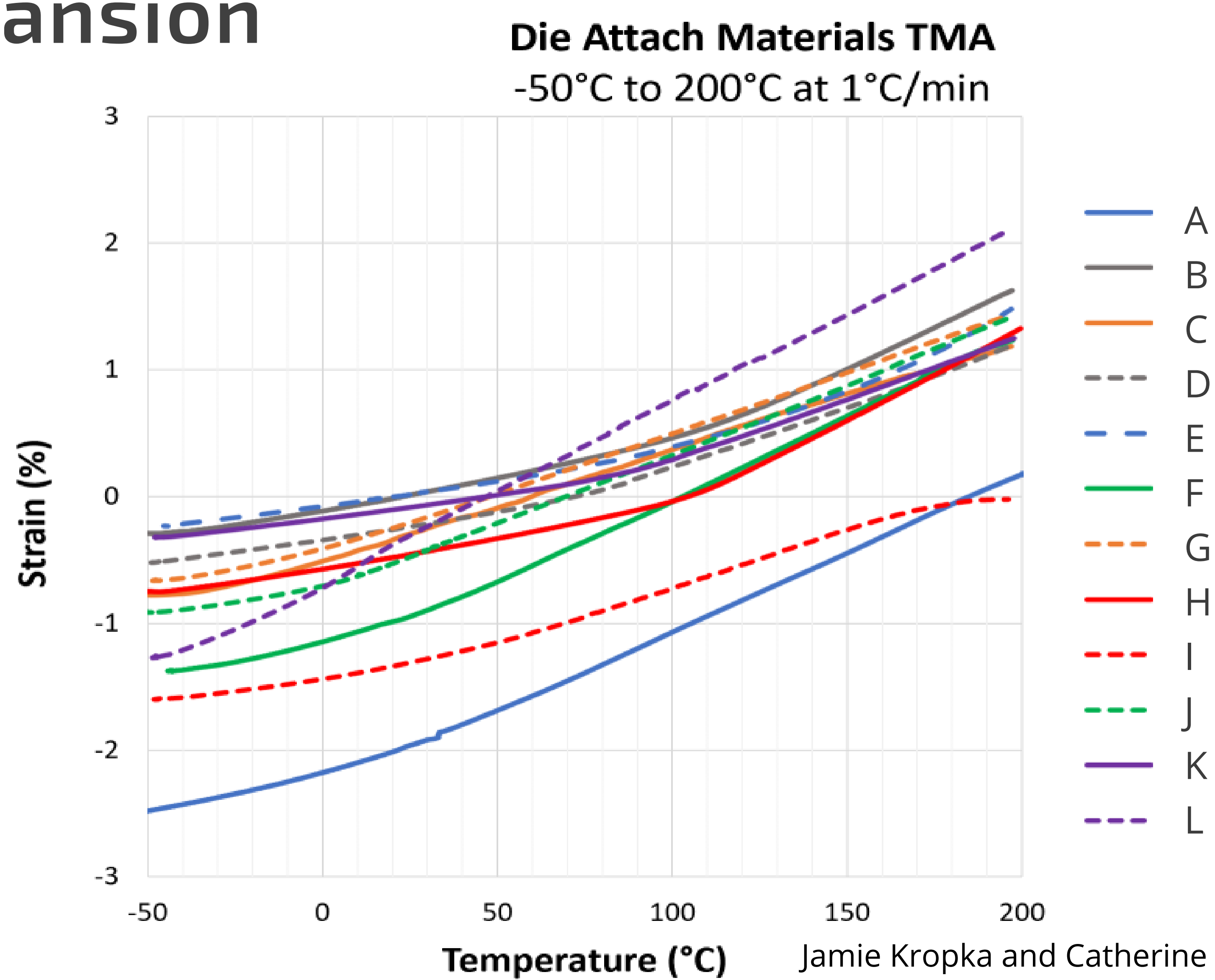
Mechanical Properties – Coefficient of Thermal Expansion

- Generally, lower thermal expansion is better for reliability
- Thermal expansion coefficient is part of the stress picture, but not all of it



Jamie Kropka and Catherine Groves
Heating rate of 1°C/min in nitrogen

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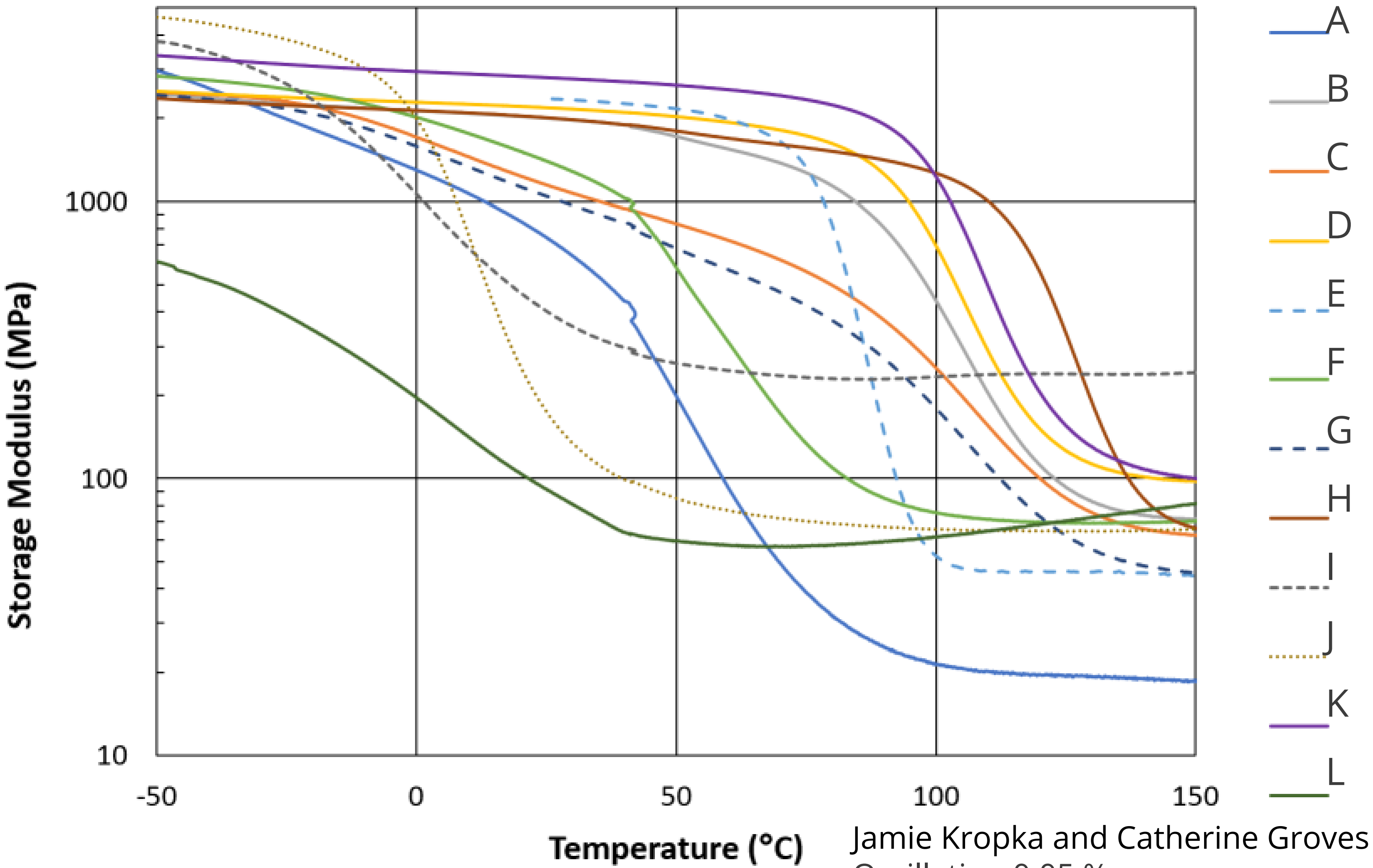
Mechanical Properties – Modulus

Equipment:

- ARES G2 torsional rheometer
- This technique measures shear storage modulus, not Young's modulus
- High modulus materials are stiff
- Low modulus materials are more flexible



Jamie Kropka and Catherine Groves
Oscillation 0.05 %

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Conclusions

Die attach material selections depend on the requirements of the system

- Material selections can affect reliability, manufacturability, and device functionality
- Characterization of critical properties improves predictive modelling fidelity versus data sheet values

To enable informed epoxy selection

- Start with the system requirements
- Derive material requirements from system requirements
- Use properties data that are trusted
- Understand that cure profile affects the die attach properties, and that data sheets often understate cure times

Thank You!!

- We couldn't have done this work without you!
  - Mia Blea
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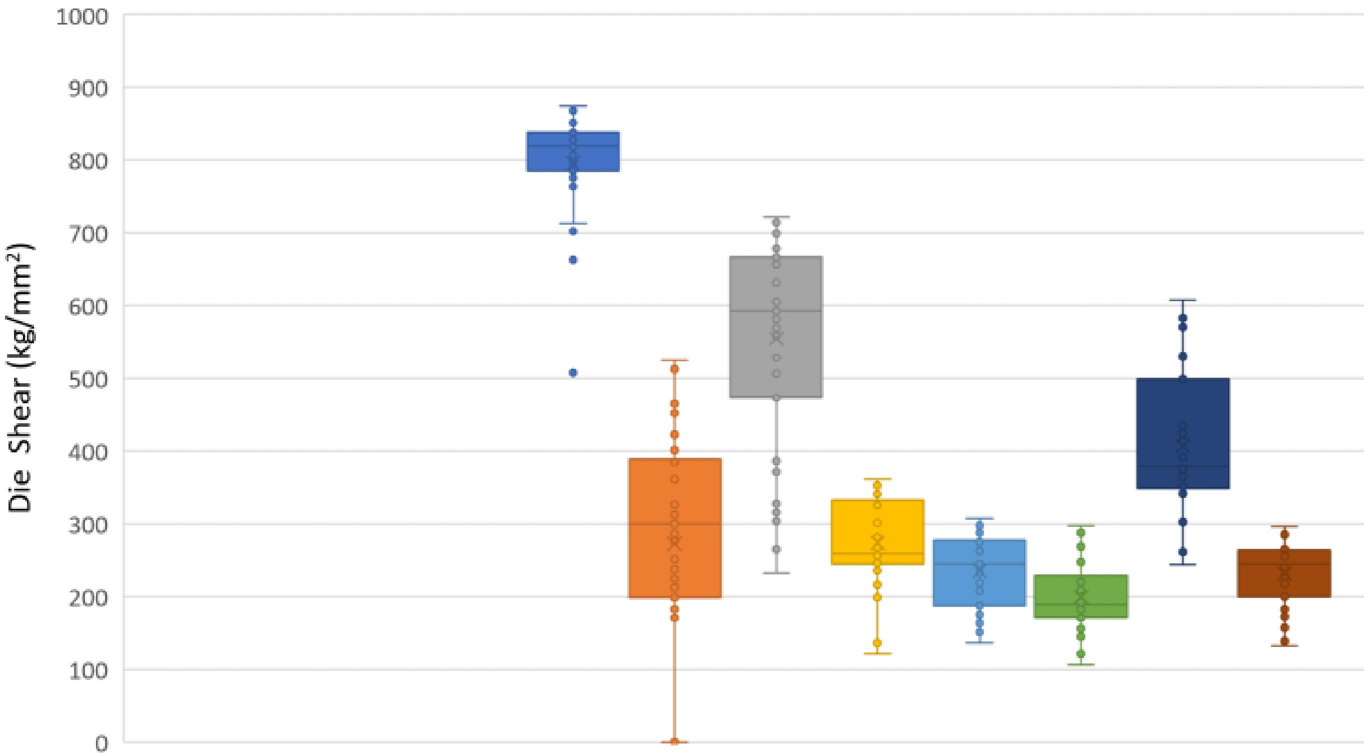
  - Shianne Carroll
  - Adrian Casias
  - Catherine Groves
  - Alvin Ha
  - Randy Hamm
  - Connor Healey
  - Jason James
  - Jamie Kropka
  - Erica McCready
  - Nalini Melon
  - Jason Tillotson
  - Daren Whitlock
  - Pin Yang

Speaker contact info: dahagen@sandia.gov

Backup Slides

Die Shear Testing



Dage 4000, Connor Healey

Adhesion to different surfaces, cure schedule, cleanliness, and many other things affect die shear strength

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