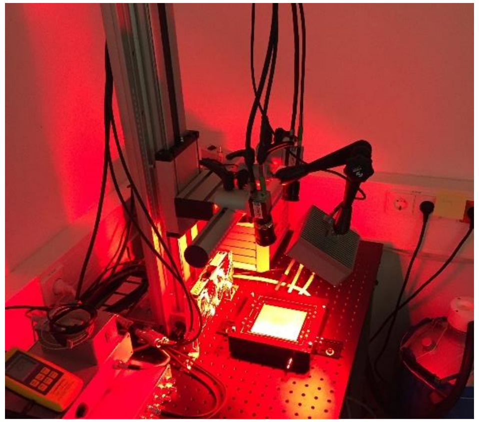
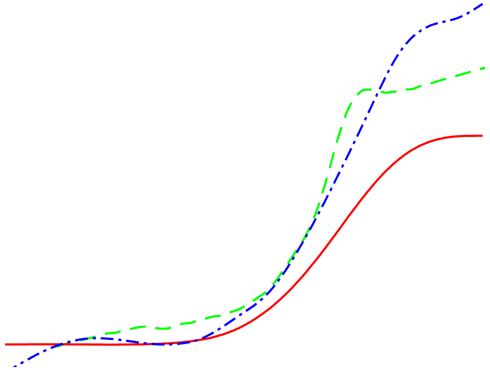
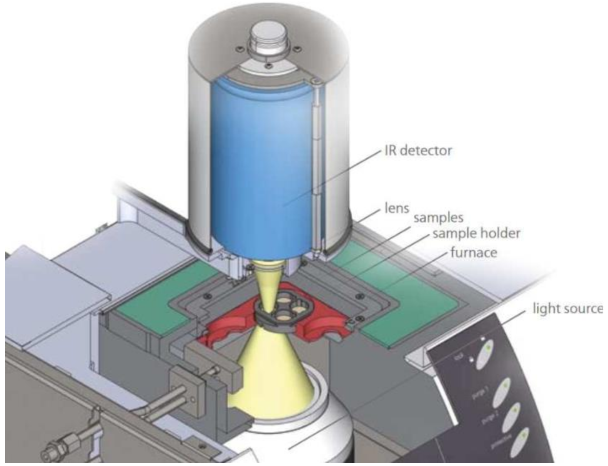




Thermal characterization of polymer and polymer composites – evaluation and comparison of measurement methods



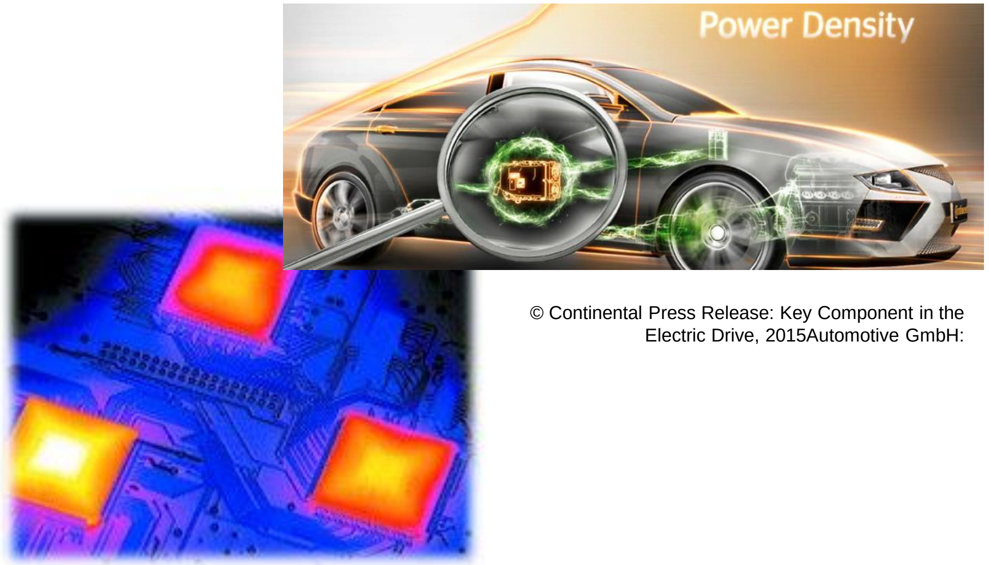
Mario Gschwandl

Polymer Competence Center Leoben GmbH

4a Technologietag 2020 - Werfenweng

Thermal Conduction

Improving thermal management for microelectronics and power packages, by enhancing thermal conductivity of polymeric insulators

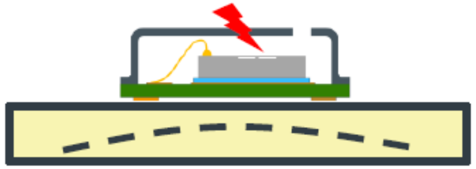


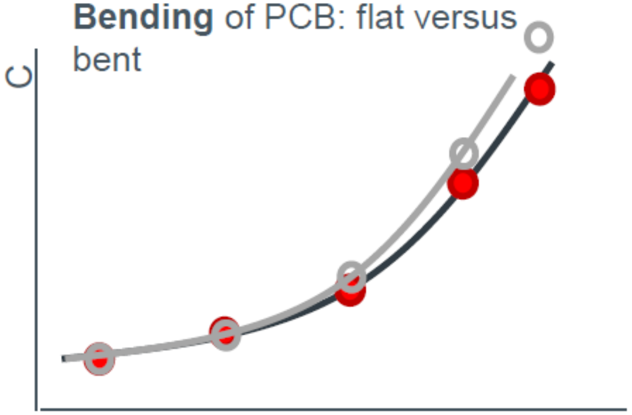
© Continental Press Release: Key Component in the Electric Drive, 2015Automotive GmbH:

Strock, J.: Does your PCB have a fever? EE-Evaluation Engineering (2000)

Thermal Expansion Behavior

Understand and adapt thermal expansion behavior to current needs for application tailored polymers.





Thermal Conduction

Thermal Conduction – Theoretical Background

Three material parameters are the crucial thermo-physical properties to define heat transfers:

$$\lambda(T) = a(T)c_p(T)\rho(T)$$

Thermal Conductivity *λ(T)*

It links heat transfer to a temperature gradient by obeying the second law of thermodynamics.

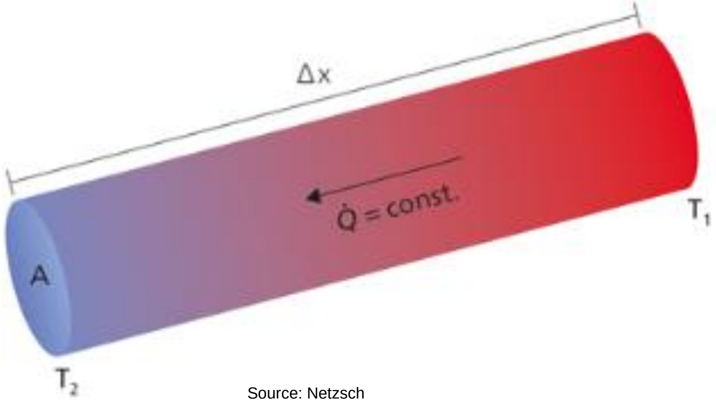
Thermal Diffusivity *a(T)*

It links an energy flux to an energy gradient, hence it is a measure for the speed of heat transfer through a body of mass.

Specific heat capacity c_p

It describes the energy consumption during heating processes.

$$\frac{dQ}{dt} = \dot{Q} = -\lambda A \frac{T_2 - T_1}{\Delta x} \quad ; \quad \dot{q} = -\lambda \frac{\Delta T}{\Delta x}$$

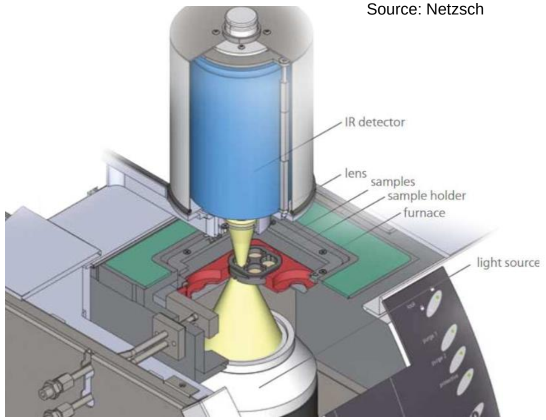


Source: Netzsch

Thermal Conductivity – Devices

Netzsch LFA 467

Source: Netzsch

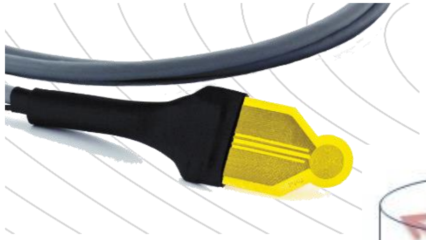


TA Instruments DTC 300

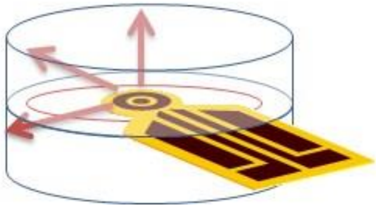
Source: TA Instruments

HotDisk TPS 2500S

Source: HotDisk AB



Source: HotDisk AB



Thermal Conductivity – Devices

	Netzsch LFA 467	DTC 300	HotDisk TPS 2500S
Temperature range	-100°C - 500°C	20°C - 300°C	20°C - 400°C
Specimen size	6 mm - 25.4 mm diameter 0.01 mm - 6 mm thickness	50 mm diameter > 1 mm to 25 mm thickness	> 10 mm diameter > 4mm thickness
Time per measurement	approx. 1s	10-30 min	1 to 2560 sec
Therm. Cond. Range	> 0.1 - 4000 W/(mK)	0.1 - 40 W/(mK)	0.005 - 1800 W/m/K.

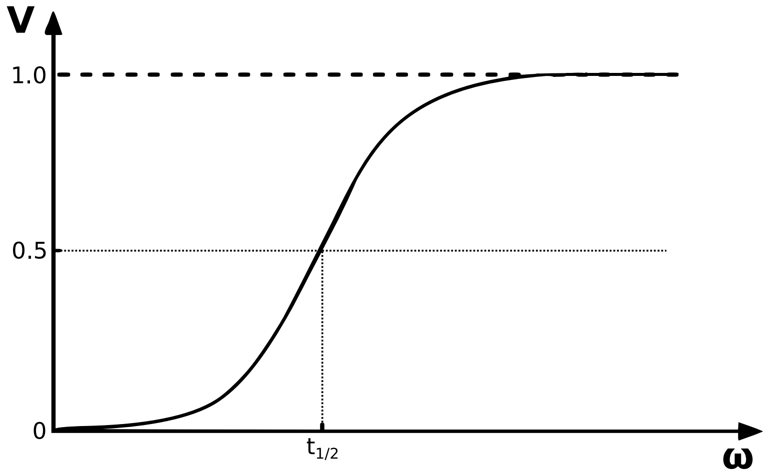
Source: Netzsch

Source: TA Instruments

Source: HotDisk AB

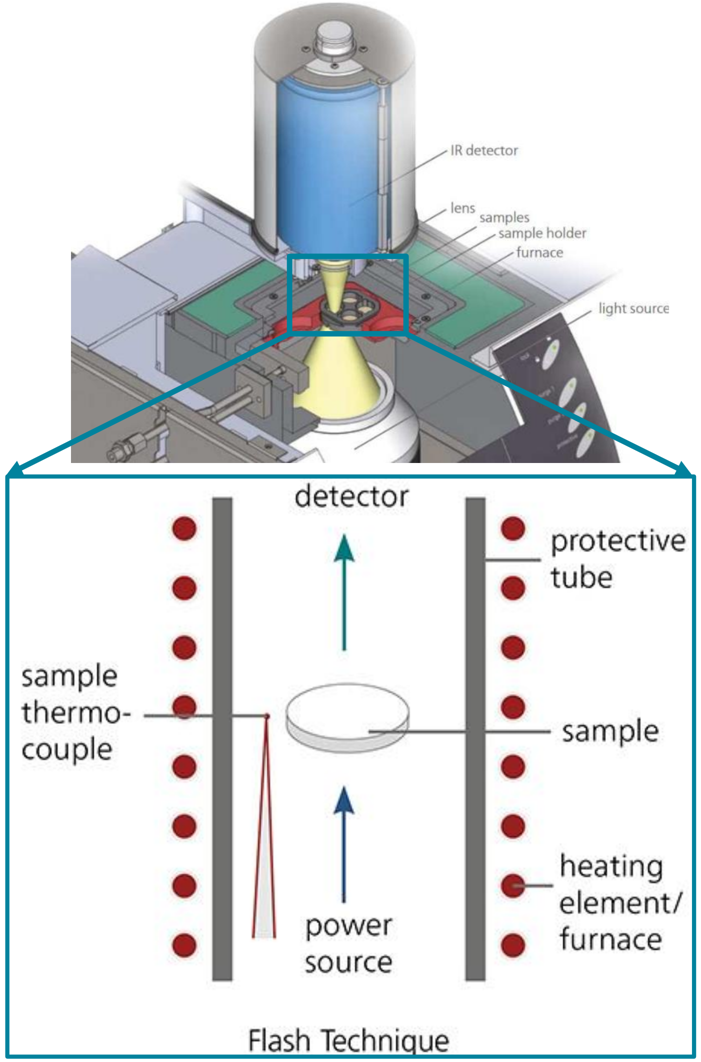
Thermal Conductivity – Laser Flash Analysis

- LFA is transient contactless method for the measurement of the thermal diffusivity *a(T)*.
- A short uniform heat pulse heats up the front surface of a plane-parallel specimen.
- At the rear side of the specimen an infrared detector is placed, which measures the temperature rise over time.
- Wide temperature and thermal diffusivity range as well as capability to measure thin (>10 µm) samples.



$$a = 0.1388 \frac{d^2}{t_{1/2}}$$

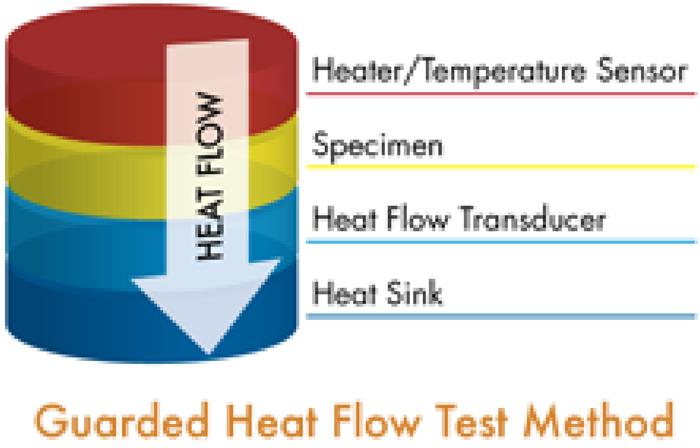
$$\lambda(T) = a(T) c_p(T) \rho(T)$$



Source: Netzsch

Thermal Conductivity – Guarded Heat Flow Meter

- TA Instruments Guarded Heat Flow Meter DTC300
- Stationary and direct method
- Limitied temperature range and precise sample dimensions necessary
- Using a steady heat flow for the determination of the thermal conductivity.
- Evaluation using Fourier's law: $\lambda = \frac{\dot{Q}d}{A\Delta T}$
-



Source: TA Instruments

Specimen

Ø = 50mm

d ≥ 1mm

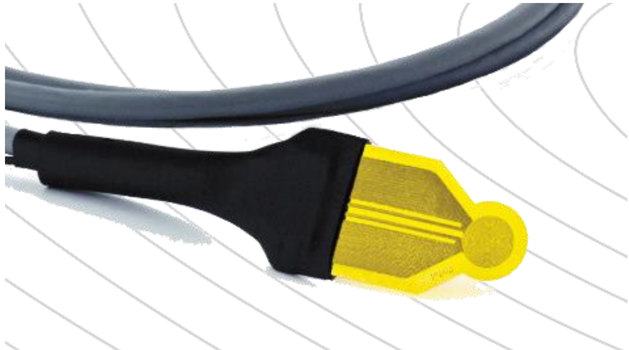
Testing Chamber

Source: TA Instruments

Thermal Conductivity – HotDisk Thermal Constants Analyzer

- Hot Disk TPS 2500S Thermal Constants Analyzer
- Transient method which determines the thermal conductivity directly.
- Relying on the Transient Plane Source (TPS) method.
- Limited temperature range, however best method for low conducting insulation materials.
- Two different measurement modes:
  - Isotropic measurement (λ)
  - Anisotropic measurement(λ_{suf}, λ_{thick})
    - ρ(T) and c_p(T) need to be known

Quelle: HotDisk AB

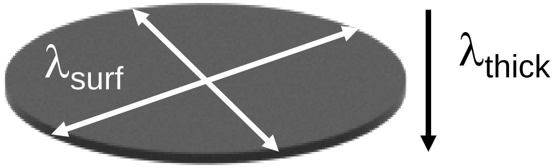


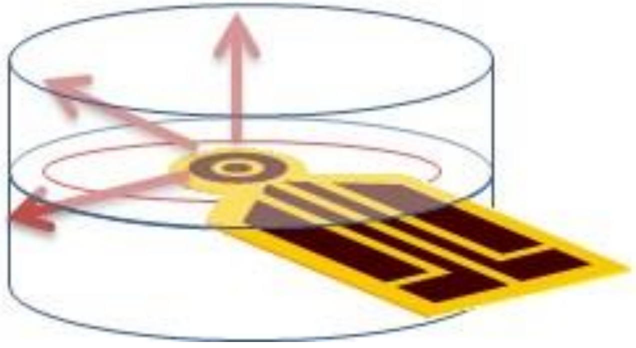
Quelle: HotDisk AB

Specimen

Ø ≥ 10mm

d ≥ 4mm





Quelle: HotDisk AB

Thermal Conductivity – Technique Comparison

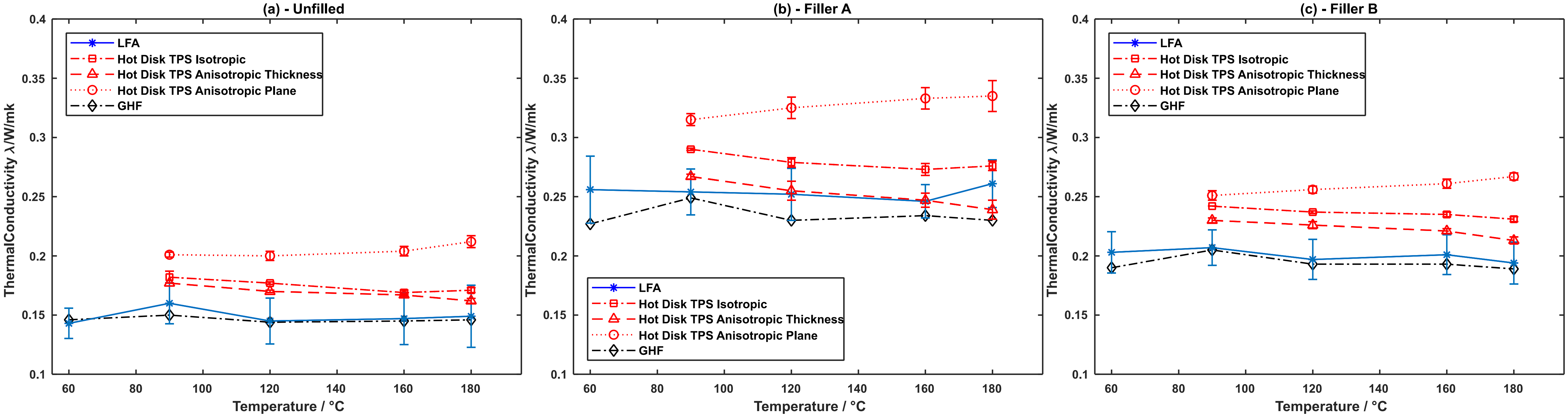
PCCL
Polymer Competence Center Leoben

- Often challenging task with polymers to define thermal conductivity.
- Material understanding required to use appropriate testing method.

Source: Netzsch

Source: HotDisk AB

Source: TA Instruments



Gschwandl ,M., et al. (2019). *Thermal conductivity measurement of industrial rubber compounds using laser flash analysis: Applicability, comparison and evaluation,* AIP Conference Proceedings 2065, 030041 (2019); https://doi.org/10.1063/1.5088299

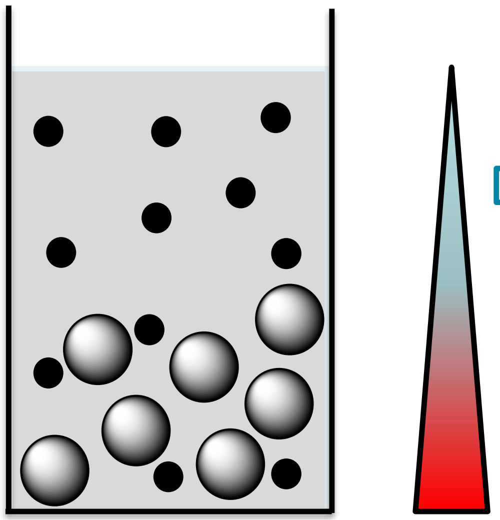
Thermal Conductivity – Gradient Composites

PCCL
Polymer Competence Center Leoben

Economic Aspects:

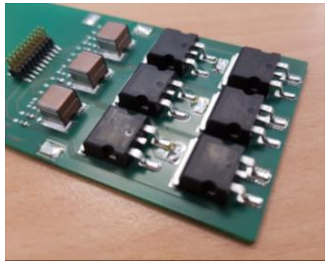
- High Thermal Conductivity where the heat is produced.
- Reduction of the overall filler content.
- **Cost reduction.**

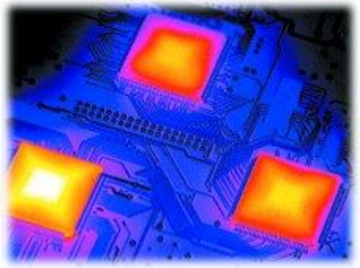
Application Example Gradient Composites

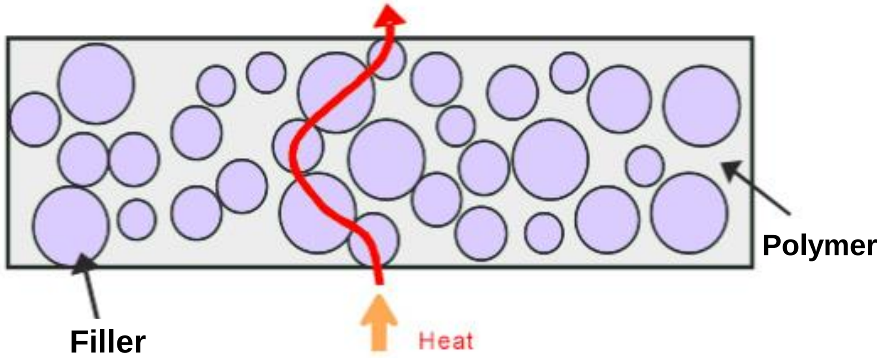


Scientific Aspects:

- Some particles are only commercially available in the micrometer range (e.g. hBN)
- Nanoparticles tend to agglomerate
- **Comparison of the heat dissipation in gradient and homogeneous materials**



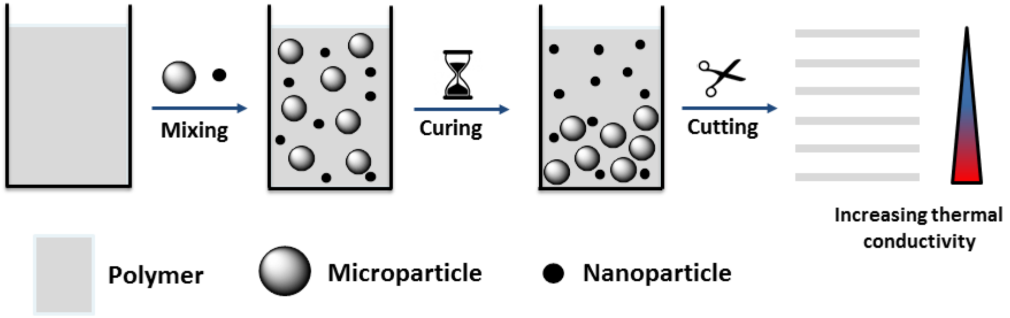




Experimental Details

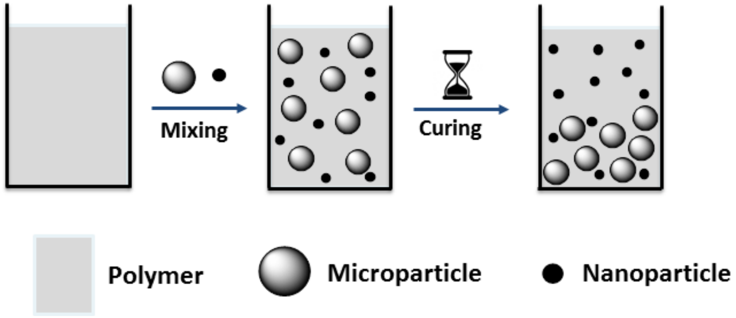
1. Thinly sliced samples were tested using the Laser Flash Analysis and Differential Scanning Calorimetry.

[1]



Source: Netzsch

2. Entire specimen was tested using the Guarded Heat Flow Meter for a homogenized thermal conductivity.



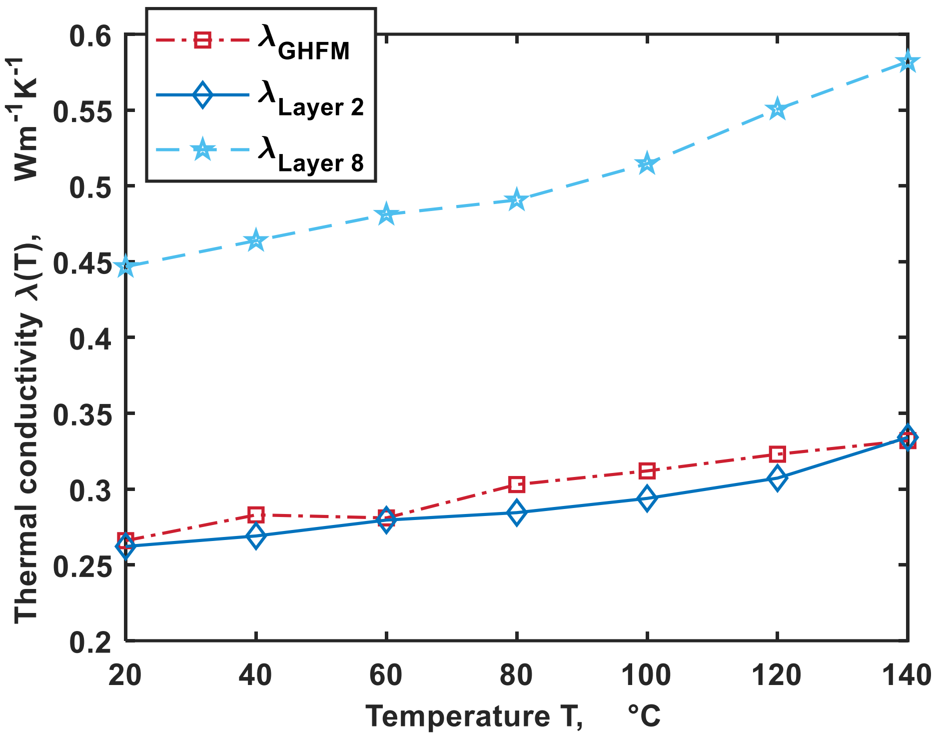
Source: TA Instruments

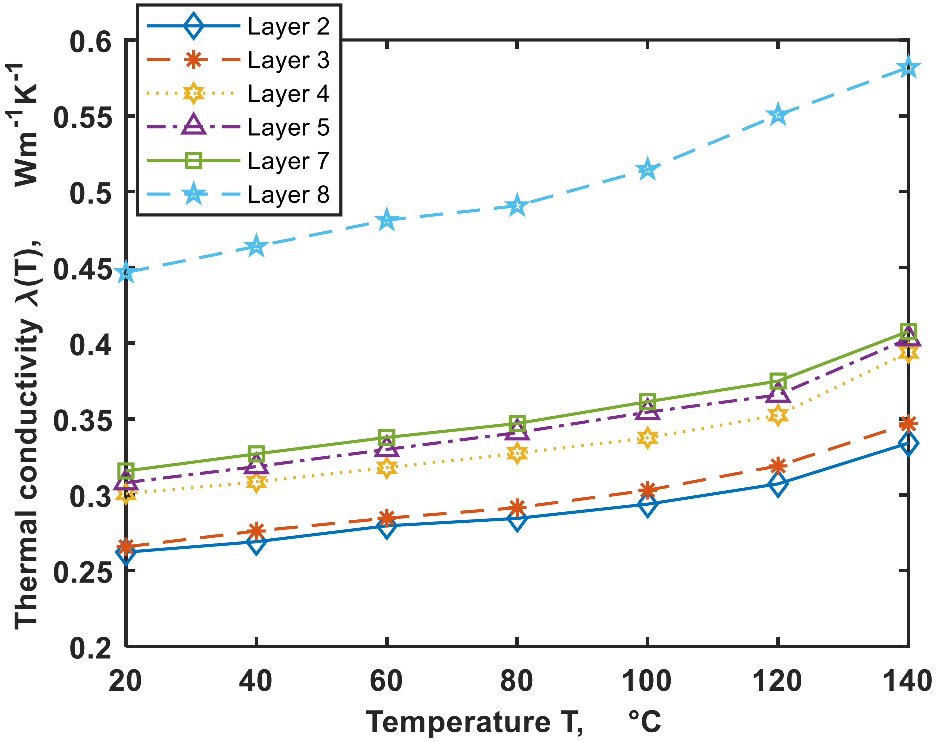
Morak ,M., et al. (2018). *Heat Dissipation in Epoxy/Amine-Based Gradient Composites with Alumina Particles: A Critical Evaluation of Thermal Conductivity Polymers 2018, Vol. 10 (10), p 1131, DOI: 10.3390/polym10101131*

Thermal Conductivity – Gradient Composites (III)

- Thermal conductivity for bulk material of 0.25 $Wm^{-1}K^{-1}$
- GHFM result slightly elevated to lowest result of LFA layer by layer measurement
- Verifies that the bulk thermal conductivity of an gradient material is limited by the lowest thermal conductivity present

Morak ,M., et al. (2018). *Heat Dissipation in Epoxy/Amine-Based Gradient Composites with Alumina Particles: A Critical Evaluation of Thermal Conductivity Polymers 2018, Vol. 10 (10), p 1131, DOI: 10.3390/polym10101131*



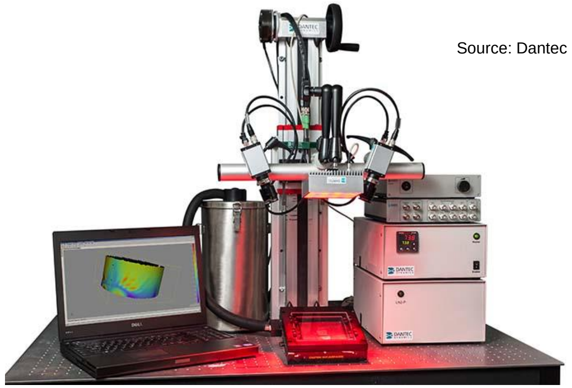


Thermal Expansion

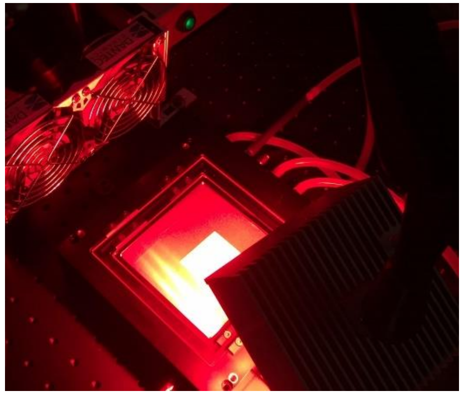
Thermal Expansion – Devices

PCCL
Polymer Competence Center Leoben

Dantec Q400 System

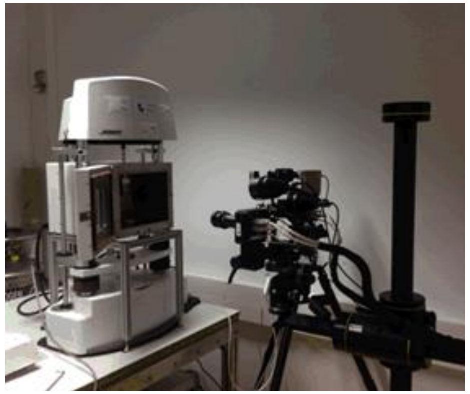


Source: Dantec



Aramis 4M System

Source: GOM



Thermo-Mechanical-Analysis

Source: Mettler Toledo

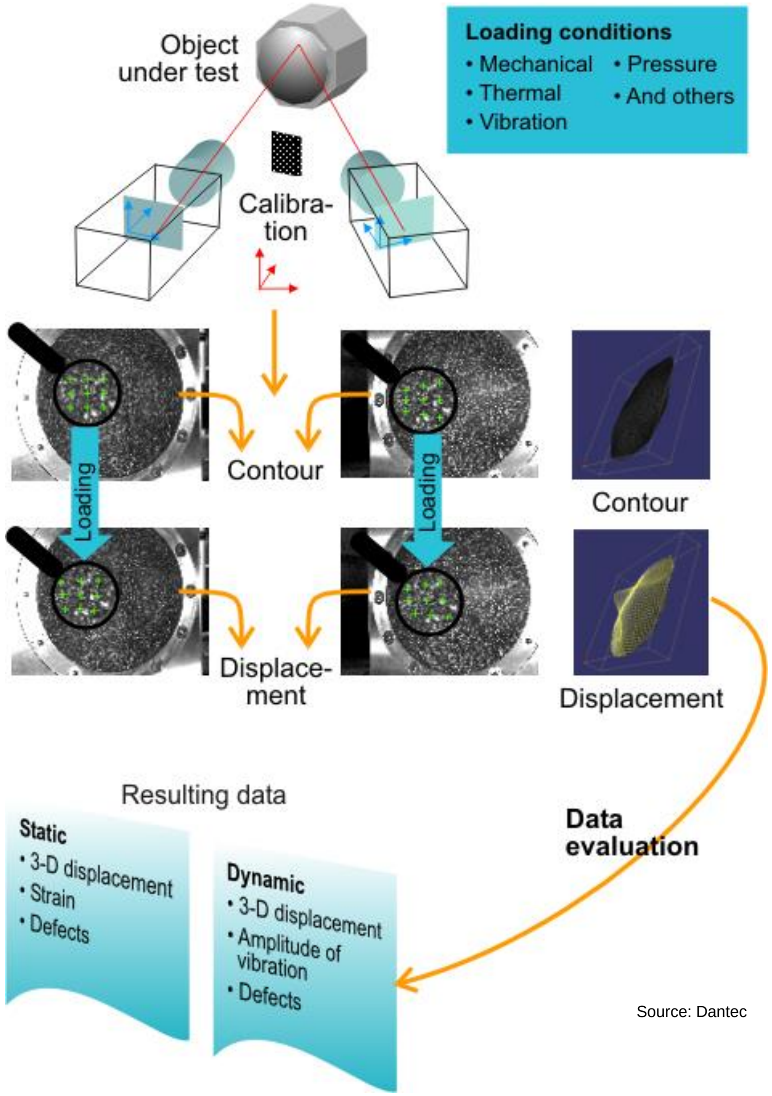
Thermal Expansion – Digital Image Correlation

Measuring Principle

- Using stereoscopic sensors (camera) setup each object point is converted into the pixel spaces of images.
- Knowing the imaging parameters and orientation of the cameras each object point can be calculated.
- Using a stochastic speckle pattern on the object surface, the position of each object can be tracked.

Displacement measurement

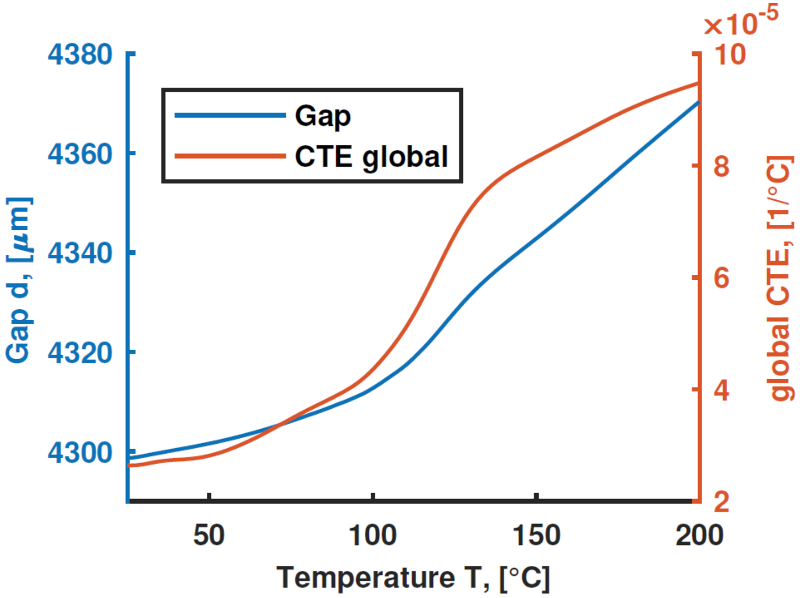
- Calculating the transformation parameters for images under different loading conditions the displacement & strain vector is determined.



Source: Dantec

Thermal Expansion – Thermo-Mechanical-Analysis

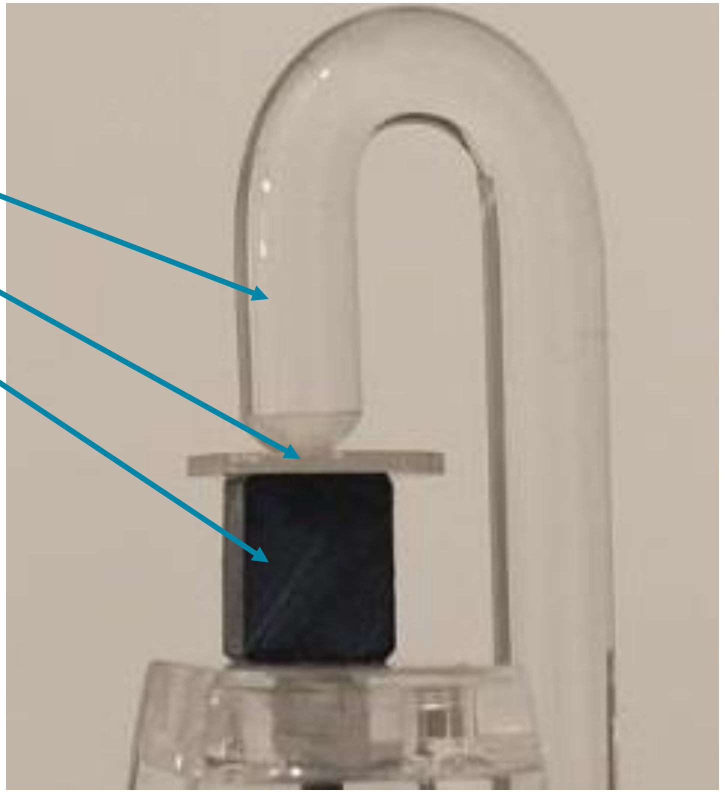
- During the measurement the change of the sample length is measured constantly over the temperature rise. For smooth contact between indenter and specimen a thin glass plate is inserted.



Indenter

Glass plate

Specimen



Thermal Expansion – Technique Comparison

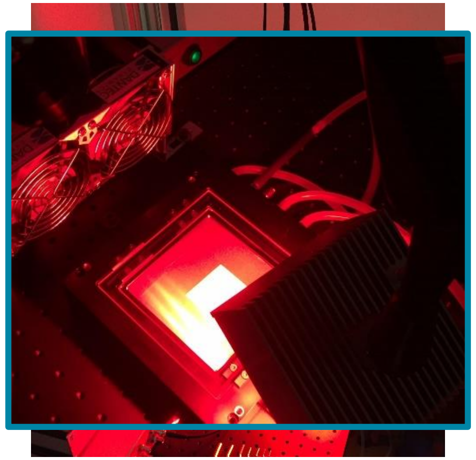
Test Parameters

Parameters	Aramis 4M	Dantec Q400	TMA
Samples resin	1	2	2
Samples FR4	2	2	-
Temperature	30°-230°C	30°-230°C	50°-230°C
Heating rate	2 K/min	1 K/min	5 K/min

Materials

- *Anisotropic* FR4-Prepreg
- Corresponding *isotropic* epoxy resin

Aramis 4M System



Dantec Q400 System

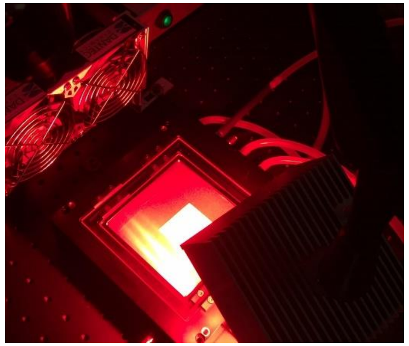
TMA

Thermal Expansion – Technique Comparison (II)

PCCL
Polymer Competence Center Leoben

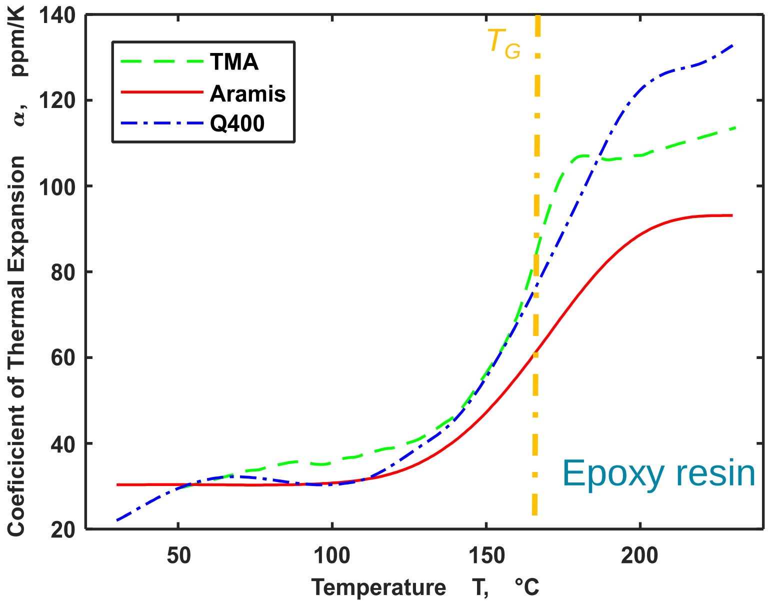
- Comparison of two DIC systems
- Isotropic resin referenced with TMA
- DIC for anisotropic thermal expansion of reinforced materials.
- Significant deviations between all systems after T_G

Dantec Q400



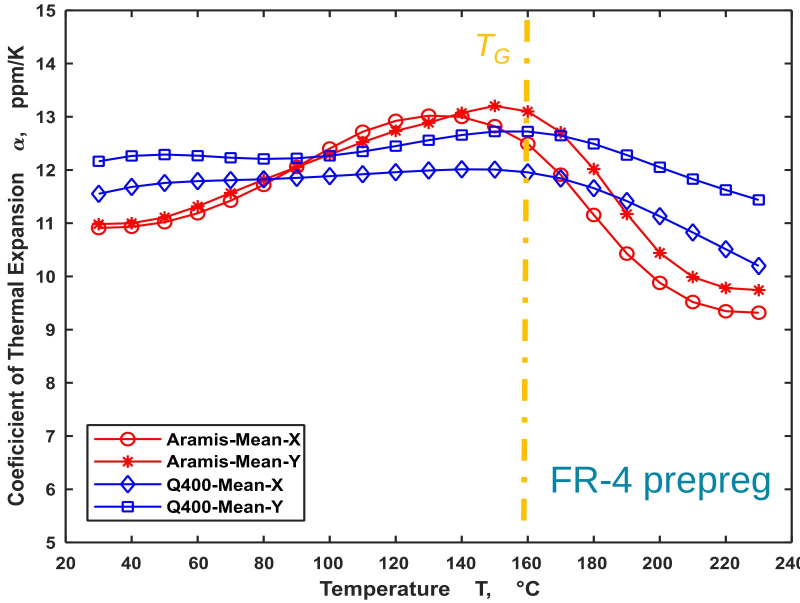
Aramis 4M

TMA



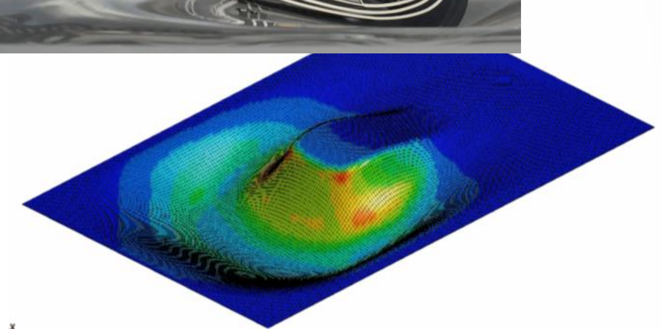
T_G = 160°C

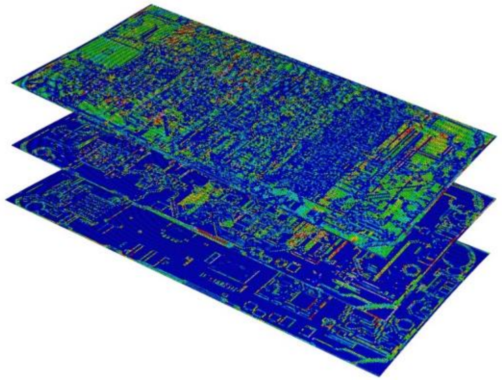
M. Gschwandl et al. "Evaluation of Digital Image Correlation Techniques for the Determination of Coefficients of Thermal Expansion for Thin Reinforced Polymers." 2019, *2018 20th* International Conference on Electronic Materials and Packaging
doi:10.1109/EMAP.2018.8660763

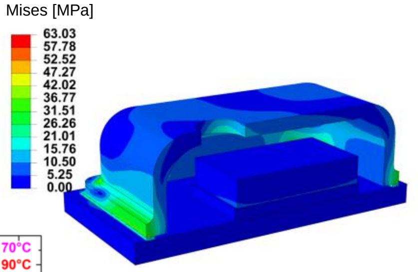


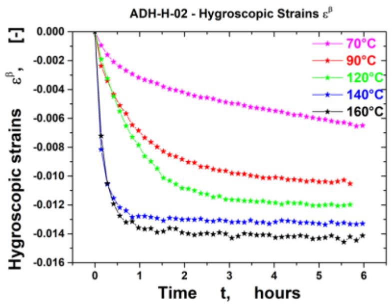
Application Examples

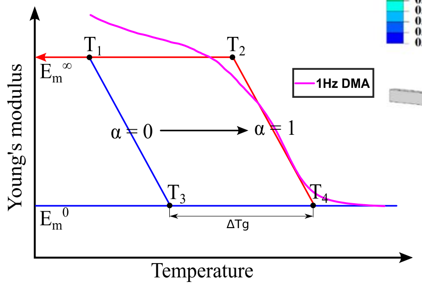
Application Examples

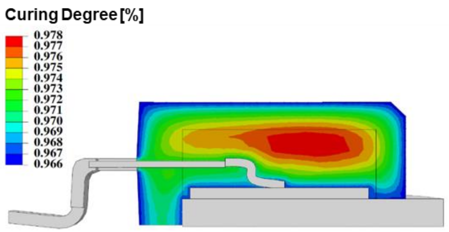


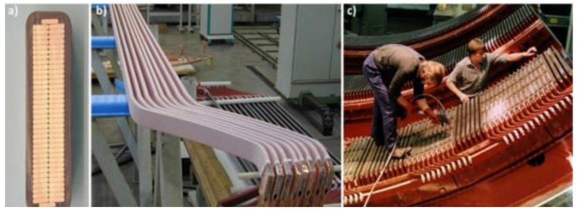


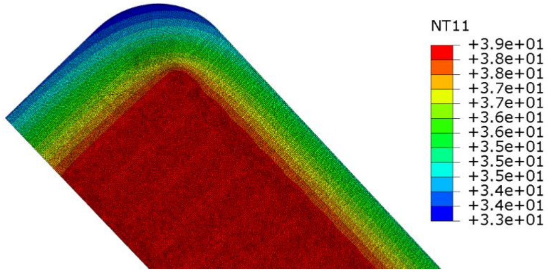


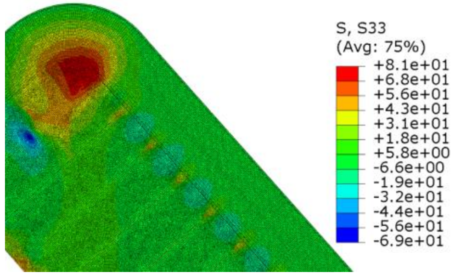












Polymeric Issues? Contact us

Polymer Competence Center Leoben GmbH

Division Simulation and Modeling

„Computation Expertise Meets Polymer Science“

Mario Gschwandl

mario.gschwandl@pccl.at