A353

Thermomechanical Analyzer (TMA)

Thermomechanical Analyzer, TA Instruments, Q400

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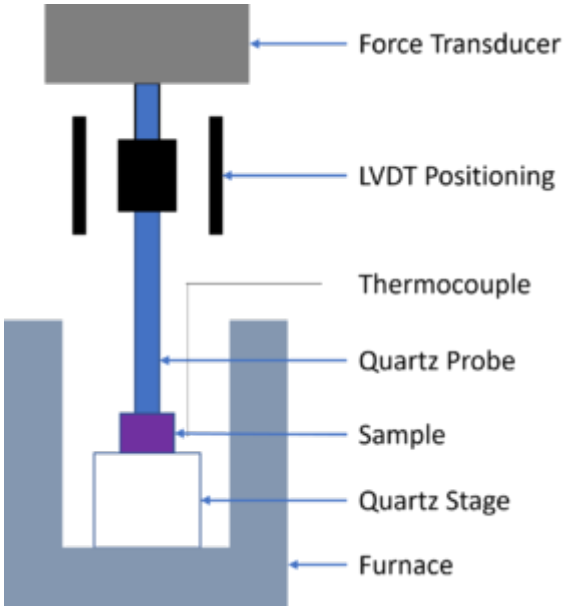
Factory Cells	• Test lab

Introduction[edit | edit source]

Thermomechanical analysis (TMA) involves monitoring the changes in dimension of a sample as the temperature is changed. It is commonly used to determine the coefficient of thermal expansion (CTE) and glass transition temperature (Tg) of a material. The dimension of the sample is monitored and presented as a function of time or temperature at atmospheric pressure[1].

Features[edit | edit source]



Internal features of a typical TMA.


Film tensile clamp for the TMA

A TMA instrument can typically heat samples up to 1000°C and cool to -150°C depending on the make and model. The sensitivity of the instrument is typically in the nanometer scale, for example, TA instruments TMA 450 has a sensitivity of 15 nm[2].

There are a variety of TMA instrument providers and models available on the market, but they all follow the same basic construction. A sample is placed on a stage inside of a moveable furnace, with a probe touching the sample. The probe is connected to a force transducer, usually some form of linear motor, with an LVDT position transformer to monitor the change in position of the probe as the sample expands/contracts. For position monitoring, optical and mechanical transducers are sometimes also used rather than an LVDT. The probe and the stage touching the sample are made from quartz due to its extremely low coefficient of thermal expansion and low thermal conductivity to separate the position monitoring form the instrument. The instrument is calibrated for the thermal expansion of the quartz. A thermocouple in close proximity to the sample is used to monitor the temperature[1].

The inside of the furnace is purged with a gas flowing in laminar flow to prevent turbulence in the air during temperature changes. The gas is also used to prevent degradation products from settling in the furnace, inert gas is used to prevent oxidation and the flowing gas increases the heat transfer into the sample. For high heat transfer into the sample helium is often used instead of nitrogen because of the relatively high thermal conductivity of the gas.

There are various fixtures that can be used in a TMA to support different sample geometries. A common sample is a cube of roughly 10x10x10mm, the cube will sit on a quartz stage with a probe

on top of it applying a very small load (0.05N). There are also tension fixtures for thin films that grip the sample and apply a small tensile load. Lastly, there are submersion fixtures for testing the volumetric expansion of samples.

Uses and Test Types[edit | edit source]

The primary use of a TMA is to determine the coefficient of linear thermal expansion (CTE or CLTE). A TMA will output a plot of temperature vs dimension change, the linear region of these plots can be used to determine the CTE in that temperature range. The CTE, α, is the slope of $\frac{\Delta L}{\Delta T}$ relative to the initial length of the sample L_0[3].

$$\alpha=\frac{1}{L_0}\left(\frac{\Delta L}{\Delta T}\right)$$

For composites it is important to keep in mind that the linear thermal expansion may be different in the x, y and z direction depending on the fibre orientation.

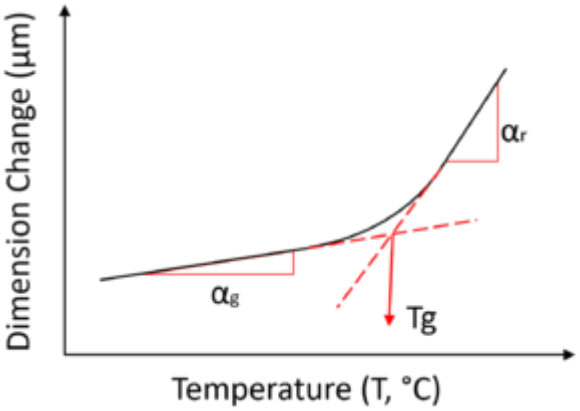
Another common use for a TMA is to determine the Tg of a polymer. The Tg is defined as the temperature where the free volume increases and there is a change in the rate of dimension change in the sample. A polymer that is above the Tg has much more degrees of freedom in the molecular chains and the CTE is higher and similar to that of a liquid[4]. To read more about Tg, see Glass transition temperature (Tg).

Some other properties that can be determined by the TMA are[1]:

- Creep – The TMA is capable of applying a constant stress on a sample and by monitoring temperature and deformation over time, a creep compliance can be determined.
- Stress relaxation – Applying a constant strain and monitoring the stress will allow the stress relaxation modulus to be established.
- Young's modulus – The slope of the stress-strain curve can be determined for small strains and stresses on a material.
- Softening point and heat deflection temperature – using a penetration probe, these temperatures are determined by when the probe sinks a certain amount into the sample.
- Hard-core volume/incompressible volume – The volume at 0K can be extrapolated by using free-volume calculations.

Analysis of Results[edit | edit source]

See figure for idealized results of a simple TMA test. There are two CTEs indicated, $\alpha_g$and α_r, g representing the glassy state CTE and r for the rubbery state. Where the slope will be used to determine the two different CTEs. As well as a Tg, determined by the intersection of the extrapolated linear regions. This shows the change in the material form where the molecular chains have more freedom to move in the rubbery state and thus increasing the size of the sample much more rapidly.



Ideal results from a TMA test of a polymer, showing two CTEs and the Tg at the inflection point.

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Case Studies	
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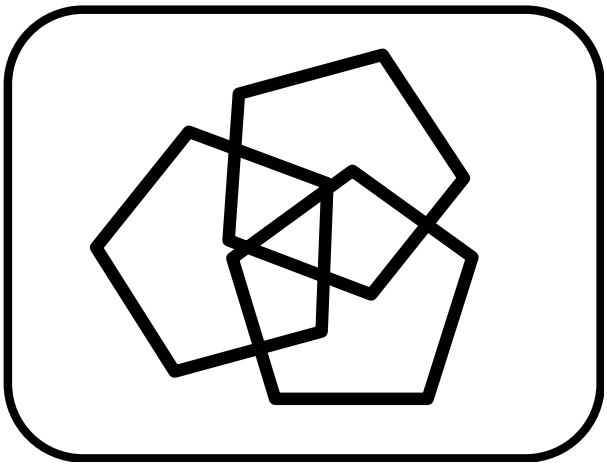
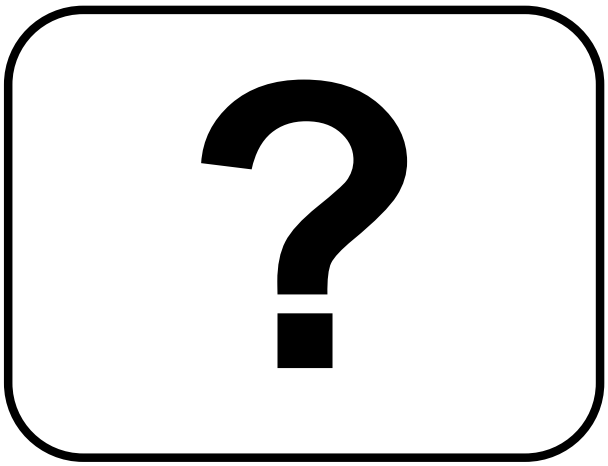
References

1. ↑ [1.0] [1.1] [1.2] [Ref] Menczel, Joseph D.; Prime, R. Bruce (2009). *Thermal Analysis of Polymers: Fundamentals and Applications*. John Wiley & Sons, Inc.
2. ↑ [Ref] TA Instruments (2021). Discovery TMA Brochure (PDF) (Report). Retrieved 23 October 2023.

3. ↑ [Ref] Cassel, Bruce; Menard, Kevin (2013). Coefficient of Thermal Expansion Measurement using the TMA 4000 (PDF) (Report). Retrieved 23 October 2023.
4. ↑ [Ref] Menard, Kevin; Cassel, Bruce (2013). Basics of Thermomechanical Analysis with TMA 4000 (PDF) (Report). Retrieved 23 October 2023.



About



Help

The glass transition temperature (T_g) is the temperature region where the polymer transitions from a hard, glassy material to a soft, rubbery material. It is one of the most important properties of any amorphous polymer.