MSE310 Lecture 5

Thermomechanical Analysis (TMA)

Recap: TGA measures weight change of a sample over a temperature range, **DSC** measures heat flow of a sample over a temperature range, and **DTA** measures heat **differences between** a reference sample and a sample of interest over a temperature range.

DSC measures the energy required to keep both the reference and the sample at the same temperature whereas **DTA** measures the **difference** in temperature **between** the sample and the reference when the same amount of energy has been introduced into both.

Thermomechanical Analysis (TMA)

Thermomechanical Analysis (TMA) studies the dimensional change of a material over a predefined temperature segment. TMA applies a stress to a material and the resulting strain is measured while the material is subjected to a controlled temperature program.

Principle of Thermomechanical Analysis (TMA)

A technique in which a deformation of the sample under non-oscillating stress is monitored against time or temperature while the temperature of the sample, in a specified atmosphere, is programmed. The stress may be compression, tension, flexure or torsion.

Description of TMA

Figure1 shows the Block Diagram of a TMA.

The sample is inserted into the furnace and is touched by the probe which is connected with the Length Detector and the Force Generator. The thermocouple for temperature measurement is located near the sample.

The sample temperature is changed in the furnace by applying the force onto the sample from the Force Generator via probe.

The sample deformation such as Thermal Expansion and Softening with changing temperature is measured as the probe displacement by the Length Detector. Linear Variable Differential Transformer (LVDT) is used for Length Detection sensor.

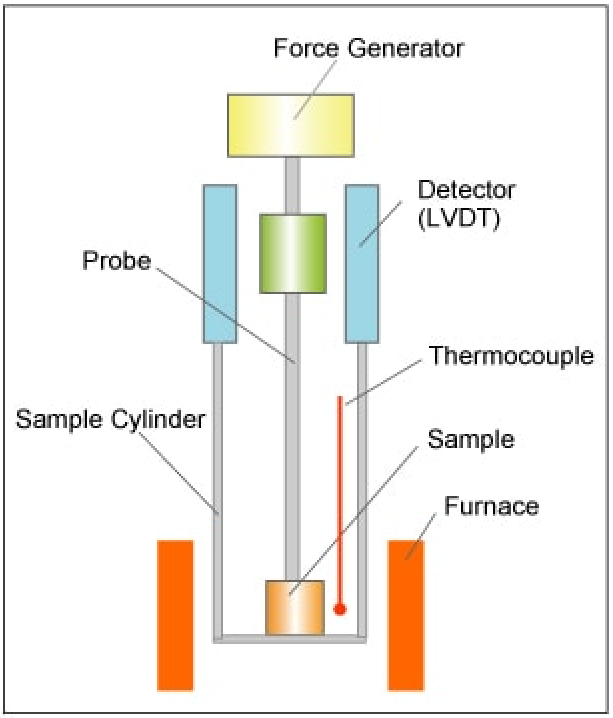

Figure 1. Block diagram of TMA

There are several types of the probe for TMA. The choice is dependent on the measurement purpose.

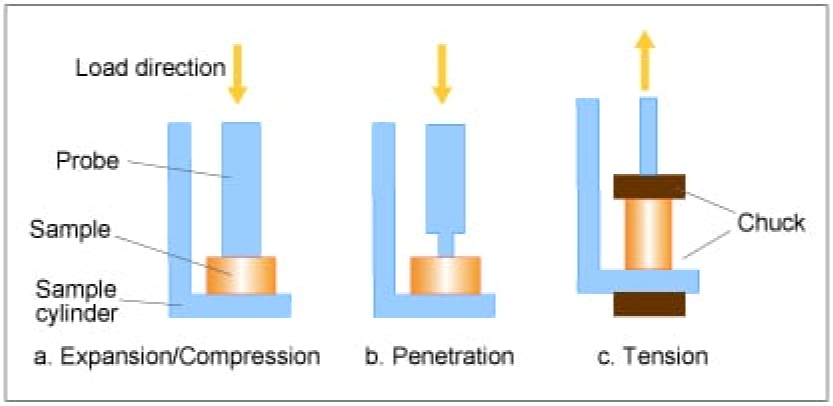

Figure 2. TMA Probe types

(a) Expansion/Compression Probe:
It is used for the measurement of the deformation by the thermal expansion and the transition of the sample under the compressed force is applied.

(b) Penetration Probe:
It is used for the measurement of the softening temperature.

(c) Tension Probe:
It is used for the measurement of the thermal expansion and the thermal shrinkage of the sample such as the film and the fiber.

The materials of probes are quartz glass, alumina, and metals. The choice is dependent on the temperature range and/or the measurement purpose.

In case of the TMA which enables the dynamic force control on top of the static force control, the measurement of the Stress-Strain, the Creep, the stress relaxation, and the DMA measurements can be performed.

Thermomechanical analysis is a method of thermal analysis mainly used to measure the thermal expansion coefficients (CTE) and is thus closely related to dilatometry.

The dilatometry measures the expansion under neglectible load and the thermomechanical analysis measures under controlled load. The displacement of the **pushrod** in contact with the sample is measured as a function of temperature.

Using higher forces and/or pushrods with a tip (penetration pushrod) the softening of samples can be investigated. This is useful for measurement of the glass transition temperature (Tg) of polymers.

Thermomechanical analysis is much more sensitive than the often used differential scanning calorimetry (DSC). Sensitivity can be increased by using oscillating forces (e.g. sinusoidal, triangular, rectangular) resulting in a oscillating response signal.

Coefficient of Linear Thermal Expansion

When a material is heated the distance between individual atoms will change. For most materials the atoms get, on average, further apart (although there are some exceptions. Since the change is the same for all atoms, the total length change depends on how many atoms are in the length. This makes the length change proportional to length. Also, for small changes in temperature the length change is proportional to the temperature change. The constant of proportionality is called the coefficient of thermal expansion, denoted by the Greek letter alpha (α). This coefficient is not really constant over large temperature ranges

Under the effects of increasing temperature any material will expand. This can lead to significant changes in dimensions.

The Coefficient of Linear Thermal Expansion (CLTE often referred to as "α") is a material property which characterizes the ability of a plastic to expand under the effect of temperature elevation. It tells you how much the developed part will remain dimensionally stable under temperature variations.

The linear coefficient 'CLTE or α' for plastic and polymer materials is calculated as:

$$\boldsymbol{\alpha = \Delta L / (L_0 * \Delta T)}$$

Where:

- α is coefficient of linear thermal expansion per degree Celsius
- ΔL is change in length of test specimen due to heating or to cooling
- L_0 is the original length of specimen at room temperature
- ΔT is temperature change, °C, during test

Therefore, α is obtained by dividing the linear expansion per unit length by the change in temperature. *When reporting the mean coefficient of thermal expansion, the temperature ranges must be specified.*

How to Measure Coefficient of Linear Thermal Expansion?

The main techniques used for CTE measurements are:

- Dilatometry
- Thermomechanical analysis

Dilatometry Technique

It is the widely used technique in which specimen is heated in a furnace and displacement of the ends of the specimen are transmitted to a sensor by means of push rod. Push rods may be of the vitreous silica type, the high-purity alumina type, or the isotropic graphite type.

Thermomechanical Analysis (TMA)

The measurements are made using a thermomechanical analyzer consisting of a specimen holder and a probe that transmits changes in length to a transducer that translates movements of the probe into an electrical signal.