## MSE 310 Lecture 6

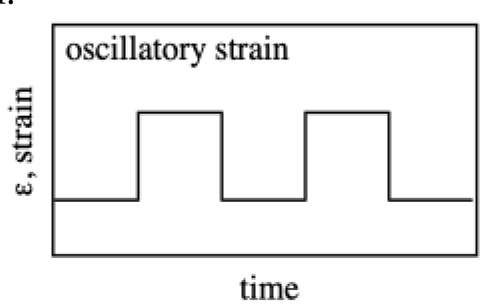
### Dynamic mechanical analysis

**Dynamic mechanical analysis** (abbreviated **DMA**, also known as **dynamic mechanical spectroscopy**) is a technique used to study and characterize materials. It is most useful for studying the viscoelastic behavior of polymers. A sinusoidal stress is applied and the strain in the material is measured, allowing one to determine the complex modulus. The temperature of the sample or the frequency of the stress are often varied, leading to variations in the complex modulus; this approach can be used to locate the glass transition temperature of the material, as well as to identify transitions corresponding to other molecular motions.

DMA, is a technique where a small deformation is applied to a sample in a cyclic manner. This allows the materials response to stress, temperature, frequency and other values to be studied.

The term is also used to refer to the analyzer that performs the test. DMA is also called DMTA for Dynamic Mechanical Thermal Analysis.

In the experiments we saw earlier if we continued to stretch the material farther and farther, increasing stress until the material finally broke. Now we will look at a much more limited approach. Instead of stretching the material as far as we can, we will only stretch it a tiny bit, then release the stress so that it snaps back to its original length. We can then stress it again and release it again. We can keep repeating. Instead of a continuously increasing strain, this sample is subjected to an oscillatory strain, one that repeats in a cycle. This approach is called dynamic mechanical analysis. We can use dynamic mechanical analysis to measure the modulus of the material.



Polymers display a little of both properties. They have an elastic element, rooted in entanglement, that makes them resist deformation and return to their original shapes. They also have a viscous element, rooted in chain flow. That viscous element means that, when we distort polymeric materials, they might not return to exactly the same form as when they started out. Taken together, these behaviors are described as viscoelastic properties. Many materials have viscoelastic properties, meaning they display some aspects of elastic solids and some aspects of viscous liquids.

**Theory**

**Viscoelastic properties of materials**

Polymers composed of long molecular chains have unique viscoelastic properties, which combine the characteristics of elastic solids and Newtonian fluids. The classical theory of elasticity describes the mechanical properties of elastic solid where stress is proportional to strain in small deformations. Such response of stress is independent of strain rate. The classical theory of hydrodynamics describes the properties of viscous fluid, for which the response of stress is dependent on strain rate. This solidlike and liquidlike behavior of polymer can be modeled mechanically with combinations of springs and dashpots.

**Dynamic moduli of polymers**

The viscoelastic property of a polymer is studied by dynamic mechanical analysis where a sinusoidal force (stress σ) is applied to a material and the resulting displacement (strain) is measured. For a perfectly elastic solid, the resulting strain and the stress will be perfectly in phase. For a purely viscous fluid, there will be a 90 degree phase lag of strain with respect to stress. Viscoelastic polymers have the characteristics in between where some phase lag will occur during DMA tests.When the strain is applied and the stress lags behind, the following equations hold:

- Stress: $\sigma = \sigma_0 \sin(t\omega + \delta)$
- Strain: $\varepsilon = \varepsilon_0 \sin(t\omega)$

Where ω is frequency of strain oscillation, t is time, $\delta$ is phase lag between stress and strain.

The storage modulus measures the stored energy, representing the elastic portion, and the loss modulus measures the energy dissipated as heat, representing the viscous portion. The tensile storage and loss moduli are defined as follows:

- Storage Modulus: $E' = \frac{\sigma_0}{\varepsilon_0} \cos\delta$
- Loss Modulus: $E'' = \frac{\sigma_0}{\varepsilon_0} \sin\delta$
- Phase Angle: $\delta = \arctan\frac{E''}{E'}$

**Instrumentation**

The instrumentation of a DMA consists of a displacement sensor such as a linear variable differential transformer, which measures a change in voltage as a result of the instrument probe moving through a magnetic core, a temperature control system or furnace, a drive motor (a linear motor for probe loading which provides load for the applied force), a drive shaft support and guidance system to act as a guide for the force from the motor to the sample, and sample clamps in order to hold the sample being tested. Depending on what is being measured, samples will be prepared and handled differently.

What does DMA measure?

A DMA measures stiffness and damping, these are reported as modulus and tan delta. Because we are applying a sinusoidal force, we can express the modulus as an in-phase component, the storage modulus, and an out of phase component, the loss modulus. The storage modulus, either E' or G', is the measure of the sample's elastic behavior. The ratio of the loss to the storage is the tan delta and is often called damping. It is a measure of the energy dissipation of a material

What is damping?

A Damping is the dissipation of energy in a material under cyclic load. It is a measure of how well a material can get rid of energy and is reported as the tangent of the phase angle. It tells us how good a material will be at absorbing energy. It varies with the state of the material, its temperature, and with the frequency.

Thermomechanical Analysis, or TMA, applies a constant static force to a material and watches the material change as temperature or time varies. It reports dimensional changes. On the other hand, DMA applies an oscillatory force at a set frequency to the sample and reports changes in stiffness and damping. DMA data is used to obtain modulus information while TMA gives coefficient of thermal expansion, or CTE. Both detect transitions, but DMA is much more sensitive.

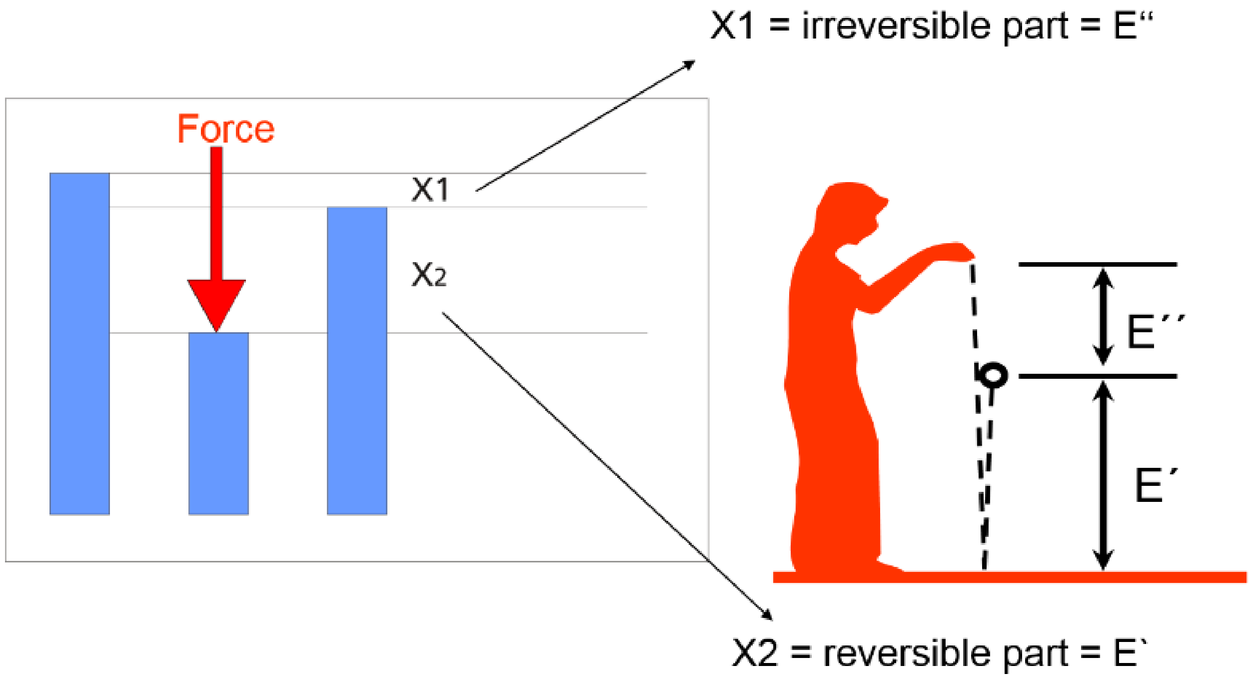
## Applications

### Measuring glass transition temperature

One important application of DMA is measurement of the glass transition temperature of polymers. Amorphous polymers have different glass transition temperatures, above which the material will have rubbery properties instead of glassy behavior and the stiffness of the material will drop dramatically with an increase in viscosity. At the glass transition, the storage modulus decreases dramatically and the loss modulus reaches a maximum. Temperature-sweeping DMA is often used to characterize the glass transition temperature of a material.

## How Do Visco-Elastic Polymers Behave?

The dynamic-mechanical properties of visco-elastic polymer materials are dependent on the operating temperature, the type of oscillating force applied to the sample in a defined deformation mode and the frequency or time of the applied oscillating force. The determined modulus of elasticity of a polymer material is not a constant number, but a function of the temperature, time and frequency of the dynamic force applied to a specimen with a defined geometry.



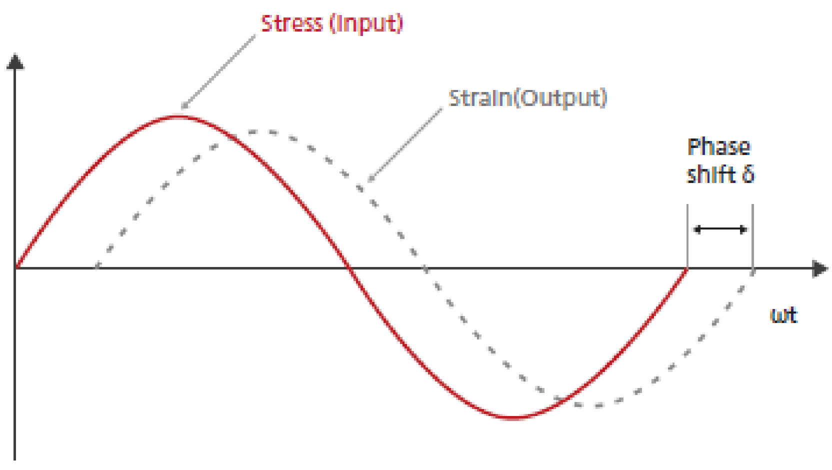

## Method

During the test, a sinusoidal force (stress σ) is applied to the sample (input). This results in a sinusoidal deformation (strain ε; output).

Certain materials, such as polymers, exhibit viscoelastic behavior; i.e., they have both elastic properties (such as an ideal spring) and viscous ones (such as an ideal dashpot). This viscoelastic behavior causes shifting of the corresponding stress and strain curves. The deviation is referred to as the phase shift δ. The response signal (strain, ε) is split into an "in-phase" and an "out-of-phase" part by means of Fourier Transformation.

## Which Materials Can Be Tested?

From viscous liquids, rubber to fiber-reinforced plastics, from food and pharmaceuticals to metals and ceramics – all such materials can be analyzed with DMA by using different sample holders, accessories and measurement modes.




DMA – Measurement principle