Physics of Electronic Polymers

Lecture 5.2:
Overview of Polymer Mechanics

Learning Objectives
By the Conclusion of this Lecture, You Should be Able to:

1. Define what is meant by the stress, strain, viscosity, and modulus of a polymer system. Also, in the appropriate cases relate these terms to one another.

2. Explain what is meant by a Newtonian fluid and what is meant by a linear response in terms of the modulus of a material.

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Polymeric Materials are Viscoelastic in Nature

- A viscoelastic material is one that has properties (e.g., viscosity and modulus) intermediate to that of an elastic material (e.g., typical solids) and a viscous material (e.g., typical liquids).

- Typically, these properties are measured through stress-strain experiments. In a representative example (shown below) a shear strain \( \gamma = \frac{dx}{dz} \) is applied by moving the upper of two parallel plates a distance \( (dx) \) while the material is between the upper and lower plate.

- There will be a certain amount of force required to cause this change in velocity \( (v_x) \), and if this force is divided by a unit area, it is called the stress \( (\sigma) \).

Note that the velocity of the plate in the x-direction is just \( v_x = \frac{dx}{dt} \).

In a similar manner, the strain rate (or stress rate) is just \( \dot{\gamma} = \frac{d(\frac{dx}{dz})}{dt} \).
The Viscosity of a Liquid is Defined as a Proportionality

We can define the viscosity ($\eta$) for a liquid-like material through the following expression.

$$\eta = \frac{\sigma}{\dot{\gamma}} \text{ or } \sigma = \eta \dot{\gamma}$$

If the viscosity of the material is independent of the magnitude of the strain rate, then the fluid is said to exhibit a **Newtonian** response.

Note that many polymers are non-Newtonian in nature, but return to Newtonian behavior as the strain rate approaches zero.
The Modulus of a Solid is Defined as a Proportionality

We can define the modulus ($G$) for a solid-like material through the following expression.

$$G = \frac{\sigma}{\gamma} \text{ or } \sigma = G\gamma$$

Here we are defining this as the shear modulus because of the means by which the response is being evaluated. However, the modulus can be measured in a variety of different geometries that will be important depending on the final end-use application. The general principle is translatable to all of these different geometries.

If the modulus of the material is independent of the magnitude of the strain, then the material is said to have a **linear response**. This response generally applies as the strain goes towards zero.

The **compliance** ($J$) of a material is the ratio of strain to stress, and this is sometimes discussed in polymer science. As shown by the definition, it is the inverse of the modulus for time-independent measurements.
The Meaning of Viscous and Elastic Responses of Materials

• The viscosity is a measure to reflect how energy is dissipated, through friction, by the molecules associated with the material.

• On the other hand, the elastic nature of a material reflects the storage of energy by a material that can be required (e.g., the stretching (and then releasing) of a spring).

• At the molecular level, we can think about each of the polymer chains being an individual spring. At small displacements (i.e., strains) the chains will rearrange and store the energy due to movement of the individual macromolecules. This will occur in an elastic manner.

• As the macromolecular chains relax, they will dissipate the energy (now in a viscous manner) that was stored during the elastic response.

• This balance between the viscous and elastic response makes polymers viscoelastic and useful for a number of mechanical systems.

Next Time: Transient Responses to Stress and Strain