Lecture 27, Mar 31, 2022

Time-Dependent Elastic Behaviour

- For metals and ceramics the stress-strain behaviour is independent of time (when below the yield strength), i.e. elastic response is instantaneous
- Some polymers have *viscous behaviour*: Under the same stress, strain keeps increasing with time, and this process is irreversible
  - This is referred to as *viscous flow*
  - The increase in strain is not necessarily a straight line, could be e.g. exponential decay
- Example: Silly putty (silicone) deforms when strained slowly, but fractures when strained quickly
  - Silly putty bounces without denting, which indicates elastic behaviour
- If we fix the strain and look at the stress (e.g. guitar string), it will slowly decrease
  - This is referred to as *stress relaxation* since length stays fixed but tension decreases
  - The shape resembles a decaying exponential
- Define the *relaxation modulus* $E_R(t) = \dfrac{\sigma(t)}{\varepsilon_0}$
- Stress relaxation behaviour depends on temperature; the warmer the temperature, the faster the stress relaxation
- Consider taking a fixed time t_0 and looking at the temperature dependence of E_R
  - For many polymers, it starts flat, then rapidly decreases, flatten outs again, and then decreases to 0
  - The final decrease is the melting temperature T_m
  - The first decrease happens at T_g, the *glass transition temperature*
    * Below T_g the polymer is brittle
    * Between T_g and T_m, the polymer is in the rubbery region (flexible and maintains shape)
    * Past the melting temperature the polymer exhibits viscous flow
  - The glass transition temperature exists due to crystalline and amorphous regions
    * When temperature above T_g the amorphous regions start breaking up
- Typical T_g values:
  - Polyethylene: 153K
    * PE has low T_g, which means it's flexible at room temperature
  - Polystyrene: 373K
  - PMMA: 378K
    * Acrylic has high T_g which is why it's rigid
  - Nylon: 323K
- Two classes of polymers:
  - Thermoplastics: Can be melted and molded without damaging the polymer
    * Polymer can enter viscous flow region with all the chains flowing past each other
    * Temperature reduces intermolecular forces
    * Cooling restores intermolecular forces again
    * Example: PE, nylon, polystyrene
  - Thermoset polymers: Cannot be melted without damaging the polymer (can't be remolded)
    * These are hardened via cross-linking (aka *curing*, an irreversible process)
    * Example: Epoxy
    * Network polymers don't melt since the strength comes from primary bonds