Mechanical Properties of Biomaterials

Academic Resource Center
Determining Biomaterial Mechanical Properties

- Tensile and Shear properties
- Bending properties
- Time dependent properties
Tensile and Shear properties

- Types of forces that can be applied to material:
  a) Tensile
  b) Compressive
  c) Shear
  d) Torsion
Tensile Testing

- Force applied as tensile, compressive, or shear.
- Parameters measured: **Engineering stress** ($\sigma$) and **Engineering strain** ($\varepsilon$).
- $\sigma = \frac{F}{A_0}$: Force applied perpendicular to the cross section of sample
- $\varepsilon = \frac{l_i-l_0}{l_0}$: $l_0$ is the length of sample before loading, $l_i$ is the length during testing.
Compression Testing

• Performed mainly for biomaterials subjected to compressive forces during operation. E.g. orthopedic implants.
• Stress and strain equations same as for tensile testing except force is taken negative and l0 larger than li.
• Negative stress and strain obtained.
Shear Testing

- Forces parallel to top and bottom faces
- **Shear stress** ($\tau$) = $F/A_0$
- **Shear strain** ($\gamma$) = $\tan\theta$; $\theta$ is the deformation angle.
- In some cases, torsion forces may be applied to sample instead of pure shear.
Elastic Deformation

- Material 1: Ceramics
  - Stress proportional to strain.
  - Governed by Hooke’s law: $\sigma = \varepsilon E; \tau = G\gamma$
  - $E$: Young’s modulus, $G$: Shear modulus - measure of material stiffness.
  - Fracture after applying small values of strain: ceramics are brittle in nature.
Elastic and Plastic deformation.

• Material 2: Metal
• Stress proportional to strain with small strain; **elastic deformation**.
• At high strain, stress increases very slowly with increased strain followed by fracture: **Plastic deformation**.
Elastic and Plastic deformation.

- Material 3: Plastic deformation polymer
- Stress proportional to strain with small strain; elastic deformation.
- At high strain, stress nearly independent of strain, shows slight increase: Plastic deformation.
Elastic and Plastic deformation.

- Material 4: Elastic polymer
- Stress increases very slowly with increasing strain.
- Do not fracture at a very high strain values.
Plastic deformation

- Plastic deformation occurs at point where Hook’s Law is no longer valid, i.e. end of elastic region.
- Stress at this point is called **yield strength** ($\sigma_y$) and strain is called **yield point strain** ($\varepsilon_{yp}$).
- Further stress increases with strain up till a maximum point M, called **Ultimate tensile strength** ($\sigma_{uts}$).
- With further increase in strain, stress decreases leading to **Fracture**.
Engineering vs. True Stress-strain

- True stress ($\sigma_t$) = force divided by instantaneous area
- $\sigma_t = F/A_{\text{in}}$
- True strain $\varepsilon_t = \ln(l/l_0)$
Stages of Plastic Deformation

a) Lamellar and amorphous regions of polymer interact in response to tensile forces.

b) Stage 1: chains extend and lamella slide past each other.

c) Stage 2: Lamella re-orient so that chain folds align along the axis of loading.
Stages of Plastic Deformation

d) Stage 3: Blocks of crystalline phases separate, adjacent lamella still attached to each other through tie molecules.

e) Stage 4: Finally blocks and tie molecules become oriented along the axis of applied tensile forces.
Bending Properties

- Helps in calculation of:
  - Stress required to fracture the sample or **Modulus of Rupture** (also called flexural strength).

\[ \sigma_{mr} = \frac{3Fl}{2bd^2} \]
Time Dependent Properties

- **CREEP**: Defined as plastic deformation of sample under constant load over time.
- Creep at 37 deg C a significant concern for biomedical applications.
  - Failure of Polymer ligaments.
Creep

• Molecular Causes of creep:
  • Metals: Grain boundary movement, vacancy diffusion
  • Ceramics: little or no vacancy diffusion
  • Polymers: viscous response in amorphous regions.
• Creep is function of crystallinity: As % crystallinity increases, creep decreases.
Creep curve

• 3 distinct regions:
  • Primary creep: increase in strain with time; creep rate decreases.
  • Secondary creep: linear relation between creep strain and time.
  • Tertiary creep: Leads to fracture.
QUESTIONS OR SUGGESTIONS?

Contact: BME Table, Academic Resource Center