Lecture 1

August 28, 2003
Syllabus

• **Unique Numbers:** 12095, 12100, 12105

• **Lectures:**  TTh 2 - 3pm (WRW 102)

• **Labs:**  12100: T 3:30 - 6:30pm (WRW 5W)  
               12095: W 3:00 - 6:00pm (WRW 5W)  
               12105: Th 3:30 - 6:30pm (WRW 5W)

• **Objectives:**
  – Learn how to characterize the mechanical properties (elastic, inelastic, fracture, fatigue) of common aerospace materials.
  – To understand the material and environmental factors that affect the behavior of materials.

• **Prerequisites:** EM 319
# Topics and Schedule

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Grading

- 4 formal lab reports (20%)
- 8 regular assignments (32%)
- 2 exams (midterm and final, 24% each)

- Late reports/assignments will be penalized
- Class and lab attendance is required
Textbooks and Lab Manual


• **Lab Manual** by K.M. Liechti (2002)
  – Copies by Sigma Gamma Tau, $8.50

• Any questions?
Engineering materials

• **Metals and alloys**
  – Iron, steel, aluminum alloys
  – Ductile, tough

• **Ceramics**
  – Cement and concrete, ice, diamond, alumina (Al$_2$O$_3$)
  – Brittle, hard, resistant to corrosion and wear

• **Glasses**
  – Silica (SiO$_2$)
  – Similar to ceramics

• **Polymers**
  – Rubber, nylon, epoxy
  – Soft, weak, creeping, light

• **Composites**
  – CFRP, Reinforced concrete, woods
  – Stiff, strong, anisotropic
Aerospace materials

- Metals and metal alloys dominate
- Polymers and composites becoming important
- Ceramics and glasses under developments
Material properties

• **Basic physical properties**
  – Density, melting point

• **Mechanical properties**
  – Elastic modulus, yield strength, fracture toughness

• **Thermal properties**
  – Thermal conductivity, thermal expansion, specific heat

• **Electrical/Magnetic properties**
  – Resistivity, dielectric constants, magnetic permeability

• **Environmental interactions**
  – Corrosion, wear

• **Economic**
  – Price and availability, production

• **Aesthetic**
  – Color, texture
Definition of stress

- Stress = force per unit area
- Normal stress
  - Simple tension/compression
- Shear stress
  - Direct shear, torsion

\[ \sigma = \frac{P}{A} \]

\[ \tau = \frac{V}{A} \]
Definition of strains

- **Normal strain** = elongation per unit length

\[ \varepsilon = \frac{\delta}{L} \]

- **Shear strain** = change of the angle between side faces (perpendicular before deformation)

\[ \gamma = \frac{u}{L} = \tan \theta \approx \theta \]

- **Volumetric strain** (dilatation) = volume change per unit volume

\[ \Delta = \frac{V - V_0}{V_0} \]
Elastic moduli

• Linear elasticity: **Hooke’s law**

• Simple tension/compression

$$\varepsilon = \frac{\sigma}{E} \quad \varepsilon' = -\nu \varepsilon$$

• Pure shear

$$\gamma = \frac{\tau}{G}$$

• Hydrostatic pressure

$$\Delta = -\frac{p}{K}$$

E: Young’s modulus

\(\nu\): Poisson’s ratio

G: Shear modulus

K: bulk modulus
Relations among elastic moduli

- For isotropic materials

\[ G = \frac{E}{2(1+\nu)} \quad K = \frac{E}{3(1-2\nu)} \]  
(Only two independent)

- Most materials are anisotropic, i.e., the elastic moduli are different at different directions. In general, there can be as many as 21 independent elastic moduli for anisotropic materials, depending on the symmetry of the atomic structure.
Physical understanding of elasticity

- Interatomic bonds act like little springs linking neighboring atoms
- Stretching and rotation of the bonds lead to elastic deformation.

![Stretching of an interatomic bond between two atoms](image)
Bond energy and interatomic force

- **Bond energy**
  \[ U(r) = U_A + U_R = -\frac{A}{r^m} + \frac{B}{r^n} \]

- **Interatomic force**
  \[ F(r) = -\frac{dU}{dr} = -\frac{mA}{r^{m+1}} + \frac{nB}{r^{n+1}} \]

- **F = 0 → Equilibrium separation** \( r_0 \)
Theoretical Young’s modulus

- Stiffness of the bond near equilibrium:
  \[ S_0 = \left( \frac{dF}{dr} \right)_{r=r_0} = \frac{m(m+1)A}{r_0^{m+2}} - \frac{n(n+1)B}{r_0^{n+2}} \]
  \[ F(r) \approx S_0 (r - r_0) \]

- Number of atoms per unit area:
  \[ N \approx \frac{1}{r_0^2} \]

- Stress:
  \[ \sigma = NF(r) = \frac{S_0 (r - r_0)}{r_0^2} \]

- Strain:
  \[ \varepsilon = \frac{r - r_0}{r_0} \]

- Young’s modulus:
  \[ E = \frac{\sigma}{\varepsilon} = \frac{S_0}{r_0} \]
Measurement of elastic modulus

- Theoretical analyses provide basic understandings;
- In engineering practices, elastic modulus is measured experimentally.

- Tension/compression tests
- Beam vibration tests
  - Natural frequency $\sim E^{1/2}$
- Acoustic tests
  - Velocity of acoustic wave $\sim E^{1/2}$
Young’s moduli of some materials

- Diamond (C): 1000 GPa
- Tungsten (W): 380-411 GPa
- Alumina (Al₂O₃): 385-392 GPa
- Silicon nitride (Si₃N₄): 280-310 GPa
- Nickel (Ni): 214 GPa
- Iron (Fe): 196 GPa
- **Steels:** 190-210 GPa
- Copper (Cu): 124 GPa
- Silicon (Si): 107 GPa
- Silica glass (SiO₂): 94 GPa
- Gold (Au): 82 GPa
- **Aluminum and alloys (Al):** 69-79 GPa
- Concrete/cement: 30-50 GPa
- Ice: 9.1 GPa
- Nylon: 2-4 GPa
- Rubber: 0.01-0.1 GPa
Nonlinear elasticity

• “Elastic” means no permanent deformation upon unloading

• Stress-strain relation can be either linear or nonlinear (rubber)
  – Difference between the proportional limit and the elastic limit

• Tangential modulus: \( E = \frac{d\sigma}{d\varepsilon} \)
Beyond elasticity

- All solid materials have an elastic limit (in terms of strain or stress)
- Beyond the elastic limit, brittle materials (like ceramics and glasses) will fracture, and ductile materials (like metals) will deform plastically.