ASE324: Aerospace Materials Laboratory

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Lecture 2

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Plasticity

- Irreversible deformation
- Yielding: onset of plastic deformation
- Yield strength or offset yield strength

Plastic strain

\( \sigma_{0.2\%} \)
Perfectly Plastic

- At the yield stress, the solid flows like a liquid.
- No volume change during plastic flow ($\nu = 0.5$).
Strain-hardening

- Further straining (plastically) requires larger stress

Power law hardening

\[ \varepsilon_p = \left( \frac{\sigma}{H} \right)^{1/n} \]

- \( n \): hardening exponent
- \( H \): hardening modulus

\[ \varepsilon_e = \frac{\sigma}{E} \]

\[ \varepsilon = \varepsilon_e + \varepsilon_p \]

\[ \sigma = E \varepsilon_e = H \varepsilon_p^n \]

Material strengthened after plastic deformation!
Tensile tests

• A useful method to determine the elastic and plastic properties of structural materials

• Features
  – Simple, uniform stress state
  – Suitable controlled so as to exhibit the response of the material and not some combined response of the specimen and the loading devices.
  – Automatic data acquisition and recording
Loading devices

- Electromechanical: electric motor drives the crosshead through rotating ball screws
  - Stiff, for slow monotonic loading

- Servohydraulic: a pump drives a fluid in and out of a cylinder to move a piston
  - For monotonic, cyclic, or complex loading
Electromechanical test machine
Servohydraulic test machine

- Load cell
- Grips
- Piston
- Specimen
- Pump
- Servo valve
Measuring components

• Load cell: measuring load (P)
• Extensometer: measuring gage length (L) and diameter (d)
• Data acquisition under computer control
  – Fast data collection results in disk storage problems
  – Slow data collection results in resolution problems
• Convert load-extension to stress-strain
Nominal and true stresses

- Nominal stress:
  \[ \sigma_n = \frac{P}{A_0} \]
  \( A_0 = \) original cross-section area

- True stress:
  \[ \sigma_t = \frac{P}{A} \]
  \( A = \) current cross-section area

- No difference for small strain \((A \sim A_0)\)
Nominal and true strains

- Deformation of the gage section

- Nominal axial strain
  \[ \varepsilon_n = \frac{L - L_0}{L_0} \]

- True axial strain
  \[ \varepsilon_t = \int_{L_0}^{L} \frac{dL}{L} = \ln \frac{L}{L_0} \]

- Transverse strains
  \[ \varepsilon'_n = \frac{d - d_0}{d_0} \quad \varepsilon'_t = \ln \frac{d}{d_0} \]

- No differences for small strain
  \[ \varepsilon_t = \ln(1 + \varepsilon_n) \approx \varepsilon_n \]
Stress-strain diagram

- For most purposes, nominal stresses and strains are used.
- Necking: plastic instability, localized plastic deformation
Measured quantities

- Young’s modulus $E$
- Poisson’s ratio $\nu$
- Yield strength $\sigma_Y$
- Ultimate tensile strength $\sigma_{UTS}$
- Ductility
  - Strain at failure $\varepsilon_f$
  - Area reduction at failure $(A_0 - A_f)/A_0$
Loading control

- Control modes: load or displacement (strain)
- Control history: ramp, step, delta, cyclic
Tensile test: control displacement in a ramp

- Difficult to control load due to yield and necking
Iron and Steels

- Iron: pure metal (Fe)
- Steels: iron-based alloys
  - Mild steel: Fe + C (0.04-0.3 wt%)
  - Cast iron: Fe + C (1.8-4 wt%)
  - Stainless steel: high alloy (C, Mn, Cr, Ni)
  - Tool steel: heavily alloyed (Cr, Mo, W, V, Co)

- Alloying provides a wide range of properties that can be manipulated by composition and heat treatment.
Carbon Steel Production

- Carbon and iron mixed in liquid form
- Poured into a mold to produce a casting known as ingot
- The ingot is “worked” into standard stock (sheet, rod, wire, tube, etc.)
- Stock is then machined into final form
Hot rolled and cold rolled steels

- Material properties depend on production processes.

- Hot rolled steels (HRS): recrystallize after rolling.

- Cold rolled steels (CRS): permanently deformed at room temperature with no recrystallization.
Hot rolled Steel

\[ \sigma \]

\[ \sigma_{UTS} \]

\[ \sigma_{YU} \]

\[ \sigma_{YL} \]

\[ \varepsilon_f \]

Stable necking

Strain hardening

Unstable necking

Fracture

elastic
Cold rolled steel

- Higher strength, but lower ductility

Permanent deformation by cold rolling

Higher strength due to hardening

- Higher strength, but lower ductility
Hardening exponent

- Power law hardening: \( \sigma = E \varepsilon_e = H \varepsilon_p^n \)
Toughness

- Definition: the ability of a material to resist fracture (work per unit volume)

\[ T = \int_{0}^{\varepsilon_f} \sigma d\varepsilon \]
Formal lab report

• Title (separate page)
• Abstract (separate page)
• Introduction
• Experimental and data reduction procedures
• Results and discussions
• Conclusions

• Answer all questions in the Lab Manual!