ASE324: Aerospace Materials Laboratory

Instructor: Rui Huang

Dept of Aerospace Engineering and Engineering Mechanics
The University of Texas at Austin

Fall 2003
Carbon steels

- 4 solid phases:
  - ferrite (α)
  - austenite (γ)
  - δ-iron (δ)
  - cementite (Fe₃C, an intermetallic compound with 6.7% C).

- **Eutectic reaction**: liquid (~4.3%C) → austenite + cementite

- **Eutectoid reaction**: austenite (~0.8%C) → ferrite + cementite
Eutectoid structure: pearlite

• A mixture of two phases (ferrite + cementite) with a structure of alternating plates produced by eutectoid reaction.

Pearlite in a eutectoid carbon steel.
Microstructures of a eutectoid steel

- Pearlite is not a phase (88.5% $\alpha + 11.5\%$ Fe$_3$C).
- Nodules, not grains.
Hypoeutectoid steel

- Slow cooling of low or medium carbon steels (< 0.8%C).
- Resulting structure: primary ferrite ($\alpha$) grains and pearlite nodules.
Hypereutectoid steel

- Slow cooling of high-carbon steels (>0.8%C).
- Resulting structure: primary Fe₃C and pearlite.
Normalized carbon steels

- Microstructures produced by slow cooling.
- Fe$_3$C acts as a strengthening phase.
- $\alpha$-Fe$_3$C interfaces in pearlite, however, is prone to crack nucleation.

- As a result, the strength increases and the ductility decreases with increasing carbon content.
TTT diagram for an eutectoid steel

- Eutectoid reaction starts at 723°C.
- Slow cooling produces pearlite by diffusive transformation.
- The nose of the C-curve is at \(~525°C\) (vs 700°C for iron)
- A cooling rate of \(~200 °C/s\) (vs \(10^5 °C/s\) for iron) misses the nose and produces martensite.
Martensite in steels

- Quenched steels form martensite.
- The martensite is oversaturated with carbon.
- Carbon atoms stretch the iron lattice to form a body centered tetragonal unit cell.
- The distortion of the lattice impedes dislocation motion (i.e., interstitial solution strengthening).
- As a result, the martensite is much harder than pearlite.
Tempered martensite

- Reheat to an intermediate temperature (300-600°C).
- Carbon atoms diffuse out to form Fe₃C precipitates.
- Distorted lattice relaxes back to bcc, and ductility goes up.
- Fe₃C precipitates keep the hardness up (precipitation strengthening).

- Big improvements in yield and tensile strength of steels can be obtained by quenching and tempering.
This week’s lab

- Use the microscope to examine microstructures of metallurgical samples
  - Cut specimens along sections of interest.
  - Polish the section.
  - Etch to expose the crystal structure.
  - View the etched surfaces under the microscope.

- Measure Rockwell hardness of steel and aluminum specimens.
Hardness test

- Hardness: resistance to indentation (plastic deformation)
- Press a hard indenter into the surface of the material under specific load (F)
- Measure the size (A, projected area) and depth of the indentation.

\[ H = \frac{F}{A} \]

Features:
- Simple, easy, and relatively non-destructive
- No absolute standards
Brinell hardness

- Indenter: hardened steel ball
- Brinell hardness number: \( BHN = \frac{P}{A_c} = \frac{P}{\pi D_t} \)
Vickers Hardness

- Indenter: a square-based diamond pyramid
- Vickers hardness number (VHN or DPH): read from table based on the measured square impression by the indenter.
Rockwell hardness

- Various indenter and load combinations
- Arbitrary definition based on the depth of indentation
- Scales depend on indenter/load combination

$$R = C_1 - C_2 \Delta t$$

$\Delta t$: change of indentation depth between a small initial load and the final load.
Hardness and yield

- Hardness is NOT a fundamental property of a material.
- Hardness is related to yield strength.

\[ H = \frac{F}{A} = 3\sigma_y \]
Slip model

• Yield by shear stress at 45° \( \tau_Y = \sigma_Y / 2 \)
• Triangles slide as rigid bodies, resisted by shear yield stress
• Work done by the shear stresses:

\[
W_\tau = 2\tau_y \frac{A}{\sqrt{2}} \left( \sqrt{2u} + 2 \times \frac{\sqrt{2}}{2} u \right) + 2\tau_y Au = 3\sigma_y u
\]

• Work done by the load (F):

\[
W_F = Fu
\]

\[
W_\tau = W_F \quad \Rightarrow \quad H = \frac{F}{A} = 3\sigma_y
\]
Summary

• Phase transformation and microstructures in carbon steels
  – Normalized steels (Eutectoid, hypoeutectoid, hypereutectoid)
  – Martensitic steels

• Hardness test
  – Kinematics and relation with yield strength