FE Review Session

Materials Science

By

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METALS HIERARCHY

- Ferrous alloys
  - Alloy steels
    - Plain carbon steels
      - Mild steel
      - Medium carbon steels
      - High carbon steels
    - Low alloy steels
      - Tool steels
      - Stainless steels
  - Cast irons
    - Grey irons
    - White irons
    - Malleable irons
    - Nodular irons

- Nonferrous alloys
  - Light alloys
    - Zinc alloys
    - Aluminium alloys
    - Magnesium alloys
    - Titanium alloys
  - Heavy alloys
    - Copper alloys
    - Lead alloys
    - Nickel alloys
  - Refractory metals
    - Molybdenum alloys
    - Tantalum alloys
    - Tungsten alloys
  - Precious metals
    - Gold alloys
    - Silver alloys
    - Platinum alloys
CERAMICS HIERARCHY

- Ceramics
  - Domestic ceramics
    - Porcelain
    - Vitreous china
    - Earthenware
    - Stoneware
    - Cement
  - Engineering ceramics
    - Alumina
    - Carbides
    - Nitrides
  - Natural ceramics
    - Carbonaceous rocks
    - Silicaceous rocks
  - Electronic materials
    - Ferrites
    - Ferroelectrics
    - Semiconductors
    - Superconducting ceramics
  - Glasses
    - Soda lime glasses
    - Borosilicate glasses
    - Pyroceramics
Corrosion

A. Requirements

1. 

2. 

3. 

B. Anodic Reaction

C. Cathodic Reactions

1. Hydrogen reduction

2. $\text{O}_2$ reduction acid solution

3. $\text{O}_2$ reduction basic or neutral solution
### 3. D. EMF Table (p.61*)

**Standard Oxidation Potentials for Corrosion Reactions**

<table>
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<tr>
<th>Corrosion Reaction</th>
<th>Potential, $E_0$, Volts vs. Normal Hydrogen Electrode †</th>
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<tbody>
<tr>
<td>$\text{Au} \rightarrow \text{Au}^{3+} + 3e$</td>
<td>$-1.498$</td>
</tr>
<tr>
<td>$2\text{H}_2\text{O} \rightarrow \text{O}_2 + 4\text{H}^+ + 4e$</td>
<td>$-1.229$</td>
</tr>
<tr>
<td>$\text{Pt} \rightarrow \text{Pt}^{2+} + 2e$</td>
<td>$-1.200$</td>
</tr>
<tr>
<td>$\text{Pd} \rightarrow \text{Pd}^{2+} + 2e$</td>
<td>$-0.987$</td>
</tr>
<tr>
<td>$\text{Ag} \rightarrow \text{Ag}^+ + e$</td>
<td>$-0.799$</td>
</tr>
<tr>
<td>$2\text{Hg} \rightarrow \text{Hg}_2^{2+} + 2e$</td>
<td>$-0.788$</td>
</tr>
<tr>
<td>$\text{Fe}^{2+} \rightarrow \text{Fe}^{3+} + e$</td>
<td>$-0.771$</td>
</tr>
<tr>
<td>$4(\text{OH})^- \rightarrow \text{O}_2 + 2\text{H}_2\text{O} + 4e$</td>
<td>$-0.401$</td>
</tr>
<tr>
<td>$\text{Cu} \rightarrow \text{Cu}^{2+} + 2e$</td>
<td>$-0.337$</td>
</tr>
<tr>
<td>$\text{Sn}^{2+} \rightarrow \text{n}^{4+} + 2e$</td>
<td>$-0.150$</td>
</tr>
<tr>
<td>$\text{H}_2 \rightarrow 2\text{H}^+ + 2e$</td>
<td>$0.000$</td>
</tr>
<tr>
<td>$\text{Pb} \rightarrow \text{Pb}^{2+} + 2e$</td>
<td>$+0.126$</td>
</tr>
<tr>
<td>$\text{Sn} \rightarrow \text{Sn}^{2+} + 2e$</td>
<td>$+0.136$</td>
</tr>
<tr>
<td>$\text{Ni} \rightarrow \text{Ni}^{2+} + 2e$</td>
<td>$+0.250$</td>
</tr>
<tr>
<td>$\text{Co} \rightarrow \text{Co}^{2+} + 2e$</td>
<td>$+0.277$</td>
</tr>
<tr>
<td>$\text{Cd} \rightarrow \text{Cd}^{2+} + 2e$</td>
<td>$+0.403$</td>
</tr>
<tr>
<td>$\text{Fe} \rightarrow \text{Fe}^{2+} + 2e$</td>
<td>$+0.440$</td>
</tr>
<tr>
<td>$\text{Cr} \rightarrow \text{Cr}^{3+} + 3e$</td>
<td>$+0.744$</td>
</tr>
<tr>
<td>$\text{Zn} \rightarrow \text{Zn}^{2+} + 2e$</td>
<td>$+0.763$</td>
</tr>
<tr>
<td>$\text{Al} \rightarrow \text{Al}^{3+} + 3e$</td>
<td>$+1.662$</td>
</tr>
<tr>
<td>$\text{Mg} \rightarrow \text{Mg}^{2+} + 2e$</td>
<td>$+2.363$</td>
</tr>
<tr>
<td>$\text{Na} \rightarrow \text{Na}^+ + e$</td>
<td>$+2.714$</td>
</tr>
<tr>
<td>$\text{K} \rightarrow \text{K}^+ + e$</td>
<td>$+2.925$</td>
</tr>
</tbody>
</table>

* Measured at 25°C. Reactions are written as anode half-cells. Arrows are reversed for cathode half-cells.

† In some chemistry texts, the signs of the values (in this table) are reversed; for example, the half-cell potential of zinc is given as $-0.763$ volt. The present convention is adopted so that when the potential $E_0$ is positive, the reaction proceeds spontaneously as written.


* Pages numbers listed are from the Fundamentals of Engineering Discipline Specific Reference Handbook.
Atomic Bonding

A. Primary Bonding

1. Metallic

2. Ionic

3. Covalent

B. Secondary

1. van der Waals or hydrogen bonding
FIGURE 2-6 The metallic bond forms when atoms give up their valence electrons, which then form an electron sea. The positively charged atom cores are bonded by mutual attraction to the negatively charged electrons.
FIGURE 2-10 The tetrahedral structure of silica (SiO$_2$), which contains covalent bonds between silicon and oxygen atoms.

FIGURE 2-11 The ionic bond is created between two unlike atoms with different electronegativities. When sodium donates its valence electron to chlorine, each becomes an ion; attraction occurs, and the ionic bond is formed.
FIGURE 2-14  (a) In polyvinyl chloride, the chlorine atoms attached to the polymer chain have a negative charge and the hydrogen atoms are positively charged. The chains are weakly bonded by Van der Waals bonds. (b) When a force is applied to the polymer, the Van der Waals bonds are broken and the chains slide past one another.
Crystallography

A. Crystal planes
   1. Miller Indices

B. Directions
Crystallography

A. bcc

\[ r = f(a) \]

1. atoms/unit cell

2. coordination number (CN)

3. packing factor
Crystallography

B. fcc

\[ r = f(a) \]

3. atoms/unit cell

4. coordination number (CN)

3. packing factor
Crystallography

C. hcp

\[ r = f(a) \]

5. atoms/unit cell

6. coordination number (CN)

3. packing factor
Crystallography

A. Density

B. Close packed plane and close packed directions
Diffusion (Thermally Activated Process)

Rate $\propto \left( \frac{Q}{e^{RT}} \right)$

$D = D_0 \left( \frac{Q}{e^{RT}} \right)$

\[ \ln D \]

\[ \frac{1}{T} \]

1. vacancy

\[ \text{Circular symbols} \]
FIGURE 5-4 As atoms squeeze past one another during diffusion, a high energy is required. This energy is the activation energy $Q$. Generally more energy is required for a substitutional atom than for an interstitial atom.
2. interstitial
FIGURE 5-7 The diffusion coefficient $D$ as a function of reciprocal temperature for several metals and ceramics. In this Arrhenius plot, $D$ represents the rate of the diffusion process.
Phase Diagrams

A. Eutectic diagrams

Eutectic reaction

B. Gibb’s Phase Rule

\[ P + F = C + 2 \]

For solids, pressure generally can be ignored and the Gibb’s phase rule may be written as:

\[ F = C - P + 1 \]
Phase Diagrams

A. Eutectoid diagrams

Iron-Iron Carbide Phase Diagram

Eutectoid reaction

Peritectic reaction

Peritectoid reaction
Thermal Processing

A. Cold working (strain or work hardening)

\[ T < \frac{1}{3} T_{M,Pt} \]

B. Annealing

1. Recovery

2. Recrystallization

3. Grain growth
Figure 3.15 The effects of different amounts of cold work on mechanical properties (Lawrence Van Vlack, Elements of Materials Science, fig. 6.26, © 1964, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts. Reprinted with permission of the publisher)
Figure 3.9 Effect of heating on hardness of cold-worked 65% Cu, 35% Zn brass, 1 hr. [Lawrence Van Vlack, *Elements of Materials Science*, fig. 6.28, © 1964, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts. Reprinted with permission of the publisher]
C. Heat treatment

1. Quenched and Tempered
   
   Austenitize

   Quench

   Temper

2. Hardenability

   Jominy Hardenability Curve
Figure 5.1: Schematic diagram of a thermal treatment for a 0.8% carbon steel

1. 1600°F (870°C)
2. Heat to 1600°F (870°C)
3. Quench
4. Temper at 500°F (260°C)
5. Fine carbide in α (BCC) matrix
6. HB 500
7. HB 200
8. HB 600
9. Tetragonal iron supersaturated with carbon
10. 0.8% steel
11. FCC iron (Carbon in solid solution)
12. One-phase (Carbon in solid solution)
13. Fe₃C carbide
14. α (BCC)
Cooling rate at 700°C, °C/sec

Hardenability Curves For Six Steels

(#2) and (#8) indicate grain size

Cooling Rates For Round Bars Quenched in
(a) Agitated Water and (b) Agitated Oil.
3. Precipitation Hardening

Solution treatment

Quenching

Aging
Mechanical Testing

A. Tensile Test

\[ \text{Stress} \quad \text{Psi (MPa)} \]

\[ \text{Strain} \quad \text{(in/in)} \]

E, Modulus of Elasticity
Yield strength
  0.2% YS
Tensile Strength (Ultimate Tensile Strength)
Ductility
  %Elongation
  %Reduction in Area
Figure 2.8 (a) Stress-strain curves for various alloys. (b) Details of an engineering stress-strain curve for mild steel (0.3% carbon) [Part (a) from J. Marin, *Mechanical Behavior of Engineering Materials*, © 1962, pp. 24. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, N.J.]

(a)

- SAE 1340 steel, water-quenched and tempered at 700°F (370°C)
- Nickel-alloy steel
- Stainless-steel sheet 17-7PH
- Stainless steel (18-8)
- Annealed titanium-alloy sheet (6Al-4V)
- Annealed N-155 alloy sheet
- Nickel-alloy steel
- Bare aluminum-alloy sheet (2024-T81)
- Alcoa 27ST
- Structural steel (mild steel)
- Magnesium

(b)

Yield strength at 0.2 percent offset

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B. Impact Test

Energy
Ft-lbs

Temperature

DBTT
Figure 3.6 (a) Operation of a Charpy impact test. (b) Effect of temperature on the impact strength of various materials (schematic) [Part (a) from H.W. Hayden, W.G. Moffatt, and John Wulff, The Structure and Properties of Materials, Vol. 3: Mechanical Behavior, John Wiley & Sons, New York, 1965]
C. Fatigue Test (Endurance Test)

S-N approach

Stress (psi)

Number of Cycles (often log scale)
Figure 2.29 Typical S-N curves for ferrous and nonferrous alloys [Courtesy of H. Mindlin, Battelle]
ASTM Grain Size

A. Surface area: \( S_v = 2P_L \)

B. Grain size: \( N_{(0.0645 \text{ mm}^2)} = 2^{n-1} \)

\[ \bar{I} = 1 / n \text{ (M)} \]
Composite Materials

A. Rule of Mixtures

\[ \rho = \Sigma f_i \rho_i \]

\[ c = \Sigma f_i c_i \]

\[ E = \Sigma f_i E_i \]

parallel

perpendicular