NONFERROUS METALS AND ALLOYS

Chapter 8
7.1 Introduction

• Usage of nonferrous metals and alloys has increased due to technology

• Possess certain properties that ferrous materials do not have
  – Resistance to corrosion
  – Ease of fabrication
  – High electrical and thermal conductivity
  – Light weight
  – Strength at elevated temperatures
  – Color
# Changes in Automotive Material Usage

<table>
<thead>
<tr>
<th>TABLE 7-1</th>
<th>The Material Content of a Typical Family Vehicle (in pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>1978</td>
</tr>
<tr>
<td>Steel</td>
<td>2103</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>26</td>
</tr>
<tr>
<td>Cast iron</td>
<td>512</td>
</tr>
<tr>
<td>Plastics</td>
<td>180</td>
</tr>
<tr>
<td>Aluminum</td>
<td>112.5</td>
</tr>
<tr>
<td>Copper</td>
<td>37</td>
</tr>
<tr>
<td>Zinc</td>
<td>31</td>
</tr>
<tr>
<td>Magnesium</td>
<td>1</td>
</tr>
<tr>
<td>Powder metal</td>
<td>15.5</td>
</tr>
<tr>
<td>Other materials</td>
<td>551.5</td>
</tr>
<tr>
<td>Total</td>
<td>3569.5</td>
</tr>
</tbody>
</table>
Common Nonferrous Metals and Alloys

Figure 7-1 Some common nonferrous metals and alloys, classified by attractive engineering property.
7.2 Copper and Copper Alloys

- General properties and characteristics
  - Backbone of the electrical industry
  - Base metal of a number of alloys such as bronzes and brasses
- High electrical and thermal conductivity
- Useful strength with high ductility
- Corrosion resistance
- About one-third of copper is used in electrical applications
- Other uses are plumbing, heating, and air conditioning
General Properties and Characteristics

• Relatively low strength and high ductility
• Can be extensively formed
• Heavier than iron
• Problems can occur when copper is used at higher temperatures
• Poor abrasive wear characteristics
Characteristics of Copper

• Low temperature properties are better than most other materials
  – Strength increases with decreasing temperature
  – Material does not embrittle
  – Retains ductility under cryogenic conditions
  – Conductivity increases with a drop in temperature
• Nonmagnetic
• Nonpyrophoric
• Nonbiofouling
• Wide spectrum of colors
Commercially Pure Copper

- Electrolytic tough-pitch (ETP) copper is refined copper containing between 0.02 and 0.05% oxygen
- Used as a base for copper alloys
- Used for electrical applications such as wire and cable
- Oxygen-free high conductivity (OFHC) copper provides superconductivity
Copper-Based Alloys

- Copper is the base metal
  - Imparts ductility, corrosion resistance, and electrical and thermal conductivity
- Standardized by the Copper Development Association (CDA)
- Common alloying elements
  - Zinc
  - Tin
  - Nickel
# Designation Systems for Copper

<table>
<thead>
<tr>
<th>Wrought Alloys</th>
<th>Cast Alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td>100–155 Commercial coppers</td>
<td>Red brasses and leaded red brasses</td>
</tr>
<tr>
<td>162–199 High-copper alloys</td>
<td>Semired brasses and leaded semired brasses</td>
</tr>
<tr>
<td>200–299 Copper–zinc alloys (brasses)</td>
<td>Yellow brasses and leaded yellow brasses</td>
</tr>
<tr>
<td>300–399 Copper–zinc–lead alloys (lead brasses)</td>
<td>Manganese and leaded manganese bronzes</td>
</tr>
<tr>
<td>400–499 Copper–zinc–tin alloys (tin brasses)</td>
<td>Silicon bronzes and silicon brasses</td>
</tr>
<tr>
<td>500–529 Copper–tin alloys (phosphor bronzes)</td>
<td>Tin bronzes</td>
</tr>
<tr>
<td>532–548 Copper–tin–lead alloys (lead phosphor bronzes)</td>
<td>Leadized tin bronzes</td>
</tr>
<tr>
<td>600–642 Copper–aluminum alloys (aluminum bronzes)</td>
<td>High–lead brasses</td>
</tr>
<tr>
<td>647–661 Copper–silicon alloys (silicon bronzes)</td>
<td>Nickel–tin bronzes</td>
</tr>
<tr>
<td>667–699 Miscellaneous copper–zinc alloys</td>
<td>Aluminum bronzes</td>
</tr>
<tr>
<td>700–725 Copper–nickel alloys</td>
<td>Copper nickels</td>
</tr>
<tr>
<td>732–799 Copper–nickel–zinc alloys (nickel silvers)</td>
<td>Leadized nickel bronzes</td>
</tr>
</tbody>
</table>
Copper-Zinc Alloys

- Zinc is the most common alloy addition
  - Known as brass
- Alpha brasses
  - Ductile and formable
  - Strength and ductility increase with increasing zinc content
- Two-phase brasses
  - High electrical and thermal conductivity
  - Useful engineering strength
  - Wide range of colors
- Rubber can be vulcanized to it
Copper-Zinc Alloys

• Brasses have good corrosion resistance
  – Brasses with 20 to 36% zinc may experience dezincification when exposed to acidic or salt solutions
  – Brasses with more than 15% zinc may experience season-cracking or stress corrosion

• Cold-worked brass is usually stress-relieved to remove residual stresses

• Lead can be added to increase machinability
## Copper-Zinc Alloys

### Table 7-3: Composition, Properties, and Uses of Some Common Copper–Zinc Alloys

<table>
<thead>
<tr>
<th>CDA Number</th>
<th>Common Name</th>
<th>Composition (%)</th>
<th>Condition</th>
<th>Tensile Strength</th>
<th>Elongation in 2 in. (%)</th>
<th>Typical Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>Commercial bronze</td>
<td>Cu 90, Zn 10</td>
<td>Soft sheet</td>
<td>38, 64</td>
<td>45, 4</td>
<td>Screen wire, hardware, screws, jewelry</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard sheet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>Low brass</td>
<td>Cu 80, Zn 20</td>
<td>Spring</td>
<td>73, 47</td>
<td>3, 47</td>
<td>Drawing, architectural work, ornamental</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Annealed sheet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard</td>
<td>75, 517</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>91, 627</td>
<td>3</td>
<td>Munitons, hardware, musical instruments, tubing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Annealed sheet</td>
<td>53, 365</td>
<td>54</td>
<td>Cold forming, radiator cores, springs, screws</td>
</tr>
<tr>
<td>260</td>
<td>Cartridge brass</td>
<td>Cu 70, Zn 30</td>
<td>Hard</td>
<td>76, 524</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Spring</td>
<td>92, 634</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Annealed sheet</td>
<td>46, 317</td>
<td>64</td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>Yellow brass</td>
<td>Cu 65, Zn 35</td>
<td>Hard</td>
<td>76, 524</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hot-rolled</td>
<td>54, 372</td>
<td>45</td>
<td>Architectural work; condenser tube</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cold-rolled</td>
<td>80, 551</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>280</td>
<td>Muntz metal</td>
<td>Cu 60, Zn 40</td>
<td>Soft</td>
<td>45, 310</td>
<td>60</td>
<td>Condenser tube (salt water), heat exchangers</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard</td>
<td>95, 655</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>443–445</td>
<td>Admiralty metal</td>
<td>Cu 71, Zn 28, Sn1</td>
<td>Soft</td>
<td>47, 324</td>
<td>60</td>
<td>Screw-machine parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard</td>
<td>62, 427</td>
<td>20</td>
<td>Cold disks, pump rods, valve stems, high-strength propellers</td>
</tr>
<tr>
<td>360</td>
<td>Free-cutting brass</td>
<td>Cu 61.5, Zn 35.3, Sn3</td>
<td>Soft</td>
<td>47, 324</td>
<td>60</td>
<td>Screw-machine parts</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hard</td>
<td>62, 427</td>
<td>20</td>
<td>Cold disks, pump rods, valve stems, high-strength propellers</td>
</tr>
<tr>
<td>675</td>
<td>Manganese bronze</td>
<td>Cu 58.5, Zn 39, Sn1</td>
<td>Soft</td>
<td>65, 448</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Bars, half hard</td>
<td>84, 579</td>
<td>19</td>
<td></td>
</tr>
</tbody>
</table>
Copper-Tin Alloys

• Tin is more cost effective than zinc
• Alloys with tin are known as bronzes
  – Bronzes can technically be any copper alloy where the major alloy addition is not zinc or nickel
• Bronzes have desirable mechanical properties
  – Good strength
  – Good toughness
  – Good wear resistance
  – Good corrosion resistance
• Often used for bearings, gears and fittings with high compressive loads
Copper-Nickel Alloys

- Copper and nickel exhibit complete solubility
- High thermal conductivity
- High temperature strength
- Corrosion resistance to a range of materials
- High resistance to stress-corrosion cracking
- Ideal choice for heat exchangers
- Cupronickels contain 2 to 30% nickel
- Nickel silvers contain 10 to 30% nickel and 5% zinc
- Constantan contains 45% nickel
- 67% nickel is known as Monel
Other Copper-Based Alloys

• Aluminum-bronze
  – High strength and corrosion resistance
  – Marine hardware, power shafts, pump and valve components

• Silicon-bronze
  – Strength, formability, machinability, and corrosion resistance
  – Boiler tanks, stove applications

• Copper-beryllium
  – Highest strengths, nonsparking, nonmagnetic, electrically and thermally conductive
  – Electrical contact springs
Lead-Free Casting Alloys

• Addition of lead can serve as a lubricant and chip breaker in machining processes
• Used in many plumbing components
• Due to increased concerns with lead in drinking water, bismuth and selenium are often substituted for lead
  – EnviroBrass alloys
  – Somewhat lower in ductility, but have other properties similar to lead alloys
7.3 Aluminum and Aluminum Alloys

- General Properties and Characteristics
  - Second to steel in quantity and usage
  - Used in transportation, packaging, containers, building construction, etc.
  - Workable, light weight, corrosion resistance, thermal and electrical conductivity, optical reflectivity, easily finished
  - Aluminum is about 1/3 the weight of steel for an equivalent volume
Characteristics of Aluminum

- Four to five times more expensive than steel per pound
- Easily recycled with no loss in quality
  - About a 50% recycling rate in the United States
- Biggest weakness of steel is its low modulus of elasticity
- Commercially Pure Aluminum
  - Soft, ductile, and low strength
  - In the annealed condition, pure aluminum has about 1/5th the strength of hot rolled steel
Aluminums for Mechanical Applications

• On a strength to weight basis, aluminum alloys are superior to steel
• Wear, creep, and fatigue resistance are lower
• For the most part, not suitable for high temperature applications
• Performs well in low temperature applications
  – Stronger at subzero temperatures than at room temperature
Aluminum vs. Steel

• A selection between aluminum and steel depends on different variables
  – Cost
  – Weight
  – Corrosion resistance
  – Maintenance expense
  – Thermal or electrical conductivity

• For the automotive industry, aluminum has become increasingly used because of its lower strength to weight ratio and therefore improves fuel efficiency
  – Use of aluminum in vehicles has doubled in cars and tripled in SUVs
Weight Savings Designs

Figure 7-3a) (Left) The space frame chassis for the 2005 Ford GT is comprised of 35 aluminum extrusions, 7 complex castings, 2 semisolid castings, and various aluminum panels, some superplastically formed. (Courtesy Ford Motor, Dearborn, MI; and HydroAluminum of North America Linthicum, MD.)

Figure 7-3b) (Right) The aluminum frame of the 2006 Corvette Z06 yielded a 30% weight savings compared to the previous steel design. (Courtesy of General Motors, Detroit, MI.)
Corrosion Resistance of Aluminum and its Alloys

• Pure aluminum is reactive and is easily oxidized
  – Oxide provides corrosion resistance layer
  – Aluminum oxides are not as reactive as pure aluminum and therefore are not as corrosion resistant

• Oxide coating may cause difficult when welding

• Welding may be done in a vacuum or in inert gas atmospheres
Classification System

- Wrought alloys are shaped as solids
  - First digit indicates the major alloy element
  - Second digit indicate a modification or improvement
  - Last two digits indicate the alloy family
  - Temper designations
    - F: fabricated
    - H: strain hardened
    - O: annealed
    - T: thermally treated
    - W: solution-heat-treated only
Wrought Alloys

<table>
<thead>
<tr>
<th>Major Alloying Element</th>
<th>1xxx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum, 99.00%</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>2xxx</td>
</tr>
<tr>
<td>Manganese</td>
<td>3xxx</td>
</tr>
<tr>
<td>Silicon</td>
<td>4xxx</td>
</tr>
<tr>
<td>Magnesium</td>
<td>5xxx</td>
</tr>
<tr>
<td>Magnesium and sulfate</td>
<td>6xxx</td>
</tr>
<tr>
<td>Zinc</td>
<td>7xxx</td>
</tr>
<tr>
<td>Other</td>
<td>8xxx</td>
</tr>
</tbody>
</table>

- Only moderate temperatures are required to lower strength, so wrought alloys may be easily extruded, forged, drawn, and formed with sheet metal operations.
Aluminum Casting Alloys

• Pure aluminum is rarely cast
  – High shrinkage and susceptibility to hot cracking

• Classification system

  • First digit indicates the alloy group
  • Second and third digit indicates the particular alloy
  • Last digit indicates the product form

<table>
<thead>
<tr>
<th>Major Alloying Element</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum, 99.00%</td>
<td>1xx.x</td>
</tr>
<tr>
<td>Copper</td>
<td>2xx.x</td>
</tr>
<tr>
<td>Silicon with Cu and/or Mg</td>
<td>3xx.x</td>
</tr>
<tr>
<td>Silicon</td>
<td>4xx.x</td>
</tr>
<tr>
<td>Magnesium</td>
<td>5xx.x</td>
</tr>
<tr>
<td>Zinc</td>
<td>7xx.x</td>
</tr>
<tr>
<td>Tin</td>
<td>8xx.x</td>
</tr>
<tr>
<td>Other elements</td>
<td>9xx.x</td>
</tr>
</tbody>
</table>
Other Forms of Aluminum

• Aluminum-Lithium Alloys
  – Lithium is the lightest of all metallic elements
    • Light weight without compromising strength and stiffness
    • Fracture toughness, ductility, and stress corrosion are lower

• Aluminum Foams
  – Made by mixing ceramic particles with molten aluminum and blowing gas into the mixture
    • Resembles metallic Styrofoam
  – Fuel cells of race cars may use aluminum foams
  – Provide excellent thermal insulation, vibration damping, and sound absorption
7.4 Magnesium and Magnesium Alloys

- General Properties and Characteristics
  - Lightest of commercially important materials
  - Poor wear, creep, and fatigue properties
  - Highest thermal expansion of all engineering metals
  - Strength drops with increase in temperature
  - Low modulus of elasticity requires thick parts
  - High strength to weight ratio
  - High energy absorptions and good damping
  - Used in applications where light weight components are the primary concern
Magnesium Alloys and Their Fabrication

• Classification system is specified by ASTM
• Two prefix letters designate the two largest alloying metals
• Numbers following the two letters indicate the percentages of the two main alloy elements
• Magnesium alloys are often processed with sand, permanent mold, die, semisolid, and investment casting
  – Wall thickness and draft angle are lower than for aluminum
• Improved machinability
7.5 Zinc-Based Alloys

- Over 50% of all metallic zinc is used for galvanizing
- Steel or iron may be hot dipped or be coated using electrolytic plating
- Provides excellent corrosion resistance
- Also used as the base metal in many die casting alloys
  - Reasonably high strength and impact resistance
  - Can be cast close to dimensional tolerances with extremely thin section
  - Low energy costs due to low melting temperature
7.6 Titanium and Titanium Alloys

• Titanium is a strong, lightweight, corrosion resistant metal
• Properties are between those of steel and aluminum
• Less dense than steel
• Can be used in high temperature applications
• High energy costs for fabrication
• Fabrication methods: casting, forging, rolling, extrusion, welding
• Abundant material, but is difficult to process from ore
• Aerospace applications, medical implants, bicycles, heat exchangers are common uses
7.7 Nickel Based Alloys

- Outstanding strength and corrosion resistance at high temperatures
  - Wrought alloys are known as Monel, Hastelloy, Inconel, Incoloy, and others
  - Good formability, creep resistance, strength and ductility at low temperatures
- Can be used in food-processing industries, turbine blades
- Electrical resistors and heating elements typically use nickel-chromium alloys ( Nichrome)
- Superalloys are those alloys that are suitable for high temperature applications
7.8 Superalloys and Other Metals Designed for High-Temperature Service

- Alloys based on nickel, iron, cobalt
- Retain most of their strength even after long exposures to high temperatures
- Strength comes from solid solution strengthening, precipitation hardening, and dispersion strengthening
- The density of superalloys is much greater than that of iron
- Difficult to machine
  - Electrodischarge, electrochemical, ultrasonic machining, powder metallurgy
High Temperature Alloys

**Refractory metals**
- Use niobium, molybdenum, tantalum, rhenium, and tungsten
- Coating technology is difficult because of their ceramic coating

**Intermetallic Compounds**
- Provide properties between metals and ceramics
- Hard, stiff, creep resistant, oxidation resistant, high-temperature strength
- Poor ductility, poor fracture toughness, and poor fatigue resistance
- Difficult to fabricate

*Figure 7-6* Temperature scale indicating the upper limit to useful mechanical properties for various engineering metals.
7.9 Lead, Tin, and Their Alloys

• Lead alloys
  – High density, high strength and stiffness
  – Storage batteries, radiation absorption
  – Good corrosion resistance, low melting point, ease of casting or forming

• Tin alloys
  – Used with lead
  – Solder
  – Bearing materials
7.10 Some Lesser Known Metals and Alloys

- **Beryllium**
  - Less dense than aluminum, greater stiffness than steel, transparent to x-rays
  - Used in nuclear reactors because of its low neutron absorption (as well as hafnium and thorium)

- **Uranium**
  - High density

- **Cobalt**
  - Base metal for superalloys

- **Zirconium**
  - Outstanding corrosion resistance
  - High strength, good weldability, fatigue resistance

- **Precious metals** offer outstanding corrosion resistance and electrical conductivity
7.11 Metallic Glasses

- Amorphous metals are formed by cooling liquid metal extremely quickly so that no crystalline structure can form
  - Lacks grain boundaries and dislocations
  - High strength, large elastic strain, good toughness, wear resistance, magnetic, corrosion resistance
  - Used in load bearing structures, electronic casings, sporting goods
7.12 Graphite

- Properties of metals and nonmetals
- Good thermal and electrical conductivity
- Can withstand high temperatures
- Lubricant
- Used as electrodes in arc furnaces
- Rocket-nozzles
- Permanent molds for casting
Summary

- Nonferrous metals are used in a variety of applications
- Many nonferrous metals are lower in weight than steel and are used in applications where weight is a consideration
- Many have better corrosion resistance than steels
- Nonferrous metals are often more expensive than iron based metals or alloys