NONFERROUS METALS AND ALLOYS

Chapter 7

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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 7-1 The Material Content of a Typical Family Vehicle (in pounds)

Material	1978	1990	2002
Steel	2103	1682.5	1757
Stainless steel	26	34	56.5
Cast iron	512	454	328
Plastics	180	229	255
Aluminum	112.5	158.5	279.5
Copper	37	48.5	50
Zinc	31	18.5	8.5
Magnesium	1	3	9.5
Powder metal	15.5	24	40.5
Other materials	551.5	488.5	573
Total	3569.5	3140.5	3357.5

Common Nonferrous Metals and Alloys

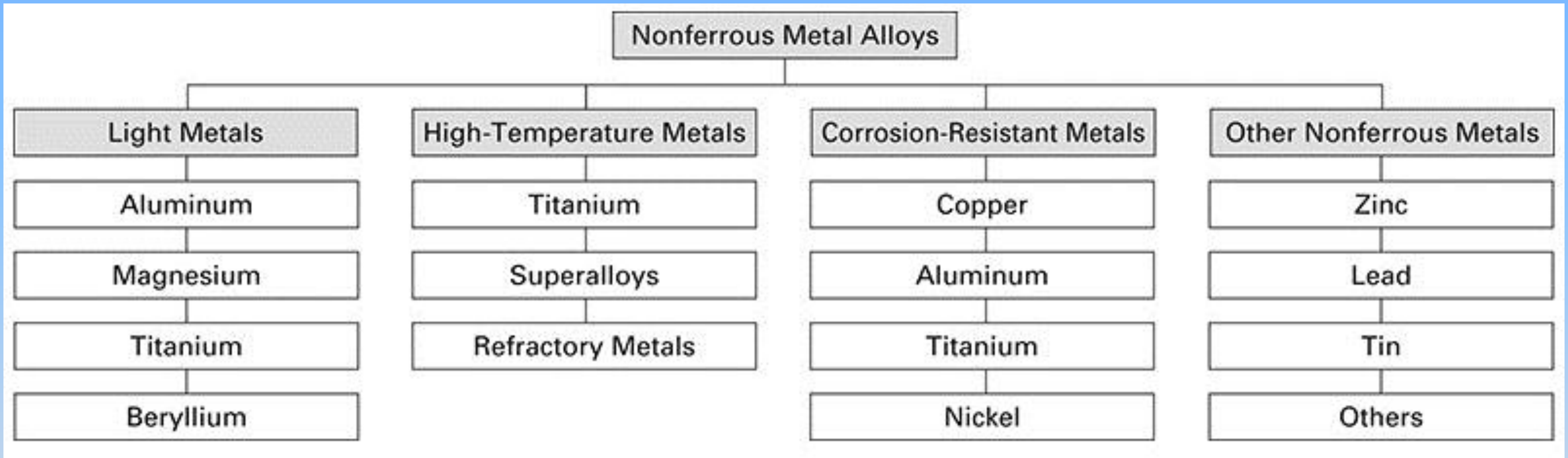


Figure 7-1 Some common nonferrous metals and alloys, classified by attractive engineering property.

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 7-2 Designation System for Copper and Copper Alloys (Copper Development Association System)

	Wrought Alloys		Cast Alloys
100–155	Commercial coppers	833–838	Red brasses and leaded red brasses
162–199	High-copper alloys	842–848	Semired brasses and leaded semired brasses
200–299	Copper–zinc alloys (brasses)	852–858	Yellow brasses and leaded yellow brasses
300–399	Copper–zinc–lead alloys (leaded brasses)	861–868	Manganese and leaded manganese bronzes
400–499	Copper–zinc–tin alloys (tin brasses)	872–879	Silicon bronzes and silicon brasses
500–529	Copper–tin alloys (phosphor bronzes)	902–917	Tin bronzes
532–548	Copper–tin–lead alloys (leaded phosphor bronzes)	922–929	Leaded tin bronzes
600–642	Copper–aluminum alloys (aluminum bronzes)	932–945	High-leaded tin bronzes
647–661	Copper–silicon alloys (silicon bronzes)	947–949	Nickel–tin bronzes
667–699	Miscellaneous copper–zinc alloys	952–958	Aluminum bronzes
700–725	Copper–nickel alloys	962–966	Copper nickels
732–799	Copper–nickel–zinc alloys (nickel silvers)	973–978	Leaded nickel bronzes

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

		Composition(%)						Tensile Strength			
CDA Number	Common Name	Cu	Zn	Sn	Pb	Mn	Condition	ksi	MPa	Elongation in 2 in. (%)	Typical Uses
220	Commercial bronze	90	10				Soft sheet	38	262	45	Screen wire, hardware, screws. jewelry
							Hard sheet	64	441	4	
240	Low brass	80	20				Spring	73	503	3	Drawing, architectural work, ornamental
							Annealed sheet	47	324	47	
							Hard	75	517	7	
260	Cartridge brass	70	30				Spring	91	627	3	Munitions, hardware, musical instruments, tubing
							Annealed sheet	53	365	54	
							Hard	76	524	7	
270	Yellow brass	65	35				Spring	92	634	3	Cold forming, radiator cores, springs, screws
							Annealed sheet	46	317	64	
							Hard	76	524	7	
280	Muntz metal	60	40				Hot-rolled	54	372	45	Architectural work; condenser tube
							Cold-rolled	80	551	5	
443–445	Admiralty metal	71	28	1			Soft	45	310	60	Condenser tube (salt water), heat exchangers
							Hard	95	655	5	
360	Free-cutting brass	61.5	35.3		3		Soft	47	324	60	Screw-machine parts
							Hard	62	427	20	
675	Manganese bronze	58.5	39	1		0.1	Soft	65	448	33	Clutch disks, pump rods, valve stems, high-strength propellers
							Bars, half hard	84	579	19	

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 it 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.)

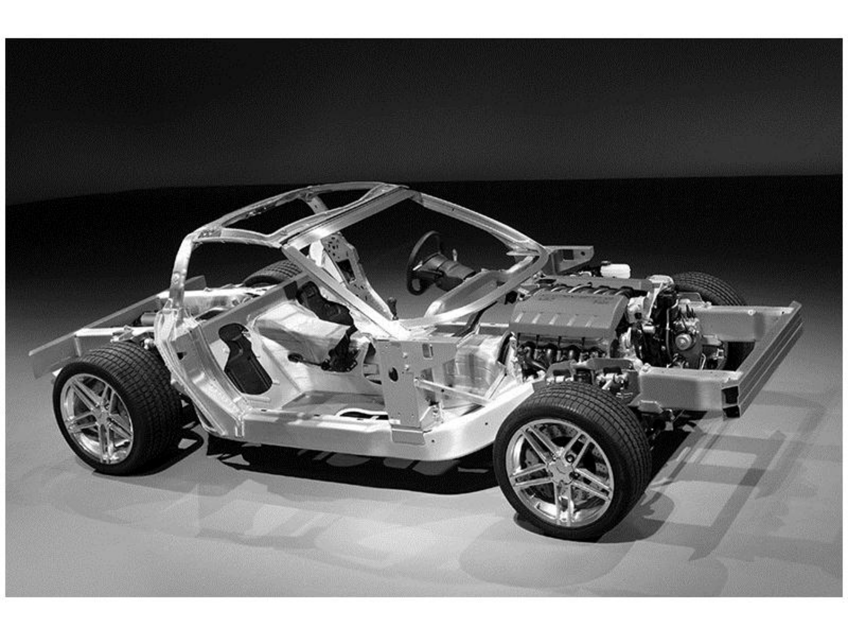


Figure 7-3b) (Right) The aluminum frame of the 2006 Corvette Z06 yielded a 30% weight savings compared to the previous steel design. (Courtesy of General Motors, Detroit, MI.)

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

Major Alloying Element	
Aluminum, 99.00%	1xxx
Copper	2xxx
Manganese	3xxx
Silicon	4xxx
Magnesium	5xxx
Magnesium and sulfate	6xxx
Zinc	7xxx
Other	8xxx

- 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

Major Alloying Element	
Aluminum, 99.00%	1xx.x
Copper	2xx.x
Silicon with Cu and/or Mg	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x
Other elements	9xx.x

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

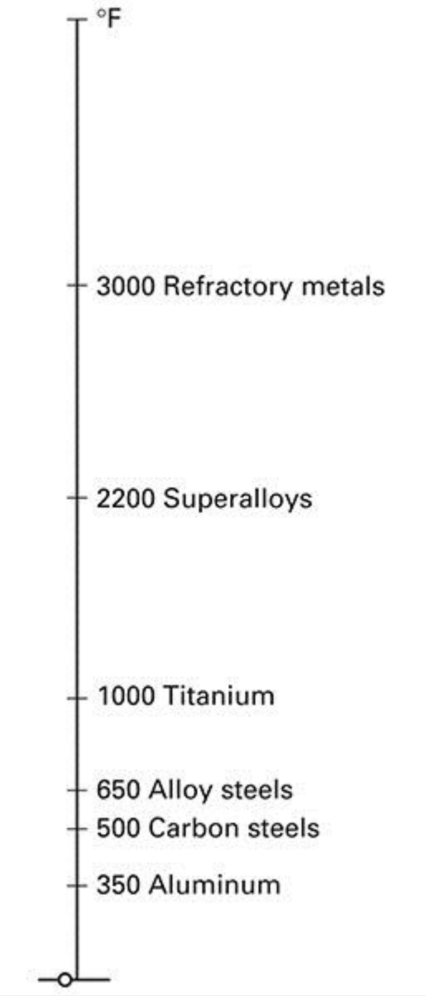
- Outstanding strength and corrosion resistance at high temperatures
  - Wrought alloys are known as Monel, Hastelloy, Inconel, Incoloy, and others
  - Good formability, creep resistance, strength and ductility at low temperatures
- Can be used in food-processing industries, turbine blades
- Electrical 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

Figure 7-6 Temperature scale indicating the upper limit to useful mechanical properties for various engineering metals.



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

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 it 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