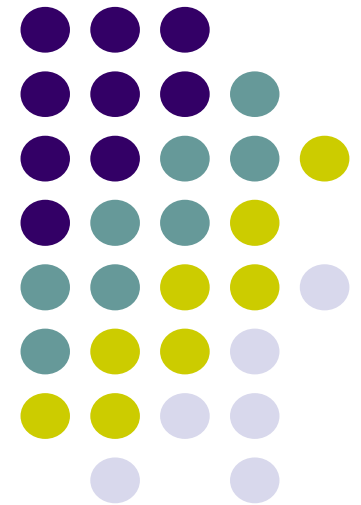


ME 216 – Engineering Materials II

Chapter 9

Nonferrous Industrial Alloys





- Great use in **reducing weight in machine parts**, especially in aeronautical and automotive industries.
- **Low density** and **good corrosion resistance** coupled with **sound mechanical properties**.

ALUMINIUM ALLOYS

Casting Alloys

- may contain as much as:
17% **Si**, 11% **Cu**, or 10% **Mg**
- produced by:
sand casting, permanent mold casting, die casting
- designated as: **XXX.X**
three digit number (indicating composition),
followed by a **letter** (indicating temper)

- **1XX.X** : Pure Al
- **2XX.X** : Al-Cu
- **3XX.X** : Al-Si,Cu,Mg
- **4XX.X** : Al-Si
- **5XX.X** : Al-Mg
- **6XX.X** : unused
- **7XX.X** : Al-Zn
- **8XX.X** : Al-Sn
- **9XX.X** : Al-others

Wrought Alloys

- contain:
small percentages of alloying elements
- produced by:
rolling, extruding, drawing, forging
- designated as: **XXXX-Y**
four digit number (indicating composition),
followed by a **letter** (indicating temper)

- **1XXX-Y** : Pure Al
- **2XXX-Y** : Al-Cu
- **3XXX-Y** : Al-Mn
- **4XXX-Y** : Al-Si
- **5XXX-Y** : Al-Mg
- **6XXX-Y** : Al-Mg,Si
- **7XXX-Y** : Al-Zn

Temper Designations (Y)

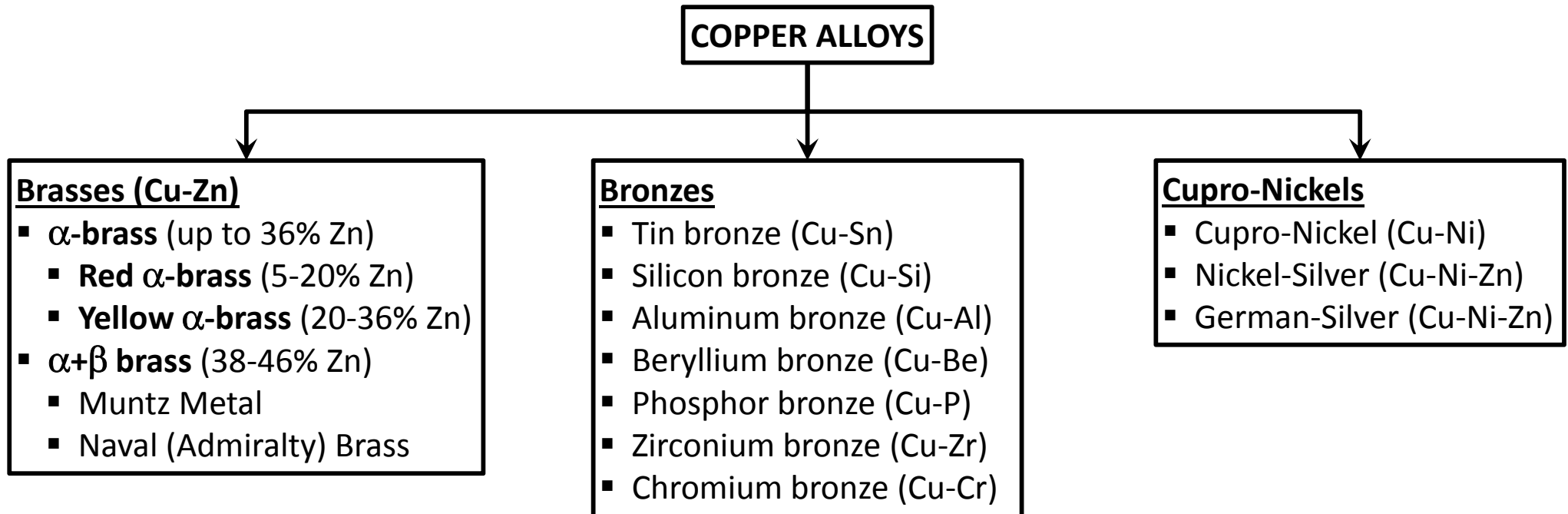
- Fabricated (**F**)
- Annealed (**O**)
- Strain-hardened (**H**)
- Heat-treated (**T**)



- **Al-Cu (2XXX)**: Heat treatable, high strength alloys. May contain small amount of **Si, Fe, Mg, Mn, Cr, Zn**. Used in aircraft applications and for components requiring high strength and hardness.
 - **2017 (duralumin)**: With 4% **Cu**. Used as rivets in aircraft (*Readily stored in fridge. After riveting, their temp. increases to room temp. and precipitation occurs, which increases the strength of rivets*)
 - **2014**: Stronger than 2017 with higher **Cu** and **Mn**. Susceptible to artificial aging. Used for heavy-duty forgings, aircraft fittings, truck frames, etc.
 - **2024**: With 4.5% **Cu**, 1.5% **Mg**. The highest strength of natural-aged Al-Cu alloys. Difficult to fabricate.
- **Al-Mn (3XXX)**: Not heat treatable due to limited solubility of **Mn**.
 - **3003**: Good formability and weldability, resistance to corrosion. Typical uses are cooking utensils, food and chemical handling and storage equipment, gasoline and oil tanks, pressure vessels, and piping.
- **Al-Si (4XXX)**: Not heat treatable. Excellent castability and resistance to corrosion.
 - **4032**: With 12.5% **Si**. Good formability, low thermal expansion (*forged automotive pistons*)
- **Al-Mg (5XXX)**: Not heat treatable. Good corrosion resistance, moderate strength.
 - **5005** (architectural extrusions), **5050** (aircraft fuel and oil lines), **5083** (marine and welded structures)
 - **214, 218** (dairy and food handling equipment, fittings for marine use, aircraft brake shoes)
- **Al-Si-Mg (6XXX)**: Excellent corrosion resistance, more workable than other heat-treatable alloys.
 - **6053, 6061, 6063** (aircraft landing mats, canoes, tubings, railings)
 - **355, 356, 360** (aircraft applications, general-purpose castings)
- **Al-Zn (7XXX)**: High strength, good corrosion resistance.
 - **40E**: High mechanical properties, good corrosion resistance, machinable (*aircraft fittings*)



- **Cu** can be used as unalloyed; but **Zn, Sn, Al, Si** serve as **solid solution hardeners**.
- **Unalloyed (pure) copper** with **high electrical and thermal conductivity** is **used in electrical industry**.
- **Electrolytic tough-pitch (ETP) Cu** is the cheapest industrial copper **used for production of wire, rod, plate**.
- Important alloys of copper are classified as: **brasses, bronzes, cupro-nickels**.





- **Brasses:** Alloys of **Cu** & **Zn** (with small addition of **Pb**, **Sn**, **Al**). Characterized by corrosion resistance combined with strength and hardness. Difficult to weld (due to loss of **Zn** during welding).
 - **Cap Copper:** Red color with 2-5% **Zn**. Very ductile. **Used for ammunition priming cases.**
 - **Gliding Metal:** Golden color with 5% **Zn**. **Used for deep drawing, jewellery, coins and medals, etc.**
 - **Cartridge Brass:** Yellow color with 30% **Zn**. Suitable for deep drawing due to high ductility. **Used as cartridge cases, electric sockets, flash light casings, etc.**
 - **Muntz Metal:** $\alpha+\beta$ alloy with 40% **Zn**. Very suitable for hot working, corrosion resistant. **Used in sheet form for condenser heads, architectural works, etc.**
 - **Naval (Admiralty) Brass:** Contains 39% **Zn**, 1% **Sn**. Very good resistance to seawater corrosion. **Used for propellers, shafts, condenser plates, etc.**
- **Bronzes:** Rich brown alloys of **Cu**. Suitable for casting, good corrosion properties, moderate strength.
 - **P-bronzes:** With 1-11% **Sn** (**P** is added to remove oxides of **Sn** & **Cu**). High tensile/fatigue strength, toughness, corrosion resistance. **Used as instrument parts (e.g. diaphragms, bellows, springs).**
 - **Si-bronzes (Everdur, Herculoy):** High-strength alloys (up to 750 Mpa).
 - **Al-bronzes:** Having 4-11% **Al**, with high strength (up to 680 Mpa) and low ductility. **Used in electrical and marine hardware, propellers, tubings, pumps.**
 - **Be-copper:** Up to 1.9% **Be**. Highest-strength bronze. Good fatigue strength, formability, resistance to corrosion and wear. **Due to its hardness, used as non-sparking hand tools (e.g. wrenches).**
 - **Zr-copper & Cr-copper:** Heat treatable. **Used for resistance welding tips, switch parts.**
- **Cupro-Nickels (Cu-Ni):** 15-20% **Ni** (condenser tubes in seawater), 40-45% **Ni** (wires in thermocouples)
 - **Nickel-silver (Cu-Ni-Zn):** 5-30% **Ni**, small addition of **Zn** (ornamental works)
 - **German-silver (Cu-Ni-Zn):** 22% **Ni**, 26% **Zn** (for cases requiring extremely low thermal conductivity)



Lead Alloys:

- In general, **Pb** does not form useful alloys except with other metals of low melting point.
- In free-machining leaded alloys, **Pb** is an inclusion (not an alloy ingredient).
- However, pure **Pb** is alloyed to increase its low strength (17 MPa). Two types of alloys are in use:
 - Tellurium lead (**Pb-Te**): addition of less than 0.1% **Te**
 - Antimony lead (**Pb-Sb**): addition of maximum 11% **Sb**
- The solders are the most commonly used alloys of **Pb** & **Sn** (having 5-50% **Sn**).

Magnesium Alloys:

- Lightness, weldability, and ease of machining greatly reduces its cost of manufacture.
- Components made of **Mg** alloys must be protected either by painting or anodizing.
- The alloys may be divided into two classes: wrought alloys & cast alloys
- Currently, the lightest commercial **Mg** alloy contains 14% **Li**, 1.25 % **Al**.
- Most **Mg** alloys are used for light-weight equipment as in aircraft, space vehicles, ladders, portable power tools, luggage or dock boards, etc. The famous type is AZ31B alloy (with 3% **Al**, 1% **Zn**).

Zinc Alloys:

- Major use is in alloys for die-casting. Zinc die-casting alloys are low in cost and easy to cast, and have greater strength than other die-casting metals (except copper alloys).
- The most popular type is Zn-Al alloy (a lamellar eutectic forms at 382 °C and 5% **Al**).



Nickel Alloys:

- Like **Cu** & **Fe**, **Ni** is capable of producing a wide range of alloys adopted to special applications.
- **Cu** is the most important alloying partner, forming solid solution in all proportions.
- The most commonly used alloys are as follows:
 - **Monel** (more **Ni** than **Cu**): used for sinks, kitchen equipment, washing machines, marine equipments.
 - Standard Monel (400): 66% **Ni**, 31.5% **Cu**, 1% **Fe**, 1% **Mn**
 - R-monel (R-405): 66% **Ni**, 31.5% **Cu**, 0.05% **S**
 - K-monel (K-500 & K-501): 66% **Ni**, 31.5% **Cu**, 2.8% **Al**, 0.5% **Ti**
 - **Inconel** (**Ni-Cr-Fe** alloy): 78% **Ni**, 14% **Cr**, 6.5% **Fe**, 0.2% **Cu** (high temp. applications, turbine blades)
 - **Hastelloys** (alloys of **Ni-Cr-Fe** & **Ni-Mo-Fe**): varying amount of elements (high corrosion resistance)
 - **Nilvar & Invar**: up to 36% **Ni** (lowest thermal expansion coefficient)
 - **Beryllium-Nickel** (Berlyco-Nickel 440): 1.95% **Be** & 0.5% **Ti** (in addition to **Ni** & **Cu**)
 - **Constantan**: 45% **Ni**, 55% **Cu**; **Alumel**: 95.3% **Ni**, 1.75% **Mn**, 1.2% **Si**; **Chromel**: 90% **Ni**, 9.5% **Cr**

Titanium Alloys:

- Titanium has **HCP structure (α -Ti)** at room temp, which transforms to **BCC structure (β -Ti)** at 882 °C. Addition of alloying elements influences transformation temperature. Thus, Ti-alloys can be in phases of α , $\alpha+\beta$, β where relative amounts of phases affect mechanical properties:
 - **α alloys**: stabilized with **Al**, weldability & high temp. strength (aircraft tailpipe assemblies, missile fuel tanks)
 - **$\alpha+\beta$ alloys**: stronger than α alloys, best examples is **Ti-6Al-4V** (aircraft compressor blades and disks)
 - **β alloys**: can be strengthened by heat treatment (high strength fasteners and aerospace components)



Die-Casting Alloys:

- Wide range of nonferrous alloys can be die-cast.
- The principal base metals in order of commercial importance:
Zn, Al, Mg, Cu, Pb, Sn
- They can be further classified as:
 - **Low-temp. alloys** (casting temp. below 550 °C): **Zn, Sn, Pb**
 - **High-temp. alloys** (casting temp. above 550 °C): **Al, Mg, Cu**

Alloy Type	Alloy Name	Composition (%)						
		Al	Cu	Mg	Pb	Si	Sn	Zn
Zn Based	903	4.1	0.1 (max)	0.04	-	-	-	rem.
	925	4.1	1.0	0.04	-	-	-	rem.
Al Based	13	rem.	-	-	-	12	-	-
	43	rem.	-	-	-	5	-	-
	218	rem.	3	8	-	-	-	-
	360	rem.	-	0.5	-	9.5	-	-
	380	rem.	3.5	-	-	9	-	-
	389	rem.	3.8	-	-	12	-	-
Cu Based	Z30A	-	57 (min)	-	1.5	-	1.5	30 (min)
	ZS331A	-	65	-	-	1	-	rem.
	ZS144A	-	81	-	-	4	-	rem.
Mg based	AZ91A	9	-	rem.	-	-	-	0.7
	AZ91B	9	0.3	rem.	-	0-5	-	0.7



Bearing Alloys:

- Bearings are used to transmit loads between relatively moving surfaces, **involving sliding contact**.
- Bearing alloy must be **relatively soft to align itself to journal under pressure** (conformability). In addition, bearing must be **strong** (compressive & fatigue strength) **with low friction and wear-resistant surface**.
- Such combination of properties is generally not obtained in a single-phase alloy. Thus, bearing metals are **traditionally two-phase alloys**. In these materials; harder, low friction particles are held in malleable, soft, solid solution (or eutectic) matrix.

Alloy Type	Cu	Sn	Pb	Sb	Al	Bearing Hardness (HV)	Recommended Journal (HV)
Sn-base babbitt	3.5	89	-	7.5	-	23-25	140
	4	87	-	9	-	27-32	150
Pb-base babbitt	1	12	74	13	-	26	140
Pb-bronze	70	-	30	-	-	35-45	25-500
	74	4	22	-	-	40-45	
	75	5	20	-	-	45-70	
	80	10	10	-	-	65-90	
	85	5	10	-	-	45-70	
P-bronze	rem.	10	0.5 (min)			70-150	500
Al-alloys	1	6	-	-	rem. (1% Ni)	45-60	250
	1	20	-	-	rem.	40	250