ME 216 – Engineering Materials II

Chapter 9

Nonferrous Industrial Alloys

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- 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)

Copper Alloys

- **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**.

COPPER ALLOYS

Brasses (Cu-Zn)

- **α-brass** (up to 36% Zn)
  - **Red α-brass** (5-20% Zn)
  - **Yellow α-brass** (20-36% Zn)
- **α+β brass** (38-46% Zn)
  - Muntz Metal
  - Naval (Admiralty) Brass

Bronzes

- Tin bronze (Cu-Sn)
- Silicon bronze (Cu-Si)
- Aluminum bronze (Cu-Al)
- Beryllium bronze (Cu-Be)
- Phosphor bronze (Cu-P)
- Zirconium bronze (Cu-Zr)
- Chromium bronze (Cu-Cr)

Cupro-Nickels

- Cupro-Nickel (Cu-Ni)
- Nickel-Silver (Cu-Ni-Zn)
- German-Silver (Cu-Ni-Zn)

- **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. diaphrams, 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**
  - Antimonium 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, α+β, β where relative amounts of phases affect mechanical properties:
  - **α alloys:** stabilized with **Al**, weldability & high temp. strength (aircraft tailpipe assemblies, missile fuel tanks)
  - **α+β 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