Outline

- Introduction: *Relative cost of materials*
- Non Ferrous Alloys
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  - *- Alluminum and its alloys*
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  - *- Titanium and its alloys*
  - *- Nickel and its alloys*
  - *- Superalloys*
- Miscellaneous Nonferrous Alloys
- Summary

Approximate Cost Per Unit Volume for Wrought Metals and Plastics Relative to Carbon Steel

Material	Cost / Cost of Carbon Steel	Material	Cost / Cost of Carbon Steel
Gold	……..	Mg Alloys	2-4
Silver	600	Al Alloys	2-3
Mo Alloys	200-250	High Strength Steels	1.4
Nickel	……..	Gray Cast Iron	1.2
Ti Alloys	20-40	Carbon Steel	1
Cu Alloys	5-6	Nylons, silicon rubber	1.1-2
Zinc Alloys	1.5-3.5	Plastics/Elastomers	0.2-1
Stainless Steels	2-9	Fiber Composites	……..

Non-Ferrous Alloys

Steel & other ferrous alloys are used in very large quantities but:
- have relatively high densities
- relatively low electrical conductivity
- susceptibility to corrosion in many atmospheres

Wrought Alloys and Cast alloys:

- ✓ Copper & alloys (including brasses, bronzes)
- ✓ Aluminum & alloys
- ✓ Magnesium
- ✓ Titanium
- ✓ Nickel
- ✓ Lead
- ✓ Zinc
- ✓ Tin ...

Copper Alloys

- Density; 8.93 Mg/m^3 so alloys are heavier than steel.
- Specific strength not very high
- Good ductility, (*very soft when pure*).
- Corrosion resistant (*some surface reactions*)
- Relatively good fatigue, creep and wear resistance compared to Al alloys.
- High electrical and thermal conductivity.
- Easily joined and fabricated.

  - Strengthening:
    - ✓ **Cold-working:** principle method for most alloys
    - ✓ **Solid solution:-** Cu-Zn, Cu-Sn, Cu-Al, Cu-Be
    - ✓ **Age-hardenable:-** Cu-Zr, Cu-Be
    - ✓ **Phase transformations:-** Cu-Al

Copper Alloys

- Strength and hardness of copper is relatively low; to improve strength, copper is frequently alloyed
- *Bronze* - alloy of copper and tin (typically ~ 90% Cu, 10% Sn), widely used today and in ancient times (i.e., the *Bronze Age*)
  - Additional bronzes include aluminum bronzes and silicon bronzes
- *Brass* - alloy of copper and zinc (typically ~ 65% Cu, 35% Zn).
- Highest strength alloy is beryllium-copper (only about 2% Be), which can be heat treated to high strengths and used for springs

- Based on the Unified Numbering System for Metals and Alloys (UNS), which uses a five digit number preceded by the letter C.
- Includes both wrought and cast copper and its alloys
- Examples:

  C10100 – 99.99% pure copper

  C17000 – 98% Cu, 1.7% Be (beryllium-copper)

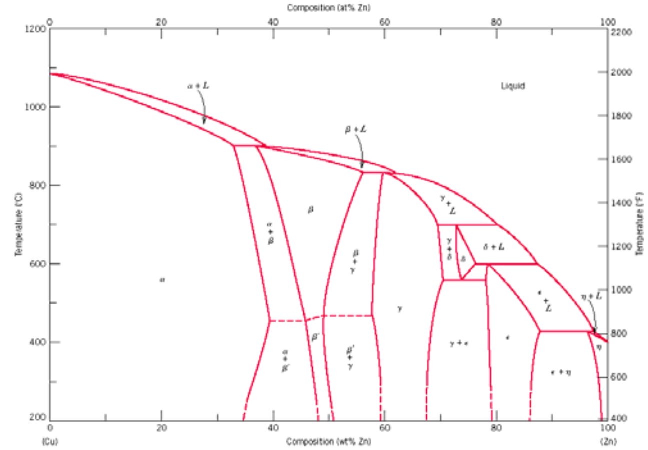
  C24000 – 80% Cu, 20% Zn (brass)

  C52100 – 92% Cu, 8% Sn (bronze)

Copper Alloys

Brasses Cu-Zn alloys

- Several phases: α (FCC) - soft, ductile, easily cold-worked.
- β' is BCC, harder & stronger than α.
- 60-40 brass is (α + β').



Copper Alloys

Bronzes Cu + Sn, Al, Si, Ni

- Stronger than brasses and still good corrosion resistance.
- Precipitation hardenable - e.g. Cu-Be - very high strength, corrosion & wear resistant…. etc.

Table 12.6 Compositions, Mechanical Properties, and Typical Applications for Eight Copper Alloys

Alloy Name	UNS Number	Composition (wt%)[a]	Condition	Mechanical Properties: Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications
Wrought Alloys							
Electrolytic tough pitch	C11000	0.04 O	Annealed	220 (32)	69 (10)	45	Electrical wire, rivets, screening, gaskets, pans, nails, roofing
Beryllium copper	C17200	1.9 Be, 0.20 Co	Precipitation hardened	1140–1310 (165–190)	690–860 (100–125)	4–10	Springs, bellows, firing pins, bushings, valves, diaphragms
Cartridge brass	C26000	30 Zn	Annealed	300 (44)	75 (11)	68	Automotive radiator cores, ammunition components, lamp fixtures, flashlight shells, kickplates
			Cold-worked (H04 hard)	525 (76)	435 (63)	8	
Phosphor bronze, 5% A	C51000	5 Sn, 0.2 P	Annealed	325 (47)	130 (19)	64	Bellows, clutch disks, diaphragms, fuse clips, springs, welding rods
			Cold-worked (H04 hard)	560 (81)	515 (75)	10	
Copper-nickel, 30%	C71500	30 Ni	Annealed	380 (55)	125 (18)	36	Condenser and heat-exchanger components, saltwater piping
			Cold-worked (H02 hard)	515 (75)	485 (70)	15	

Copper Alloys

Table 12.6 Compositions, Mechanical Properties, and Typical Applications for Eight Copper Alloys

Alloy Name	UNS Number	Composition (wt%)[a]	Condition	Mechanical Properties: Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications
Cast Alloys							
Leaded yellow brass	C85400	29 Zn, 3 Pb, 1 Sn	As cast	234 (34)	83 (12)	35	Furniture hardware, radiator fittings, light fixtures, battery clamps
Tin bronze	C90500	10 Sn, 2 Zn	As cast	310 (45)	152 (22)	25	Bearings, bushings, piston rings, steam fittings, gears
Aluminum bronze	C95400	4 Fe, 11 Al	As cast	586 (85)	241 (35)	18	Bearings, gears, worms, bushings, valve seats and guards, pickling hooks

[a] The balance of the composition is copper.

Aluminum and Its Alloys

- Low Density: 2.7 Mg/m^3 (*Steel 7.87 Mg/m^3*)
- Pure Al is very soft and ductile but alloys of strengths of **690 MPa** are possible by combining **cold working**, alloying, and precipitation hardening mechanisms.
- Many alloys very ductile/workable even at low temperatures (FCC).
- Gives good specific strength: σ/ρ
- Good Corrosion Resistance : Aluminium oxide film on surface protects metal.
- Also aluminum:
  - ✓ Non-toxic
  - ✓ High electrical conductivity
  - ✓ High thermal conductivity
  - ✓ Non-magnetic
  - ✓ No fatigue limit
  - ✓ Low melting point (660°C) restricts operating temp. but facilitates casting.
  - ✓ Low hardness/wear resistance

Designations of Wrought and Cast Al Alloys

Alloy group	Wrought code	Cast code
Aluminum ≥ 99.0% purity	1XXX	1XX.X
Copper alloy	2XXX	2XX.X
Manganese alloy	3XXX	
Silicon alloy	4XXX	4XX.X
Zinc alloy	7XXX	7XX.X
Tin alloy		8XX.X

- Properties of Al alloys are influenced by work hardening and heat treatment, so temper must be designated in addition to composition
  - *This designation is attached to the 4-digit code, separated by a hyphen, to indicate treatment or no treatment*
  - *Temper treatments that specify strain hardening do not apply to the cast alloys*

Temper	Description
F	As fabricated - no special treatment
H	Strain hardened (wrought aluminums)
O	Annealed to relieve strain hardening and improve ductility
T	Thermal treatment to produce stable tempers other than F, H, or O

Aluminum and Its Alloys

WROUGHT ALLOYS & CASTING ALLOYS

- Heat-treatable and nonheat-treatable.
- Advanced alloys - **Al-Lithium**

Table 12.7 Compositions, Mechanical Properties, and Typical Applications for Several Common Aluminum Alloys

Aluminum Association Number	*UNS Number*	*Composition (wt%)[a]*	*Condition (Temper Designation)*	*Mechanical Properties* Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	*Typical Applications/ Characteristics*
Wrought, Nonheat-Treatable Alloys							
1100	A91100	0.12 Cu	Annealed (O)	90 (13)	35 (5)	35–45	Food/chemical handling & storage equipment, heat exchangers, light reflectors
3003	A93003	0.12 Cu, 1.2 Mn, 0.1 Zn	Annealed (O)	110 (16)	40 (6)	30–40	Cooking utensils, pressure vessels and piping
5052	A95052	2.5 Mg, 0.25 Cr	Strain hardened (H32)	230 (33)	195 (28)	12–18	Aircraft fuel & oil lines, fuel tanks, appliances, rivets, and wire

Cu increases strength, but >0.5% reduces corrosion resistance

Mn or Cr increases strength, grain size control

Aluminum and Its Alloys

Table 12.7 Compositions, Mechanical Properties, and Typical Applications for Several Common Aluminum Alloys

Aluminum Association Number	*UNS Number*	*Composition (wt%)[a]*	*Condition (Temper Designation)*	*Mechanical Properties* Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	*Typical Applications/ Characteristics*
Wrought, Heat-Treatable Alloys							
2024	A92024	4.4 Cu, 1.5 Mg, 0.6 Mn	Heat treated (T4)	470 (68)	325 (47)	20	Aircraft structures, rivets, truck wheels, screw machine products
6061	A96061	1.0 Mg, 0.6 Si, 0.30 Cu, 0.20 Cr	Heat treated (T4)	240 (35)	145 (21)	22–25	Trucks, canoes, railroad cars, furniture, pipelines
7075	A97075	5.6 Zn, 2.5 Mg, 1.6 Cu, 0.23 Cr	Heat treated (T6)	570 (83)	505 (73)	11	Aircraft structural parts and other highly stressed applications

Aluminum and Its Alloys

Table 12.7 Compositions, Mechanical Properties, and Typical Applications for Several Common Aluminum Alloys

Aluminum Association Number	UNS Number	Composition (wt%)[a]	Condition (Temper Designation)	Mechanical Properties: Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications/ Characteristics
Cast, Heat-Treatable Alloys							
295.0	A02950	4.5 Cu, 1.1 Si	Heat treated (T4)	221 (32)	110 (16)	8.5	Flywheel and rear-axle housings, bus and aircraft wheels, crankcases
356.0	A03560	7.0 Si, 0.3 Mg	Heat treated (T6)	228 (33)	164 (24)	3.5	Aircraft pump parts, automotive transmission cases, water-cooled cylinder blocks

T4 *– Solution heat-treated and naturally aged to a substantially stable condition*

T6 *– Solution heat-treated and then artificially aged.*

Magnesium and Its Alloys

- Very low density: 1.74 Mg/m^3 (Al: 2.7 Mg/m^3)
- HCP
- relatively soft
- **low E** (*45GPa*) (but better than ………)
- But:
  - Expensive,
  - Difficult to cast,
  - Low strength,
  - Low creep, fatigue and wear resistance
  - Low room temp. ductility (hcp) so cold-working limited.
- Fabricated by casting - (melts at 651°C) or hot-working (200-350°C).
- Used for weight saving applications; *Missiles, luggage, laptops, cellphones, chainsaws, cameras….*

Magnesium and Its Alloys

Table 12.8 Compositions, Mechanical Properties, and Typical Applications for Six Common Magnesium Alloys

ASTM Number	UNS Number	Composition (wt%)[a]	Condition	Mechanical Properties: Tensile Strength [MPa (ksi)]	Yield Strength [MPa (ksi)]	Ductility [%EL in 50 mm (2 in.)]	Typical Applications
Wrought Alloys							
AZ31B	M11311	3.0 Al, 1.0 Zn, 0.2 Mn	As extruded	262 (38)	200 (29)	15	Structures and tubing, cathodic protection
HK31A	M13310	3.0 Th, 0.6 Zr	Strain hardened, partially annealed	255 (37)	200 (29)	9	High strength to 315°C (600°F)
ZK60A	M16600	5.5 Zn, 0.45 Zr	Artificially aged	350 (51)	285 (41)	11	Forgings of maximum strength for aircraft
Cast Alloys							
AZ91D	M11916	9.0 Al, 0.15 Mn, 0.7 Zn	As cast	230 (33)	150 (22)	3	Die-cast parts for automobiles, luggage, and electronic devices
AM60A	M10600	6.0 Al, 0.13 Mn	As cast	220 (32)	130 (19)	6	Automotive wheels
AS41A	M10410	4.3 Al, 1.0 Si, 0.35 Mn	As cast	210 (31)	140 (20)	6	Die castings requiring good creep resistance

[a] The balance of the composition is magnesium.

Designation of Magnesium Alloys

For example, the alloy AZ91C-T6

- The principle alloying elements are aluminum (A), 9 percent and zinc (Z), 1 percent *{note: the numbers are rounded off}*
- The letter C, the third letter of the alphabet, indicates that this is the third alloy standardized, after A and B, which were the first and second alloys, respectively, that were standardized.
- **T6** indicates that this alloy has been solution treated and artificially aged.
- The temper of the material, indicated by the same symbols used for Al-alloys

Titanium and Its Alloys

- ✓ Medium density 4.54 Mg/m^3 (steel 7.9 Mg/m^3)
- ✓ High melting point (1668˚C)
- ✓ But relatively strong. $\sigma_{YS} \approx 800$ MPa (max ≈ 1100 MPa)
- ✓ Stiffer than Aluminium; 107 - 116 GPa vs 70 GPa but not as stiff as steel (207 GPa).
- ✓ Highly ductile
- ✓ Good corrosion resistance
- ✓ Good strength to weight ratio
- ✓ Expensive production due to reactivity at high temperature.

Almost all Ti alloys contain aluminum

- Al increases ductility, and
- reduces density

Titanium and Its Alloys

"Pure" titanium has lower strength, but more **corrosion resistant** and **less expensive**

Table 12.9 Compositions, Mechanical Properties, and Typical Applications for Several Common Titanium Alloys

				Average Mechanical Properties			
Alloy Type	*Common Name (UNS Number)*	*Composition (wt%)*	*Condition*	*Tensile Strength [MPa (ksi)]*	*Yield Strength [MPa (ksi)]*	*Ductility [%EL in 50 mm (2 in.)]*	*Typical Applications*
Commercially pure	Unalloyed (R50500)	99.1 Ti	Annealed	484 (70)	414 (60)	25	Jet engine shrouds, cases and airframe skins, corrosion-resistant equipment for marine and chemical processing industries
α	Ti-5Al-2.5Sn (R54520)	5 Al, 2.5 Sn, balance Ti	Annealed	826 (120)	784 (114)	16	Gas turbine engine casings and rings; chemical processing equipment requiring strength to temperatures of 480°C (900°F)
Near α	Ti-8Al-1Mo-1V (R54810)	8 Al, 1 Mo, 1 V, balance Ti	Annealed (duplex)	950 (138)	890 (129)	15	Forgings for jet engine components (compressor disks, plates, and hubs)
α-β	Ti-6Al-4V (R56400)	6 Al, 4 V, balance Ti	Annealed	947 (137)	877 (127)	14	High-strength prosthetic implants, chemical-processing equipment, airframe structural components
α-β	Ti-6Al-6V-2Sn (R56620)	6 Al, 2 Sn, 6 V, 0.75 Cu, balance Ti	Annealed	1050 (153)	985 (143)	14	Rocket engine case airframe applications and high-strength airframe structures
β	Ti-10V-2Fe-3Al	10 V, 2 Fe, 3 Al, balance Ti	Solution + aging	1223 (178)	1150 (167)	10	Best combination of high strength and toughness of any commercial titanium alloy; used for applications requiring uniformity of tensile properties at surface and center locations; high-strength airframe components

Format: Titanium alloyed with 6% Aluminum, 4% Vanadium ==> Ti-6Al-4V

Nickel and Its Alloys

- ✓ Nickel: FCC (*tough and ductile*)
- ✓ Good high and low temperature strength, high oxidation resistance
- ✓ Highly resistant to corrosion especially alkaline.
- ✓ Highly desirable material, but extremely expensive
- ✓ Primary Nickel reserves in **……………** and New Caledonia

- Nickel is often coated or plated on some metals that are susceptible to corrosion as a protective measure.
- **Monel**, (65 wt% Ni - 28 wt% Cu & Fe-balance), has very high strength and is extremely corrosion resistant; it is used in pumps, valves, and other components that are in contact with some acid and petroleum solutions. (*also Ni is used in stainless steels and* ***superalloys***)
- **Chromium** improves corrosion resistance and mechanical properties at elevated temperature → Inconel series (*Ni-Cr alloys*)

Superalloys

- High temperature performance (strength)
- Gas turbines, steam turbines, reciprocating engines
- Hot working and casting tools and dies
- Aircraft & space vehicles
- Nuclear and chemical industries

Iron based alloys:

- 32% to 67% Fe, 15% to 22% Cr and 9% to 38% Ni.
- common alloys: *Incoloy* series

Cobalt based alloys:

- 30% to 65% Co, 19% to 30% Cr and up to 35% Ni.
- they retain their strength at high temp. but not as strong as Ni-base superalloys

Nickel based alloys:

- 38% to 76% Ni, up to 27% Cr and 20% Co.
- are the most common superalloys
- common alloys: *Hastelloy, Inconel, Nimonic, Rene and Astroloy* series

Miscellaneous Nonferrous Alloys

- **Cobalt** similar in size, melting point and density to nickel
- less susceptible to hot corrosion, but more susceptible to oxidation
- useful for low stress, long life at high temperature

- **Lead, tin and their alloys**:
  - ✓ Both are mechanically soft and weak,
  - ✓ have low melting temperatures,
  - ✓ are quite resistant to many corrosion environments,
  - ✓ and have recrystallization temperatures below room temperature.

- Many solders are lead-tin alloys.
- Lead & alloys - x-ray shields and storage batteries.

- Tin - a very thin coating on the inside of plain carbon steel cans (tin cans); this coating inhibits chemical reactions between the steel and the food products.

Miscellaneous Nonferrous Alloys

- Zinc: unalloyed zinc also is a relatively soft metal having a low melting temperature and a subambient recrystallization temperature.
- Susceptible to corrosion.
  - Galvanized steel (*the zinc preferentially corrodes and protects the steel*.)
- Common applications of zinc alloys include die-castings - padlocks, automotive parts (*door handles and grilles*), and office equipment.

- Zirconium alloys are ductile and have other mechanical characteristics that are comparable to *titanium alloys* & *austenitic stainless steels*.
- Primary asset is their resistance to corrosion in a host of corrosive media, including superheated water.
- Zirconium is **transparent to thermal neutrons**, alloys used as cladding for uranium fuel in water-cooled nuclear reactors.
- In terms of cost, these alloys are also often the materials of choice for heat exchangers, reactor vessels, and piping systems for the chemical-processing and nuclear industries.

Nonferrous Alloys

NonFerrous Alloys

- **Cu Alloys**
  Brass: Zn is subst. impurity (costume jewelry, coins, corrosion resistant)
  Bronze: Sn, Al, Si, Ni are subst. impurity (bushings, landing gear)
  Cu-Be: precip. hardened for strength
- **Al Alloys**
  - lower ρ: 2.7g/cm³
  - Cu, Mg, Si, Mn, Zn additions
  - solid sol. or precip. strengthened (struct. aircraft parts & packaging)
- **Mg Alloys**
  - very low ρ: 1.7g/cm³
  - ignites easily
  - aircraft, missles electronics, cars
- **Ti Alloys**
  - lower ρ: 4.5g/cm³ vs 7.9 for steel
  - reactive at high T
  - space applic.
- **Noble metals**
  - Ag, Au, Pt
  - oxid./corr. resistant
- **Refractory metals**
  - high melting T
  - Nb, Mo, W, Ta

Next Time

Review for the Final