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METALS

1. Alloys and Phase Diagrams
2. Ferrous Metals
3. Nonferrous Metals
4. Superalloys
5. Guide to the Processing of Metals


Non Ferrous Metals

Nonferrous Metals

Metal elements and alloys not based on iron

- Most important nonferrous metals are aluminum, copper, magnesium, nickel, titanium, and zinc, and their alloys
- Although not as strong as steels, certain nonferrous alloys have corrosion resistance and/or strength-to-weight ratios that make them competitive with steels in moderate to high stress applications
- Many nonferrous metals have properties other than mechanical that make them ideal for applications in which steel would not be suitable

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Aluminum and Magnesium

- Aluminum (Al) and magnesium (Mg) are light metals
  - They are often specified in engineering applications for this feature
- Both elements are abundant on earth, aluminum on land and magnesium in the sea
  - Neither is easily extracted from their natural states
- Principal ore is *bauxite* - mostly hydrated aluminum oxide (Al_2O_3-H_2O) + other oxides

Properties of Aluminum

- High electrical and thermal conductivity
- Excellent corrosion resistance due to formation of a hard thin oxide surface film

- Very ductile metal, noted for its formability
- Pure aluminum is relatively low in strength, *but it can be alloyed and heat treated to compete with some steels, especially when weight is taken into consideration*

Designations of Wrought and Cast Aluminum Alloys (Partial List)

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

Four-digit code number to identify composition

- Two designations to distinguish wrought aluminums from cast aluminums
  - Difference is that a decimal point follows the third digit for cast aluminums, no decimal point for wrought product

Magnesium and Its Alloys

- Lightest of the structural metals
- Available in both wrought and cast forms
- Relatively easy to machine
- In all processing of magnesium, small particles of the metal (such as small metal cutting chips) oxidize rapidly, and care must be taken to avoid fire hazards

Ipod case

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Properties of Magnesium

- As a pure metal, magnesium is relatively soft and lacks sufficient strength for most engineering applications
- However, it can be alloyed and heat treated to achieve strengths comparable to aluminum alloys
- In particular, its strength-to-weight ratio is an advantage in *aircraft* and *missile* components

Copper

- One of the oldest metals known to mankind
- Good electrical conductor - commercially pure copper is widely used as an electrical conductor

- Also an excellent thermal conductor
- One of the *noble metals* (gold and silver are also noble metals), so it is corrosion resistant

Copper Alloys

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

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Coins?!

What are the coins made of?

The Australian 10 cent coin is roughly the same size as a US Quarter.

And an Australian 5 cent coin is roughly the size of a US Dime.

Dimes are made out of an alloy of 91.67 percent copper and 8.33 percent nickel (before 1965, the dime was made out of silver).

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Nickel and Its Alloys

- Similar to iron in some respects:
  - Magnetic
  - Modulus of elasticity ≅ *E* for iron and steel
- Differences with iron:
  - Much more corrosion resistant - widely used as
    1. an alloying element in steel, e.g., *stainless steel*,
    2. as a plating metal on metals such as plain *carbon steel*
  - High temperature properties of Ni alloys are superior

Nickel Alloys

Alloys of nickel are commercially important and are noted for corrosion resistance and high temperature performance

- In addition, a number of superalloys are based on nickel
- Applications: stainless steel alloying ingredient, plating metal for steel, applications requiring high temperature and corrosion resistance

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Titanium and Its Alloys

- Abundant in nature, constituting ~ 1% of earth's crust (aluminum is ~ 8%)
- Density of Ti is between aluminum and iron
- Importance has grown in recent decades due to its aerospace applications where its light weight and good strength-to-weight ratio are exploited

Properties of Titanium

- Coefficient of thermal expansion is relatively low among metals
- Stiffer and stronger than Al
- Retains good strength at elevated temperatures
- Pure Ti is reactive, which presents problems in processing, especially in molten state
- At room temperature Ti forms a thin adherent oxide coating (TiO_2) that provides excellent corrosion resistance

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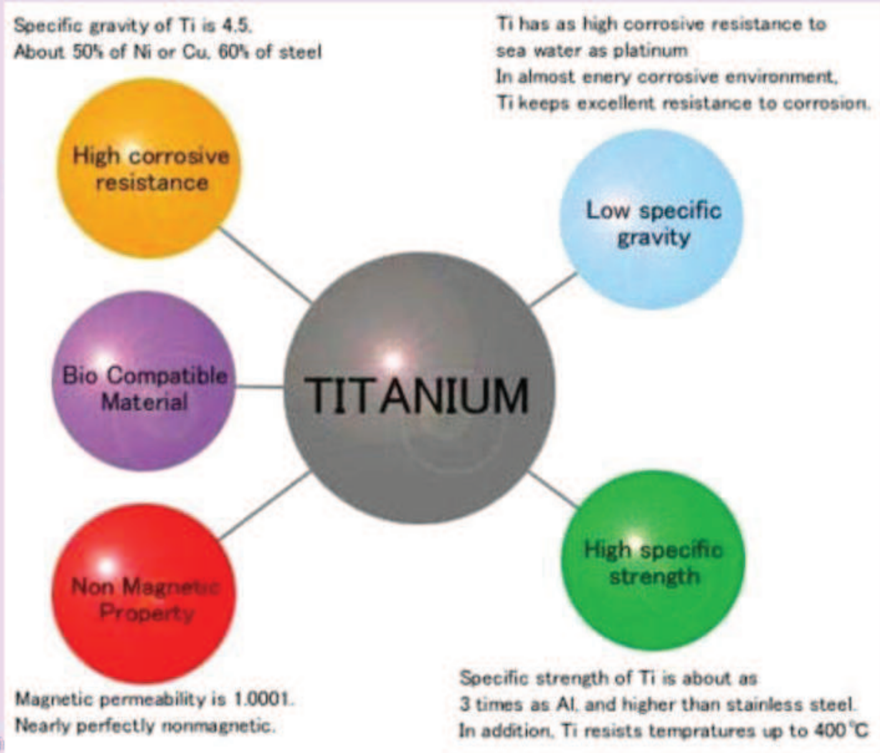
Properties of Titanium



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Applications of Titanium

- In the commercially pure state, Ti is used for corrosion resistant components, such as marine components and prosthetic implants
- Titanium alloys are used as high strength components at temperatures ranging up to above 550°C (1000°F), especially where its excellent strength-to-weight ratio is exploited

Examples: aircraft and missile components

Alloying elements used with titanium include aluminum, manganese, tin, and vanadium

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Summary

Nonferrous Metals

- Aluminum
- Copper
- Magnesium
- Nickel
- Titanium
- Zinc

Aluminum Alloys

- Abundantly Available on Land (Bauxite)
  - ~ 8% of earth's crust
- Light Weight
- More complex ore extraction than steel
- Excellent Thermal & Electrical Conductor
- Great Corrosive Resistance
- Easily Formed

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Aluminum Designations

Major Alloy	Wrought Code	Cast Code
99%+ Pure	1XXX	1XX.X
Copper	2XXX	2XX.X
Manganese	3XXX	
Si + Cu +/- Mg		3XX.X
Silicon	4XXX	4XX.X
Magnesium	5XXX	5XX.X
Magnesium & Si	6XXX	
Zinc	7XXX	7XX.X
Tin		8XX.X
Other	8XXX	9XX.X

Magnesium Alloys

- Mined from sea-water
- Lightest of the structural alloys
- Easy to machine
- Small Mg particles easily oxidize
  - Fire hazard
- 3 to 5 alpha code alloy designation

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Copper Alloys

- One of the Oldest Metals Known
  - ~ 6000 B.C.
- Found in naturally & extracted from ore
  - Chalcopyrite ($CuFeS_2$)
- One of the lowest electrical resistivities
- Noble metal (corrosive resistant)
- Low strength & hardness
- Bronze – when alloyed with Tin
- Brass – when alloyed with Zinc

Nickel Alloys

- Similar strength to iron
- More corrosive resistant than iron
- Commonly used as an alloying element with iron
- Extracted from pentlandite ($(NiFe)_9S_8$)

Titanium Alloys

- Fairly abundant in nature
  - ~ 1% of earth's crust
- Principle ores:
  - Rutile - TiO_2
  - Ilmenite - FeO & TiO_2
- Good strength to weight ratio
- Relatively low thermal expansion
- Stiffer & stronger than aluminum
- Good hot hardness
- Excellent corrosion resistance

Superalloys

Superalloys

High-performance alloys designed to meet demanding requirements for strength and resistance to surface degradation at high service temperatures

- Many superalloys contain substantial amounts of three or more metals, rather than consisting of one base metal plus alloying elements
- Commercially important because they are very expensive
- Technologically important because of their unique properties

Why Superalloys are Important

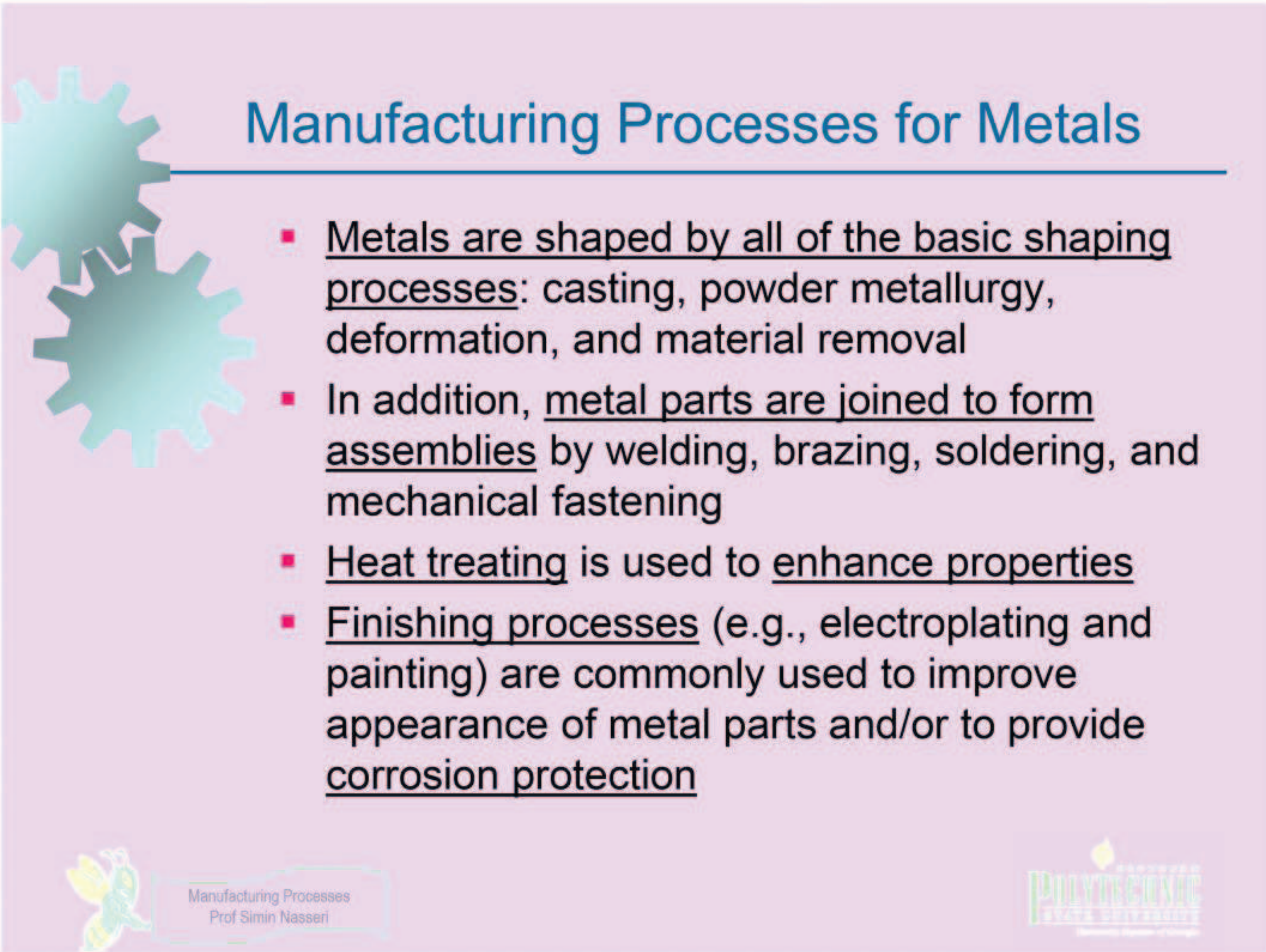
- Room temperature strength properties are good but not outstanding
- High temperature performance is excellent - tensile strength, creep resistance, and corrosion resistance at very elevated temperatures
- Operating temperatures often around 1100°C (2000°F)
- Applications: gas turbines - jet and rocket engines, steam turbines, and nuclear power plants (all are systems in which operating efficiency increases with higher temperatures)

Three Groups of Superalloys

1. Iron-based alloys - in some cases iron is less than 50% of total composition
   - Alloyed with Ni, Cr, Co
2. Nickel-based alloys - better high temperature strength than alloy steels
   - Alloyed with Cr, Co, Fe, Mo, Ti
3. Cobalt-based alloys - ~ 40% Co and ~ 20% chromium
   - Alloyed with Ni, Mo, and W

- In virtually all superalloys, including iron based, strengthening is by precipitation hardening


Manufacturing Processes for Metals


Manufacturing Processes for Metals
Metals are shaped by all of the basic shaping processes: casting, powder metallurgy, deformation, and material removal
In addition, metal parts are joined to form assemblies by welding, brazing, soldering, and mechanical fastening
Heat treating is used to enhance properties
Finishing processes (e.g., electroplating and painting) are commonly used to improve appearance of metal parts and/or to provide corrosion protection
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How to Enhance Mechanical Properties

- Alloying - to increase strength of metals
- Cold working - strain hardening during deformation to increase strength (also reduces ductility)
  - Strengthening of the metal occurs as a byproduct of the forming operation
- Heat treatment - heating and cooling cycles performed on a metal to beneficially change its mechanical properties
  - Operate by altering the microstructure of the metal, which in turn determines properties