Module 4

ENGINEERING MATERIALS

Steels - classification

- Steels – Alloys containing up to 2% C
- Cast Iron – 2 to 4.3% C
- Plain Carbon Steels: C is the main alloying element
- Alloy steels: in addition to C, one or more other metallic elements also present
- Low C steels: 0.1 to 0.3%
- Medium C steels: 0.3 to 0.6%
- High C steels: 0.6 to 1.2%

Alloy steels

- Alloy steels: Carbon steels to which 1 or more elements are added to obtain some positive effects
- Mn, Ni, W, Cu, B, Si, Al, Cr, Mo, V
- Leads to improvements in properties of C steels
- Have higher hardness, strength, toughness, corrosion and oxidation resistance

Effects of Alloying elements on Dislocation movement

- Introduction of impurity atoms creates a pinning point for dislocations
- An alloying element is by nature a point defect
- It creates a stress field (due to size) when placed in to another crystallographic position
- The alloying atom may have a different elastic modulus
- Reduce dislocation mobility; increase strength and hardness

Effects of Alloying elements on

Polymorphic transformation temperature

- α-γ transformation at A_3 (912˚C) and γ-δ transformation at A_4 (1394˚C)
- δ –ferrite, γ-austenite, α-ferrite exist in distinct regions of phase diagram
- Mo, Cr, W, Si, V, Ti raise the A3 temp and lower the A4 temp…….
- Contract γ region and enlarge ferrite region
- Ni, Mn, Cu, Co has the opposite effect

- Cr, Mo, and W form very stable carbides and favour precipitation of carbides
- In second case carbon tends to remain in solid solution in the austenite

Effects of Alloying elements on
Strengthening of Ferrite

- Most of the alloying elements form solid solutions with ferrite
- Increase the hardness and strength
- Ni, Al, Si, Cu have better solubility in ferrite
- The effectiveness of strengthening is low

Effects of Alloying elements on

Formation and stability of Carbides

- Alloying elements may combine with C to form Carbides
- These are hard and brittle, hence provide better hardness and wear resistance
- Carbides of Cr and V have very high hardness and wear resistance
- Also act to reduce grain growth
- Ni, Al, Si don’t form carbides in the presence of iron and causes instability of iron carbide
- Ti and Niobium have very strong crbide forming tendencies
- Cr, Mo, W, V, Mn also form carbides
- When more than one is added Complex carbides formed

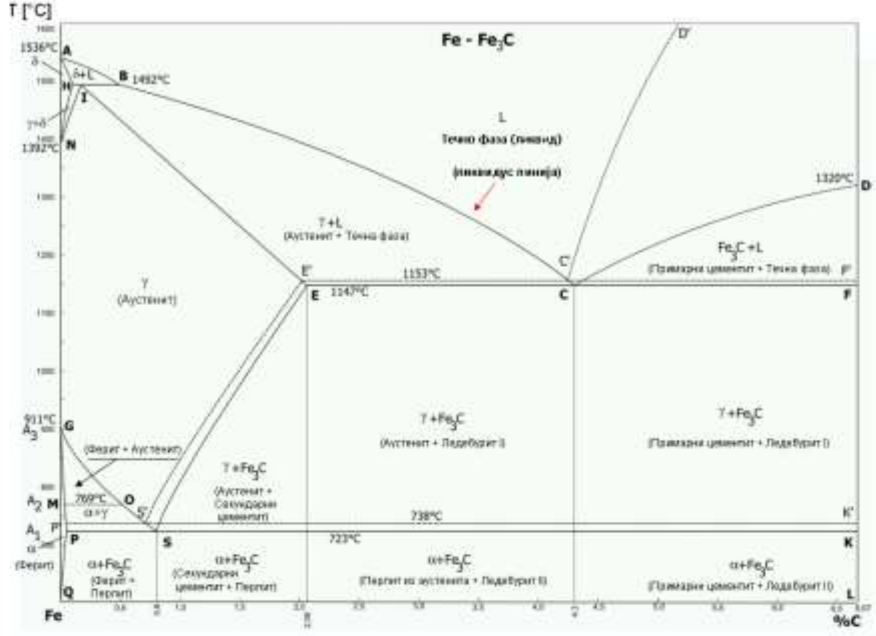
Effects of Alloying elements on

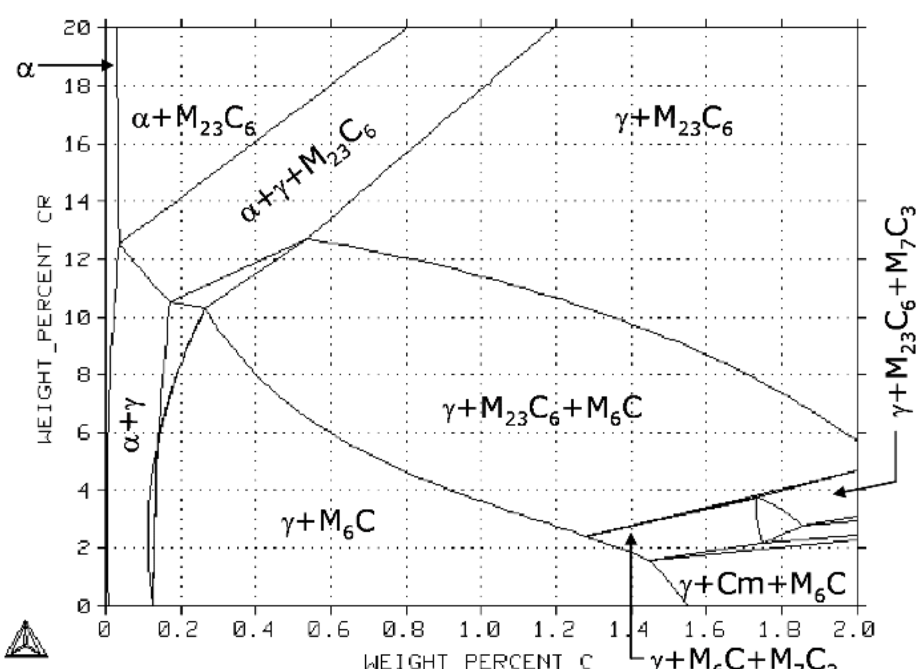
Displacement of the eutectoid point

- Affects equilibrium conditions
- Change position of eutectoid point and the positions of α and δ phase fields
- Most of the alloying elements shift Eutectoid composition to lower C content values
- Presence of Ni and Mn lowers the Eutectoid temperature

Effects of Alloying elements on Retardation of transformation temp:

- Austenite transformation temp is shifted up or down by alloying elements
- Ni and Mn content lower Austenite transformation temp – postpone transformation of Austenite on slow cooling
- Austenite stabilizers





Fe-4Mo-Cr-C @ 1000°C

Effects of Alloying elements on

Lowering of critical cooling rate

- Due to alloying elements TTT curve is displaced to right side
- ie, CCR required for transformation of Martensite is decreased and leads to better hardenability
- Makes possible to obtain a hard Martensitic structure throughout
- Cr, Mo, Mn, Ni are more effective
- One of the most useful feature of Alloying

Effects of Alloying elements on

Improvement in corrosion resistance

- Thin oxide layers and protection against corrosion
- Al, Si, Cr
- Cr only when a min: 13% is added

Effects of Alloying elements on Grain growth

- Accelerate grain growth and increase brittleness
- Cr is the most important
- Ni, V retard grain growth
- Grain refiners

Functions of alloying elements

- Mn
- Present in all steels and functions as a deoxidiser
- It forms MnS and takes care of the negative effects of residual S content
- 0.5-2% to increase hardness and strength
- Also improves hardenability

- Mo
- Relatively expensive
- Found in high strength structural steels
- Also added to Cr-Ni steels to improve resistance to corrosion
- Improves hardenability and eliminates brittleness
- 0.1-0.4%
- Forms carbides having high red hardness and wear resistance

- Ni
- First alloy steels to be used in large engg structures
- Increases strength and toughness of steels; least effect on hardness
- Increase impact resistance at low temperatures
- 1-5%
- In SS above 8% is added – improve corrosion resistance

- <u>Cr</u>
- Less expensive and most common
- 0.5-4%
- Forms carbides having high hardness and wear resistance
- Increases hardenability, strength and wear resistance
- Added to tool steels, structural steels and SS
- In SS 12% or more is added
- High temp proprties and corrosion resistance are greatly improved when added in excess of 5%

- Vanadium
- A powerful deoxidiser, strong carbide former and prevents grain growth
- Expensive
- Increase hardenability, elastic limit, fatigue and wear resistance
- 0.1-0.3%

- <u>Tungsten</u>
- Forms hard and stable carbides
- Excellent wear resistance and hardness
- 2-3% to tool steels and heat resisting steels

- <u>Cobalt</u>
  - Increases heat and wear resistance
  - High cobalt alloy steels, known for excellent corrosion resistance over a wide range of temperatures
  - Also increases cutting efficiency and red hardness of tool steels

<u>Silicon</u>

- Added up to 0.3% as deoxidizer
- Forms SiO_2 and eliminates the presence of oxygen
- 1.5 to 2.5 %to improve strength and toughness
- Also increases magnetic permeability of steels used for transformers and motors

- <u>Cu</u>
- 0.15-0.25% is normally added to improve corrosion resistance
- Also promotes precipitation hardening thereby higher strength and hardness

- <u>Lead</u>
- Up to 0.35%
- Improve machinability
- Doesn’t affect other properties like ductility, toughness etc

- Ti
- Strongest carbide former
- Added up to 1%
- Strength and corrosion resistance improves
- **Sulphur**
- Up to 0.33% to increase machinability
- Higher amounts is undesirable
- Can be overcome by adding Mn
- **Phosphorus**
- Present as a residue
- Upto 0.12% - increase strength, hardness, corrosion resistance and machinablity
- Higher phosphorous content may lead to cold shortness

- <u>Al</u>
- Most active deoxidizer
- 0.01-0.06%
- Controls grain growth – fine grained steels

- **<u>Boron</u>**
- 0.001-0.005%
- Increase hardenability
- Increases depth of hardening during quenching

Nickel-Steels

- Most fundamental alloying element in steel
- Highly soluble in γ and ferrite phases
- Contributes to strength and toughness
- Lowers critical temperature
- Retards transformation of austenite; doesn't form any carbides
- Shifts the position of eutectoid point – lowers C content of Eutectoid alloy
- Pearlite is formed at lower temp
- Have better toughness, plasticity and fatigue resistance
- Mild effect on hardenability

Chromium steels

- Less expensive alloying element
- Forms carbides having high hardness and wear resistance
- Cr is soluble up to 13% in γ-iron and unlimited solubility in α-ferrite
- More than 5% - high temp properties and corrosion resistance improved
- Plain Chromium steels – 0.7 to 1.15% Cr and 0.15-0.65% C
- Steel containing 1%C and 2-4% Cr – excellent magnetic properties

Nickel-Chromium steels

- Contains both Ni and Cr – with 5:2
- Increased toughness, ductility, hardenability and wear resistance
- Combined effect on hardenability is better

Molybdenum steels

- Relatively costlier element
- Limited solubility in γ and α irons and is a strong carbide former
- Has a good effect on hardenability and increases high temperature hardness and strength of steel
- Used along with Cr, Ni or both
- Ni-Cr-Mo steels have the advantages Ni-Cr steels along with high hardenability due to Molybdenum
- Aircraft industry

High Speed Steels

- Steels which maintain high hardness at temperature up to 550˚C
- Can be used as cutting tools at high speeds at which high temperatures are developed
- Presence of wear resistant carbides makes HSS suitable
- Possesses high wear resistance, excellent red hardness, good shock resistance, machinability

W based and Molybdenum based HSS

- Tungsten HSS – W is the principal alloying element with additions of Cr, V, and Co
- Molybdenum HSS – in addition Mo is also present
- Formation of alloy carbides: retain hardness at high temperatures
- 18% W, 4% Cr, 1% V with 0.6-0.7% C
- 18W4Cr1V or 18:4:1 HSS
- 6W6Mo4Cr1V

- Cobalt is added to HSS to improve red hardness
- V improves hardness and abrasion resistance
- Cr (0.5-12%) increases hardness
- W & Mo provides resistance to softening at high temperatures
- Mn (0.6-2%) improves hardenability
- Si in low amounts increases toughness

Free cutting steels

- Used where free machining is the primary requirement
- Components provide good surface finish even at high temperatures
- 2 types:
  - High sulphur steels (0.33%S,0.12%P)
  - Leaded steels (0.35%Pb)
- Improves machinability

Rail steels

- Steels used for railway tracks
- Good combination of strength and ductility along with high impact and fatigue resistance
- Mn and Cr up to 1% improves these properties

Spring steels

- Used for springs subjected to compression, tension & torsion
- Should possess high elastic limit, good elongation, high fatigue resistance
- Mn and Si
- Si is replaced by a combination of Cr, Ni, V

Tool steels

- Used for machining and shaping metals
- To make tools: chisels, hammers, punches, cutting tools
- Tool steels: high hardness, wear resistance, toughness etc (also at high temps:)
- Attained by the addition of Cr, W, Mo, V, Mn, Si, Co to high C steels
- Grouping: cold work tool steels

  Hot work tool steels

  High speed tool steels

  special purpose tool steels

HSLA Steels

- Improvement in strength is achieved through addition of ***small quantities*** of alloying elements
- Possess high strength to weight ratio
- Attractive balance of toughness, fatigue resistance and formability
- C content 0.07-0.13%
- Ti, V, Al – less than 0.5%
- Known as micro alloyed steels

TMT Steels

- Thermo Mechanically Treated (TMT) steel
- TMT steel bars widely used as structural material
- 0.17-0.24% C, 0.05% S, 0.045% P
- TM Treatment………….

Stainless Steels

- Used where corrosion and oxidation resistance is important
- Also have good creep strength
- Cr – main alloying element – it forms a protective film
  a. Ferritic stainless steels
  b. Martensitic stainless steels
  c. Austenitic stainless steels

Ferritic stainless steels

- Contain 16-25% Cr, 0.12-0.2% C
- The steel is in the ferritic state
- Strength is increased by cold working followed by grain refinement through annealing
- High Cr content – excellent corrosion and oxidation resistance
- For house hold appliances, transportation industry
- **Martensitic SS** : 12-14% Cr, up to 0.15% C
- Respond to heat treatment
- Low C – Martensite formed isn't brittle
- Cutlery items, surgical instruments, ball bearings

Austenitic SS

- Austinite is stable at even room temp.
  So not heat treatable
- Very good formability
- 18% Cr, 8% Ni, 0.08%C
- Addition of 2% Mo gives better resistance to pitting corrosions
- 18/8 steels have excellent formability
- House hold articles, sanitary fittings, vessels in chemical industry

Duplex stainless steels

- Have a 2 phase mic: consisting of grains of ferritic and austenitic structure – Duplex
- When melted it solidifies to a completely ferritic structure
- As cooled to room temp: about half of the ferritic grains transform to austenitic grains
- Have twice the strength of Austenitic SS
- Resistance to pitting corrosion, crevice corrosion, and stress corrosion cracking
- Better toughness and ductility
- N addition – improved strength, corrosion resistnce

Sensitization in SS

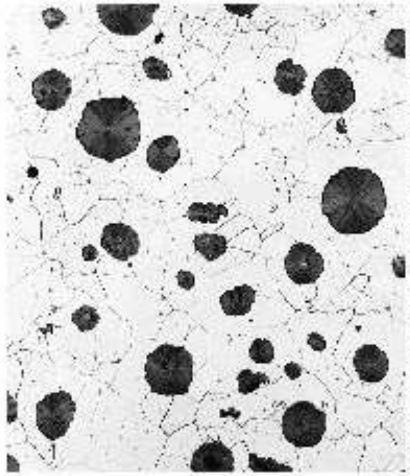
- Is the precipitation of Cr Carbide along the grain boundaries of SS leading to intergranular corrosion.
- Phenomenon which happens in SS heated between 400 to 850^{o}C
- To prevent this SS is heated to 1060 to 1120^{o}C And water quenched (Solution annealing/quench annealing/solution quenching)
- C content is <0.03% insufficient for carbide formation and sesitization is prevented

Cast Irons

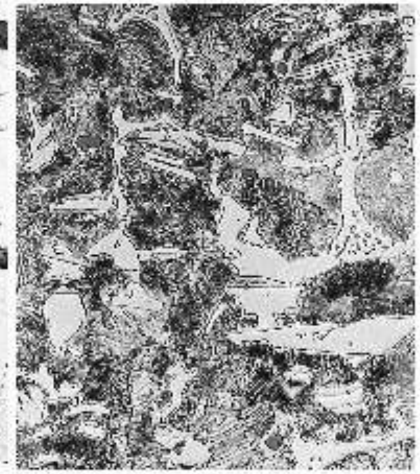
- Most of the *CI* contains 3-4.5% C
- Fe-C alloys in this range becomes completely liquid b/w 1150-1300˚C aprox:
- Thus they are easily melted and cast
- Most *CIs* are brittle; hence casting is convenient

Microstructures of Cast Iron

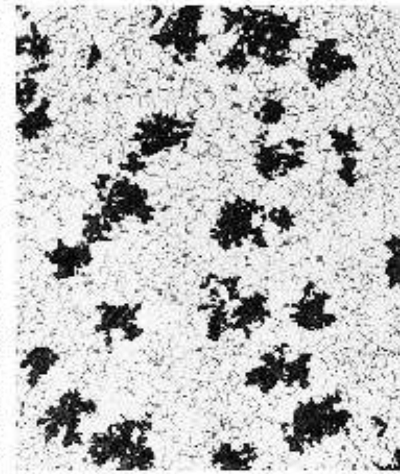
Gray iron
α Fe and
graphite flakes



Nodular iron
α Fe and
graphite spheres

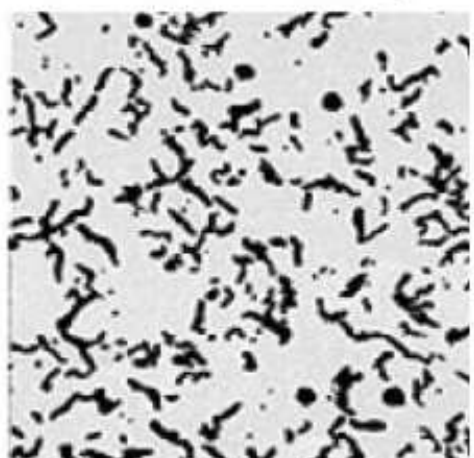


White iron
cementite and
pearlite



Malleable iron
α Fe and
tempered
graphite flakes

low melting point, castable, cheap; however, can be brittle.



Compacted Graphite Iron

Characteristics of Cast Irons

- Low melting temperatures with good fluidity
- Low cost material (low cost raw material & tech.)
- Higher compressive strength, damping capacity, wear resistance, rigidity, machinability
- Variety of mic: can be developed
- Alloy CIs - high corrosion and heat resistance
- Not ductile to be rolled, drawn, or mechanically worked

CI classification

- Factors that control the structure & appearance
- 1) C content:

  - C is present either as Fe_3C or as free C (Graphite)

  - when alloyed, alloy carbides are formed

  - free C can exist as flakes, irregular shaped globules (rosette) or as round nodules
- 2) presence of other elements:
  - Some present as impurities
  - Some form carbides

  - some, stabilize carbide, and keep C in the combined form

  - others have a graphitizing effect

- 3) cooling rate:

  higher- help formation of carbides

  slow- help C to be in free form

- 4) Heat treatments:

  - Helps either the formation of carbides or decomposition of Fe_3C into free C

  - when C decomposed, it causes changes in shape, size & distribution of graphite particles

Gray Cast Iron

- Contains 2.5-3.5% C, 1-2.8% Si
- Mn, S, Phosphorous may also be present
- C exists in the form of graphite flakes in a matrix of α-ferrite or Pearlite
- Moderate cooling – Pearlite matrix
- Slow cooling – Ferrite matrix
- Due to presence of graphite flakes, a fractured surface appears gray in color

- Low strength and brittle in tension
- Under compressive loads, strength and ductility higher
- Low melting point, good fluidity, castability, machinability, damping capacity, impact strength
- Lowest production cost – widely used CI
- AUTOMOBILE PARTS: cylinder block, cylinder head, underground pipes, c/f pump parts, m/c tool beds, house hold appliances etc.

Ductile (Nodular) CI

- When Mg or Cerium added to Gray iron before casting leads to different mic:
- C exists as Graphite, in the form of nodules or speroids instead of flakes – **Nodular CI** or **SG iron**
- Depending on the cooling rate matrix phase is either Pearlite or Ferrite
- 3-4.3% C, 1-3.5% Si, 0.3-0.8% Mn, 0.03% S, 0.08%Phosphorous
- Stronger and much ductile than gray iron
- Comparable properties with steel
- Automobile parts, farm machinery, earth moving machinery, rolls, gears, valves

White Cast Iron

- CIs containing lower Si content, on rapid cooling results in a mic: in which C exists as Fe_3C
- Fracture surface of this alloy has a white appearance
- 2-3.5% C, 0.5-1.3%Si, 0.2-0.8%Mn, 0.18%S, 0.1%P
- Due to large amounts of Fe_3C, this CI is very hard and brittle
- Also good wear resistance, high comp: strength
- Difficult to machine
- Pump liners, rollers, for production of malleable iron

Malleable Iron

- Produced from white iron using a heat treatment process – Malleabilising
- White iron is heated above 700˚C – soaking – cooling
- Cementite in white iron decomposes in to graphitic C with an irregular shaped globules (rosette)
- Matrix is either pearlite or ferrite
- Mic: similar to ductile CI (fig)
- High strength compared to white/malleable
- Vibration and wear resistance

- High strength compared to white/malleable
- Vibration and wear resistance
- Proper HT – wide range of properties can be obtained
- Automobile, electrical and railway industries
- For brackets, brakedrum, cam-crank shafts, agricultural machinery

- Grey & ductile commonly used

  white and malleable in small quantities

Wrought iron

- An alloy with very low C content and added with tiny fibrous inclusions of iron silicate (slag)
- Presence of slag changes the chemical properties of iron – a new alloy formed
- Good strength under tensile pressure, resistance to corrosion, malleability
- Upon rusting, it distributes the rust in to a beautiful brownish finish – good surface finish
- Lacks the C content necessary for hardening

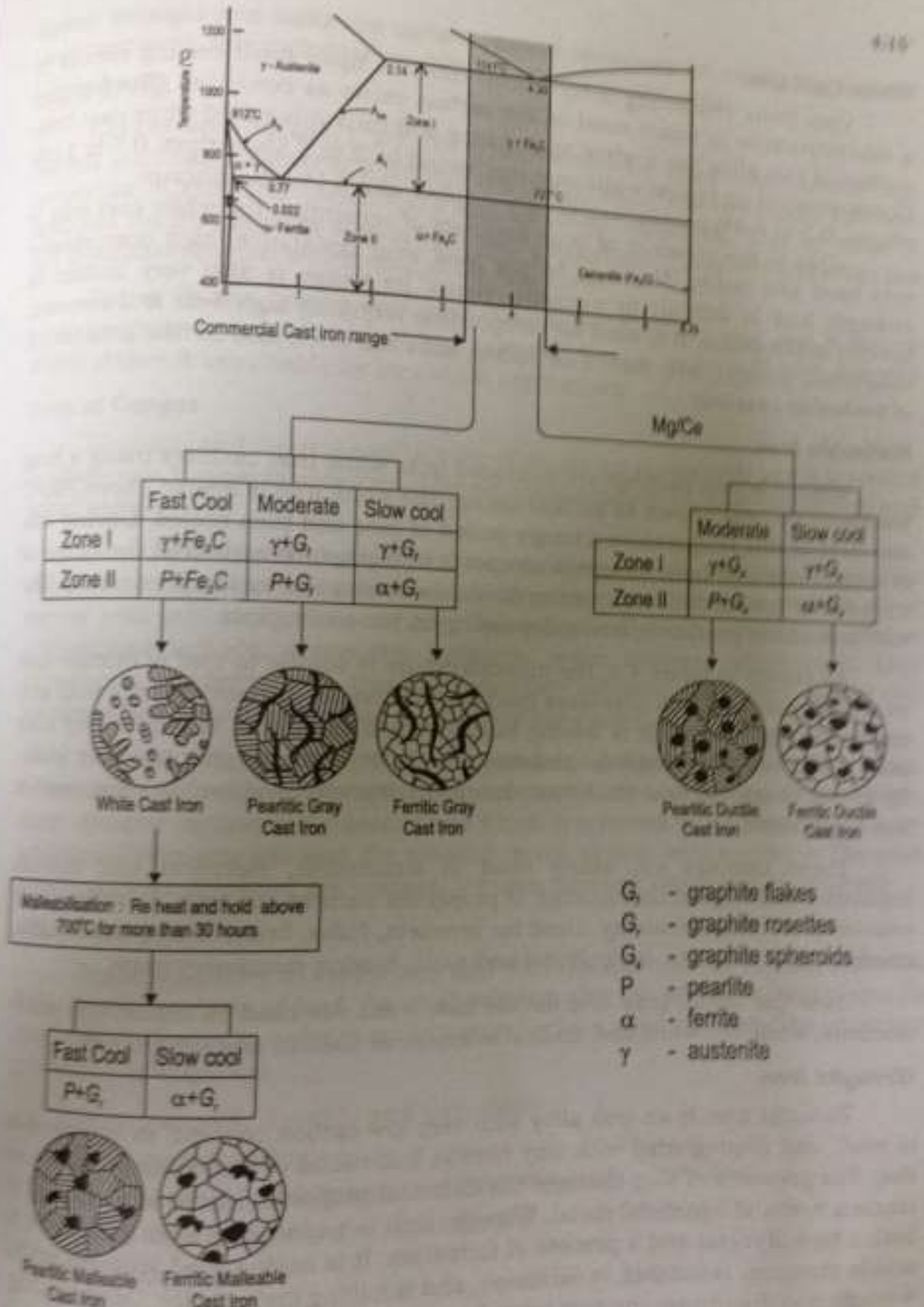


Figure 4.2 *Different types of cast irons*

Non Ferrous Alloys

Copper

- Most extensively used
- Two most important properties: electrical conductivity and corrosion resistance
- Second place among engg materials
- Can be easily machined, welded, brazed, soldered
- Lacks strength

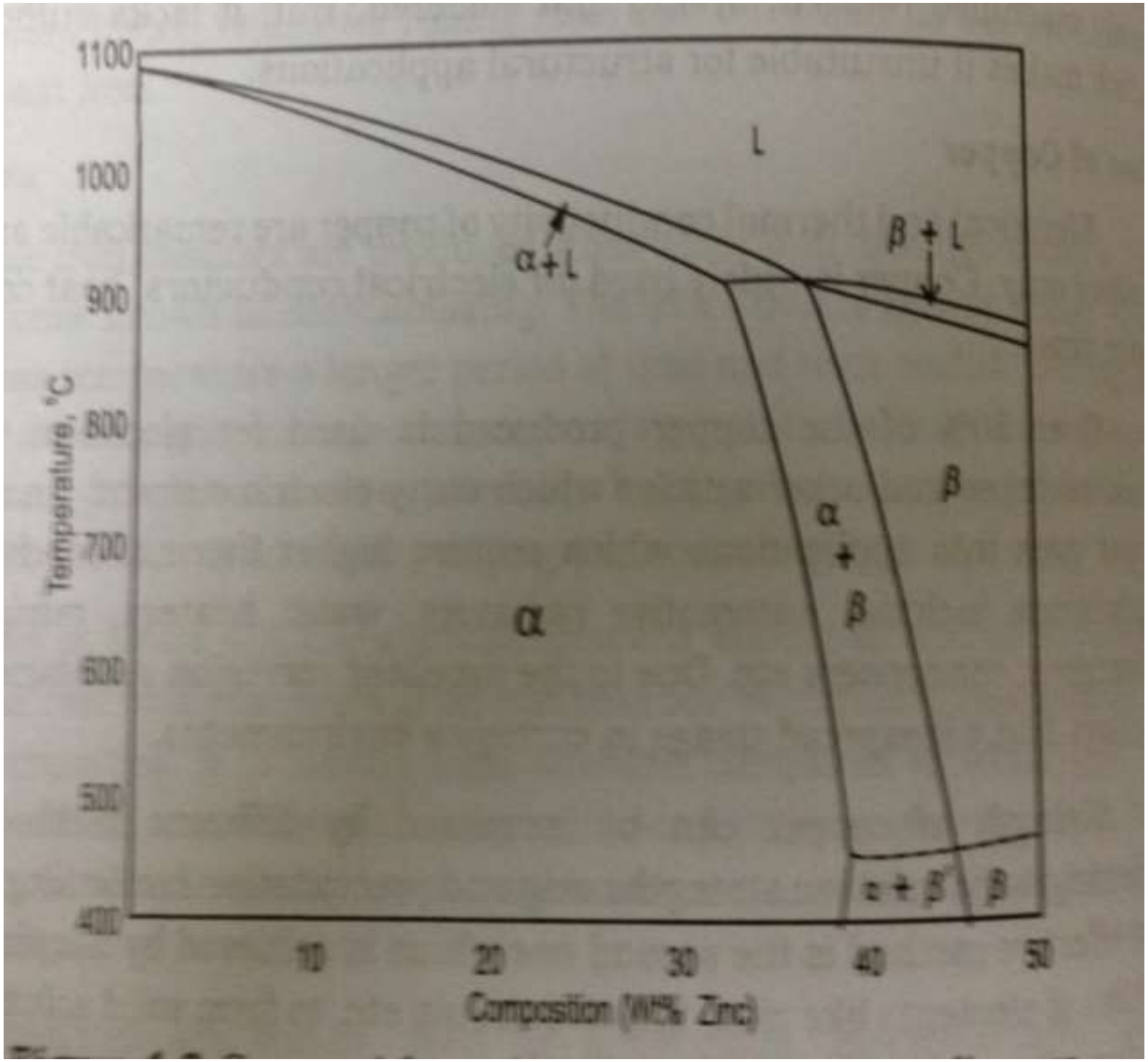
Uses

- Electrical conductors, heat conductors
- Over 50% is used for electrical purposes – wires, switches…
- Applications which require higher thermal conductivity – radiators, water heaters, refrigerators, heat exchangers
- Excellent corrosion resistance – used in corrrossive environments
- Cu Strengthening methods – strain hardening, solid solution strengthening, precipitation hardening…
- Alloying with Zn, Tin, Al…
- Solid solutions are Brasses, Bronzes…

Brasses

- Alloy of Cu and Zn – 5 to 54% Zn
- Also Pb, Tin, Al
- Wide variety of Brasses are used today
- Cu-Zn phase diagram

- Cu-Zn phasediagram



- Cu and α solid solution – FCC and β – BCC
- In β, Cu and Zn atoms randomly dispersed at lattice points
- An ordered structure β' – Cu at corners and Zn at body centers of BCC
- Based on solid solution formed:

  α-brsses

  Duplex Brasses

- **α Brasses**
- Cu can dissolve up to 38% Zn to form FCC structure called α phase
- Brasses containing only α phase – α Brasses
- Highly ductile at room temperature – easily deformed by cold working, corrosion resistance
- Types
- **Yellow α brass**: lower Cu content (20-36%)
- Yellow color
- Good corrosion resistance
- **Cartridge Brass:** used for cartridge and shell cases of rifles
- 70% Cu 30% Zn
- High strength, ductility

- **Admiralty Brass:** Tin in small% added to improve resistance to certain types of corrosion
- Suitable for marine applications
- 71% Cu, 28% Zn, 1% Sn
- Tubes for condensers, heat exchangers…
- **Aluminium Brass**: 76% Cu, 22% Zn, 2% Al
- Better corrosion resistance
- Marine applications
- **Red α Brass:** Zn content in the range 5 to 20% only
- Higher Cu content – red appearance
- Good corrosion resistance, workability
- Variants of this category…

- **Gilding metal:** α Brass with highest Cu content (95% Cu, 5% Zn)
- Closely matches gold in color
- Softest type of brass
- High ductility, corrosion resistance
- Coins, medals, jewellary…
- **Leaded red brass:** Pb, Sn, Zn in 5% each to Cu
- Also called three fives
- Pressure valves, pipe fittings, pump castings…
- Good strength, machinability

Duplex or (α+β) Brasses

- Zn content beyond 38% results in (α+β) brass
- At lower temperatures β changes to β’ phase making the alloy harder and brittle
- At high temp: changes back to β phase
- Good strength, suitable for hot working
- Types:
- **Muntz metal: 60**% Cu, 40% Zn
- Springs, chains
- Also as a brazing alloy for steel

- **Naval Brass:** 1%Sn with 60% Cu, 39% Zn
- Tin improves corrosion resistance – used in contact with sea water
- Propeller shafts, valves, impellers…
- **Forging Brass:** 60% Cu, 38% Zn, 2% Pb
- Best hot working properties
- For hardware and plumbing parts

Bronzes

- Alloys of Cu with elements other than Zn
- Simplest bronze – 88% Cu with 12% Sn
- Pb, Ni, P, Al, Si also added
- Zn may also be present in very small%
- Softer and weaker than steel
- Better heat and electric conductivity
- Costlier than steel
- Good castability, anti-friction properties
- Bearings, springs, bells, statues

- **Tin Bronze:** 88-98%Cu, 1-11% Sn, 0.1-0.5% P
- Tin improves wear and corrosion resistance
- P acts as deoxidiser, also contributes to hardness
- Also called *phosphor Bronze*
- **Gun metal:** Zn replaces P in tin bronze
- 88% Cu, 10% Sn, 2%Zn
- Marine components
- **Aluminium Bronze:** alloys of Cu and Al (4-11%)
- Other elements: Fe, Ni, Mn, Si also added
- Better strength and corrosion resistance
- called imitation gold

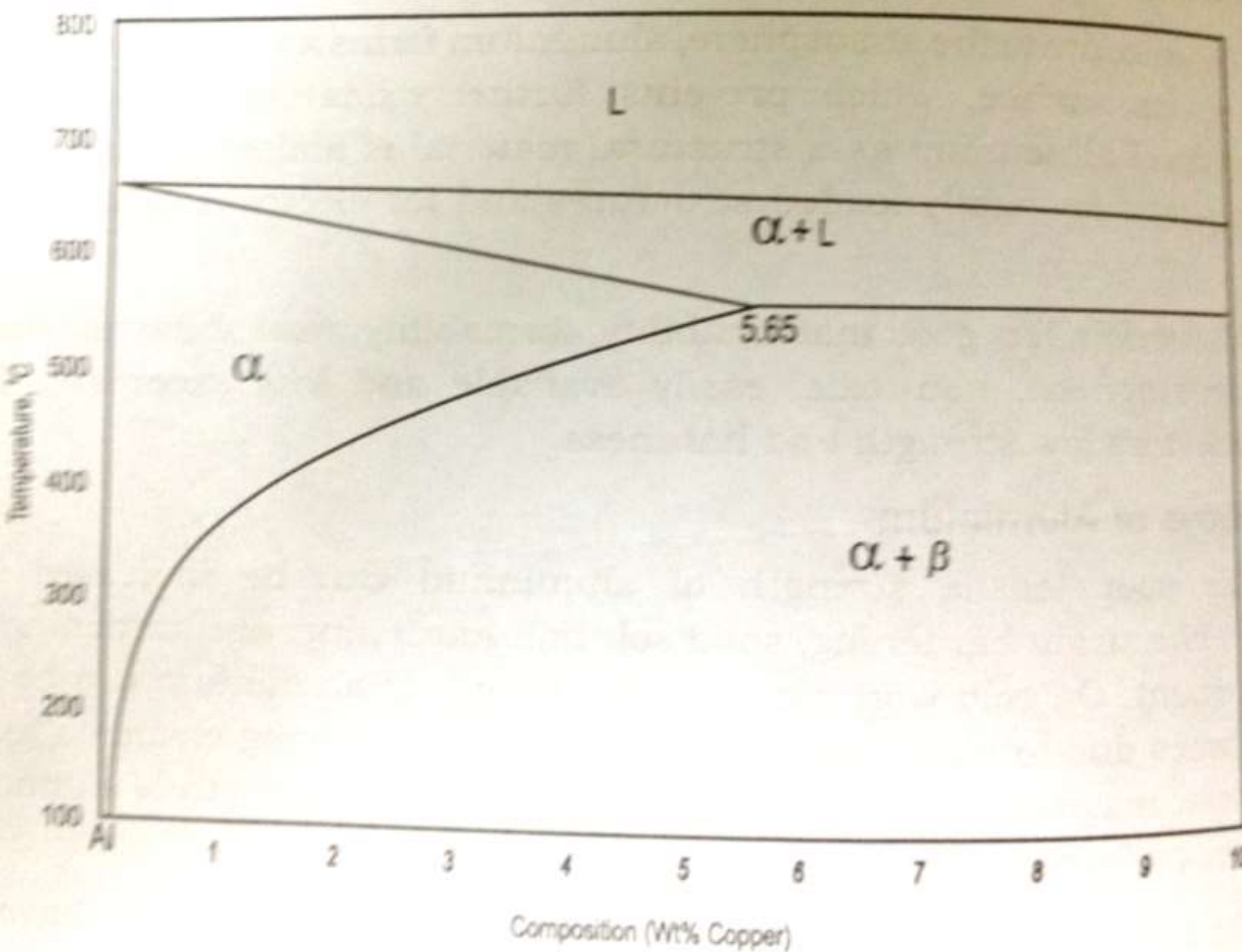
- **Silicon Bronze:** Cu-Si alloys (1-4% Si)
- Small amounts of Mn, Zn, Fe
- Si improves strength
- Rivets, bolts, nuts…
- **Beryllium Bronze:** Cu-Be alloy (0.6-3% Be)
- Attains high strength upon precipitation hardening
- Expensive
- Also called Beryllium Copper
- High elasticity, fatigue resistance
- Used for springs

Aluminium

- 3rd place among engg materials
- Low density, low melting point, high electrical and thermal conductivities
- Low strength and hardness
- High ductility and malleability
- AlO_2 formed prevents further oxidation and corrosion
- Good machinability, formability
- Non magnetic, non toxic, easily available

Al alloys

- Strengthened by strain hardening, solid solution hardening, age hardening, fiber reinforcement
- Alloying elements: Cu, Mn, Mg, Si increase the strength of Al upto 4 times
- Due to increased strength Al alloys widely used in commercial applications
- Duralumin and Y alloy



L
α + L
5.65
α
α + β
Temperature, °C
800
700
600
500
400
300
200
100
Al
1
2
3
4
5
6
7
8
9
10
Composition (Wt% Copper)

- **Wrought alloys:** Al-Mn, Al-Mg alloys - form homogeneous solid solutions
- Lower strength and high ductility
- Other wrought alloys: avial (Al-Mg-Si), Duralumin (Al-Mg-Cu)
- **Casting alloys:** Silumin; Al-Si alloy with Mg, Mn and Cu
- Suitable for casting
- **Duralumin:** 94%Al, 4%Cu, and 0.5% each of Mg,Mn,Si,Fe
- High tensile strength and high electrical conductivity
- For sheets, tubes, forgings,rivets…
- Also for aeroplanes, surgical equipments…

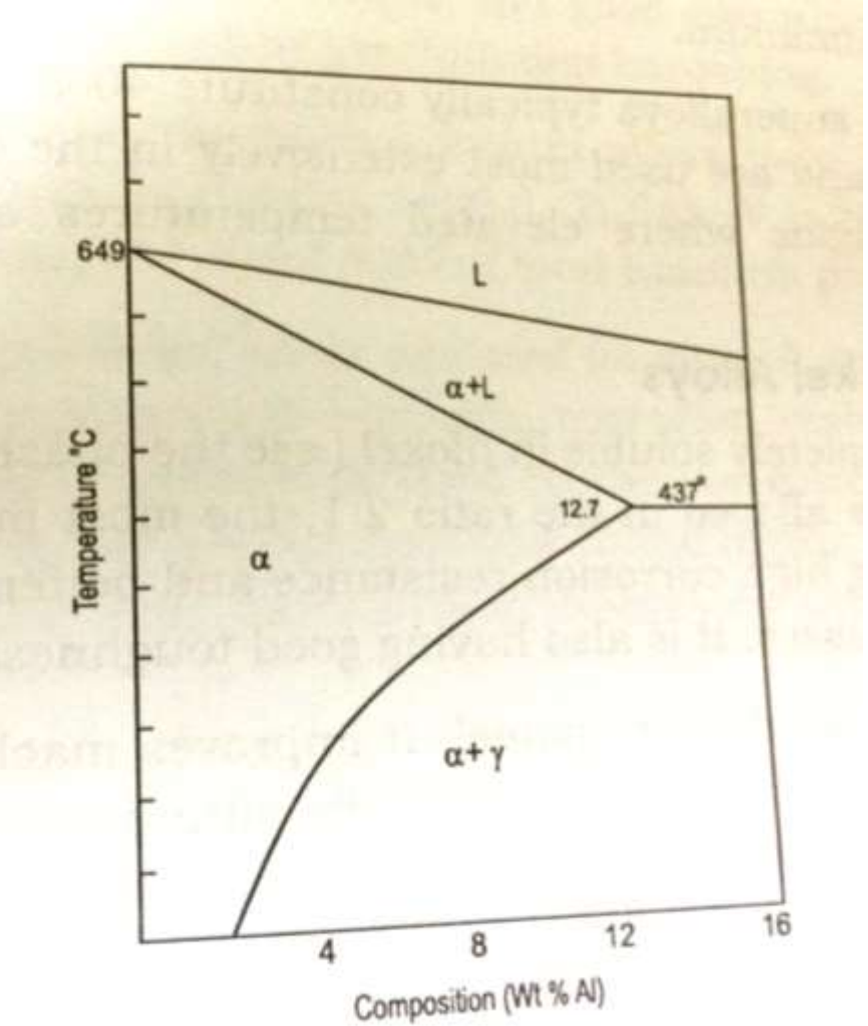
- **Y-Alloy**: 92.5% Al, 4%Cu, 2%Ni,1.5% Mg
- High strength and hardness (even at 200˚C)
- Suitable for cold working and casting
- Cylinder heads and crankcases of engines
- **Magnelium:** alloying elements Mg and Cu
- Ni, Sn, Fe, Mn, Si also added
- Better tensile strength and machinability
- Brittle
- Aircraft and automobile industries
- **Silumin alloys:** based on Al-Si system
- 88%Al and 12% Si
- Good castability, corrosion resistance, ductility…

Magnesium

- HCP crystal Structure
- Lighter and less ductile than Al
- Poor modulus of elasticity
- Poor resistance to wear, fatigue and creep
- Response to strengthening mechanisms is poor

Magnesium

- Phase dgm



Magnesium Alloys

- Addition of Al to Mg increases strength, hardness, castability
- Zn and Mn also added
- Mn increases corrosion resistance, but little effect on mech: properties
- Mg-Al-Zn alloys have higher mech: properties
- Zirconium has grain refining effect
- Mg alloys – aerospace, high speed machinery, transportation equipments
- Mg-Mn alloys used for sheet forming processes

- Mg-Al-Zn alloys are suitable for sand and die casting, extrusion and forging processes
- Mg alloys have poor ductility and formability but poor fatigue and stress corrosion resistance

Nickel

- A metal having good corrosion resistance
- Strengthened by strain hardening, age hardening, dispersion hardening
- Common alloying elements: Cu, Fe, Cr, Mo, Mn, Al
- Ni based alloys constitute 40-50% of total weight of an aircraft engine (combustor and turbine sections
- Extensively used at elevated temperatures

Cu-Ni Alloys

- Cu is completely soluble in Ni
- Monel – when Ni and Cu alloyed in 2:1 ratio
- High corrosion resistance, better mech: properties than Bronzes, brasses
- Also good toughness, fatigue strength
- When S is added to Monel, machinability improves – R monel
- K-monel; contains 3% Al (age hardenable)
- H-monel; 3% Si (improved strength and corrosion resistance)
- S-monel; 4% Si (improved strength and corrosion resistance)

- Cu-Ni alloys (cupro-nickels) suitable for service at elevated temperatures
- cupro-nickels with 30 % nickel – condenser tubes in naval applications
- *Constantan* – alloy containing 40% Ni and 1.5% Mn
- It has high electrical resistivity unaffected with change in temperature
- Used in rheostats, thermocouples and in heating devices
- Nickel Silvers or German silvers- ternary alloys of copper containing 5-45% Zn & 5-30% Ni.
- Good strength and plasticity, low thermal conductivity
- plumbing hardware and tableware which are silver plated

Titanium

- Has two allotropic forms
- Upto 880˚C; α titanium (hexagonal)
- At higher temperatures β titanium (BCC)
- Pure titanium – strong, ductile and light
- High corrosion resistance and high strength at elevated temperatures – used as structural material
- Suitable for hot and cold working
- Good weldability but Poor machinability

Titanium Alloys

- Elements: Al, Cr, Mn, V, Fe, Mo, Sn
- Fe, Cr, Al – highest strengthening effect
- Ti alloys – creep resistance, fatigue strength, corrosion resistance
- High specific strength
- Ti-6Al-4V is the most widely used alloy
- Used for aircraft structures, air craft turbines
- Construction of leaching and purification plants for cobalt production
- Various chemical processing equipments, valves, tanks…

- **Babbit Metal:** also called white metal
- A set of tin or lead based alloys
- 90%Sn, 10%Cu
- 89%Sn,7% Antimony, 4%Cu
- 80% Pb, 15% Antimony, 5% Sn
- Structure is made up of small hard crystals dispersed in a matrix of softer alloy
- Low friction lining for bearing shells

Thank you