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

• $\alpha$-$\gamma$ transformation at $A_3$ (912°C) and $\gamma$-$\delta$ transformation at $A_4$ (1394°C)
• $\delta$ –ferrite, $\gamma$-austenite, $\alpha$-ferrite exist in distinct regions of phase diagram
• Mo, Cr, W, Si, V, Ti raise the A3 temp and lower the A4 temp……
• Contract $\gamma$ 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 carbide 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 $\alpha$ and $\delta$ 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
• **Cr**
• 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 properties 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%
• **Tungsten**
• Forms hard and stable carbides
• Excellent wear resistance and hardness
• 2-3% to tool steels and heat resisting steels
• **Cobalt**
  – 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

**Silicon**
- Added up to 0.3% as deoxidizer
- Forms SiO\textsubscript{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
• **Cu**
• 0.15-0.25% is normally added to improve corrosion resistance
• Also promotes precipitation hardening thereby higher strength and hardness

• **Lead**
• 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
  - Up to 0.12% - increase strength, hardness, corrosion resistance and machinability
  - Higher phosphorous content may lead to cold shortness
- **Al**
  - Most active deoxidizer
  - 0.01-0.06%
  - Controls grain growth – fine grained steels

- **Boron**
  - 0.001-0.005%
  - Increase hardenability
  - Increases depth of hardening during quenching
Nickel-Steels

- Most fundamental alloying element in steel
- Highly soluble in $\gamma$ 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 $\gamma$ and $\alpha$ 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 resistnec
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°C
- To prevent this SS is heated to 1060 to 1120°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
  - low melting point, castable, cheap; however, can be brittle.

- Nodular iron
  - α Fe and graphite spheres

- White iron
  - Cementite and pearlite

- Malleable iron
  - α Fe and tempered graphite flakes

- 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 Fe₃C 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 Fe3C 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 microstructure in which C exists as Fe3C
- 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 Fe3C, this CI is very hard and brittle
- Also good wear resistance, high compact 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 into 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

- $G_1$ - graphite flakes
- $G_2$ - graphite rosettes
- $G_3$ - graphite spheroids
- $P$ - pearlite
- $\alpha$ - ferrite
- $\gamma$ - austenite

Diagram showing the different types of cast irons:
- White Cast Iron
- Pearlitic Gray Cast Iron
- Ferritic Gray Cast Iron
- Pearlitic Ductile Cast Iron
- Ferritic Ductile Cast Iron

Diagram showing the commercial cast iron range and the effect of Mg/Ce on the types of cast iron.

Diagram showing the chemical composition and microstructure of cast irons under different cooling conditions.
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 corrosive environments
• Cu Strengthening methods – strain hardening, solid solution strengthening, precipitation hardening…
• Alloysing 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 $\alpha$ solid solution – FCC and $\beta$ – BCC
• In $\beta$, Cu and Zn atoms randomly dispersed at lattice points
• An ordered structure $\beta'$ – Cu at corners and Zn at body centers of BCC
• Based on solid solution formed:
  \begin{itemize}
    \item $\alpha$-brasses
    \item Duplex Brasses
  \end{itemize}
• **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
- **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; \( \alpha \) titanium (hexagonal)
- At higher temperatures \( \beta \) 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, aircraft 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