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Permanently affiliated to JNTUH

Department of Mechanical Engineering
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Subject: Metallurgy and Material science

Code: 23ME3003

- What is material science?
- Why should we know about it?

- Materials drive our society
  - Stone Age
  - Bronze Age
  - Iron Age
  - Now?
    - Silicon Age?
    - Polymer Age?

WHY STUDY MATERIALS SCI. & ENG.?

- To be able to select a material for a given use based on considerations of cost and performance.

- To understand the limits of materials and the change of their properties with use.

- To be able to create a new material that will have some desirable properties.

MATERIALS SICENCE VS MATERIALS Engg

On the basis of functional prospective:

•The role of materials scientist is to develop or synthesize new materials

•Materials Eng. is called upon to create new products or systems using existing materials, and/or develop techniques for processing materials.

TYPES OF MATERIALS

Most engineering materials can be classified into one of three basic categories:

1. Metals
2. Ceramics
3. Polymers

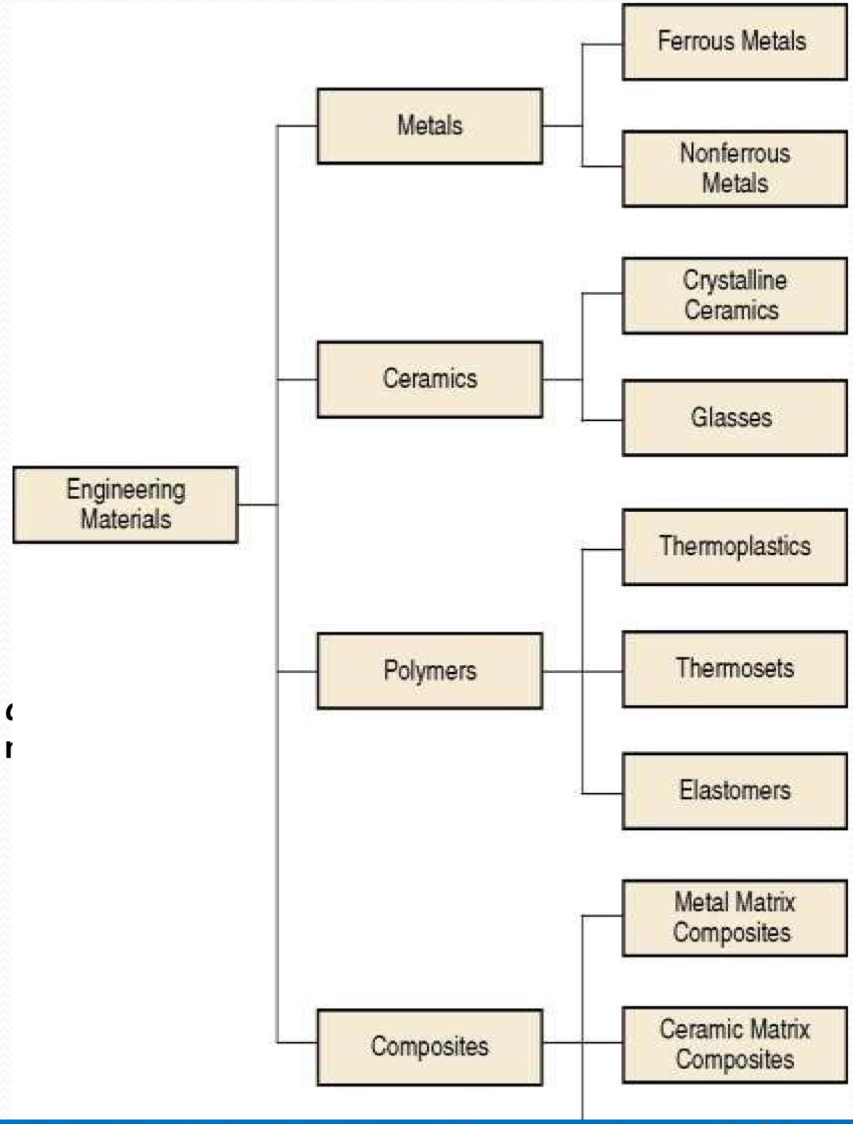
Their chemistries are different, and their mechanical and physical properties are different

In addition, there is a fourth category:

4. Composites

-is a nonhomogeneous mixture of the other three types, rather than a unique category

TYPES OF MATERIALS (con't)



METALS

Metallic bonds

- Strong, ductile, resistant to fracture
- High thermal & electrical conductivity
- Opaque, reflective.

Fig 1.8 Familiar objects that are made of metals and metal alloys

CERAMICS

Ionic bonding

-Brittle, glassy, elastic

-Non-conducting (insulative to the passage of heat & electricity)

-Transparent, translucent, or opaque

-Some exhibit magnetic behavior (e.g. Fe_3O_4)

Fig 1.8 Familiar objects that are made of ceramic materials

POLYMERS/PLASTICS

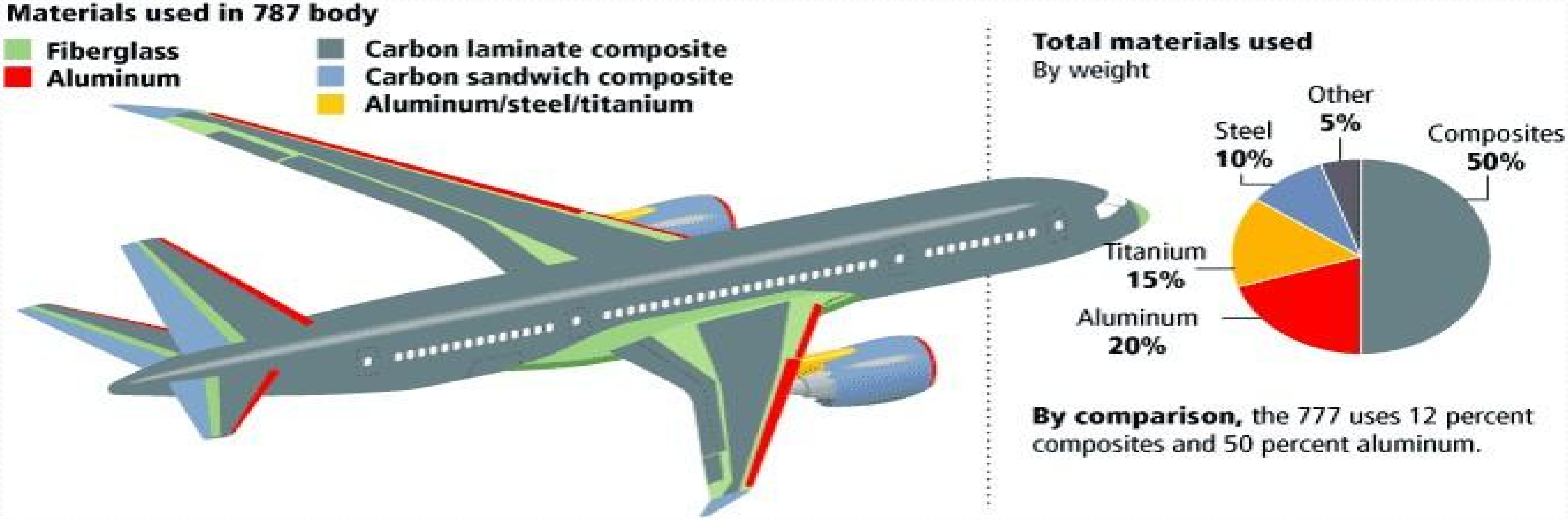
Covalent bonding → sharing of e's

- -Soft, ductile, low strength, low density
- -Thermal & electrical insulators
- -Optically translucent or transparent.
- -Chemically inert and unreactive
- -Sensitive to temperature changes

Fig 1.8 Familiar objects that are made of polymeric materials

COMPOSITES

- Light, strong, flexible
- High costs



ADVANCED MATERIALS

Materials that are utilized in high-tech applications

- **Semiconductors**

Have electrical conductivities intermediate between conductors and insulators

- **Biomaterials**

Must be compatible with body tissues

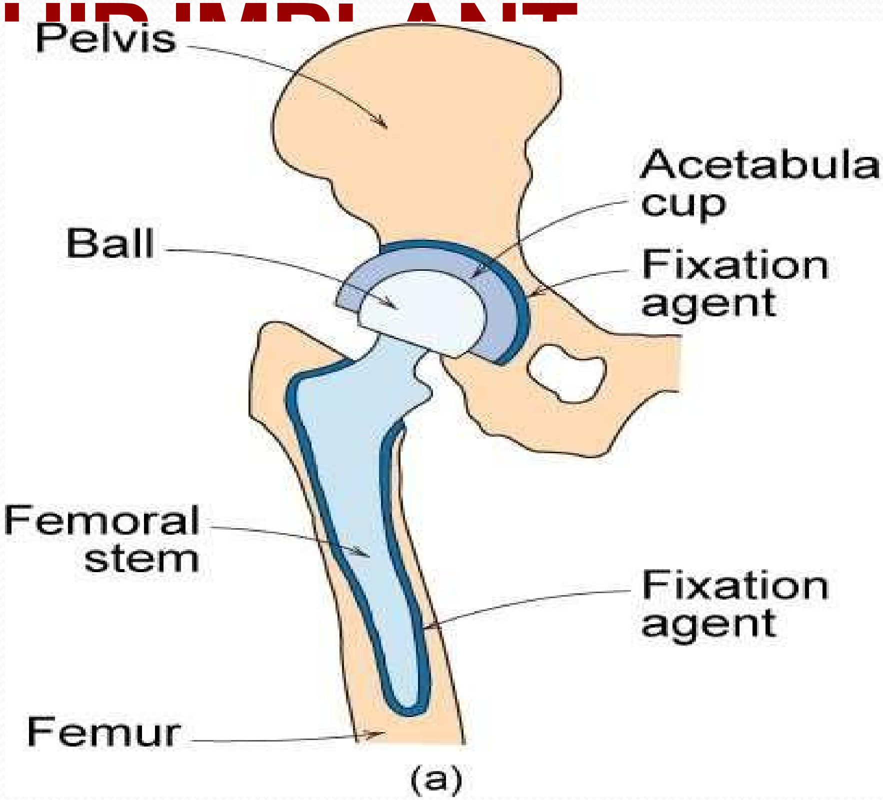
- **Smart materials**

Could sense and respond to changes in their environments in predetermined manners

- **Nanomaterials**

Have structural features on the order of a nanometer, some of which may be designed on the atomic/molecular level

Example –



Adapted from Fig. 22.26, *Callister 7e.*

- Requirements
  - mechanical strength (many cycles)
  - good lubricity
  - biocompatibility

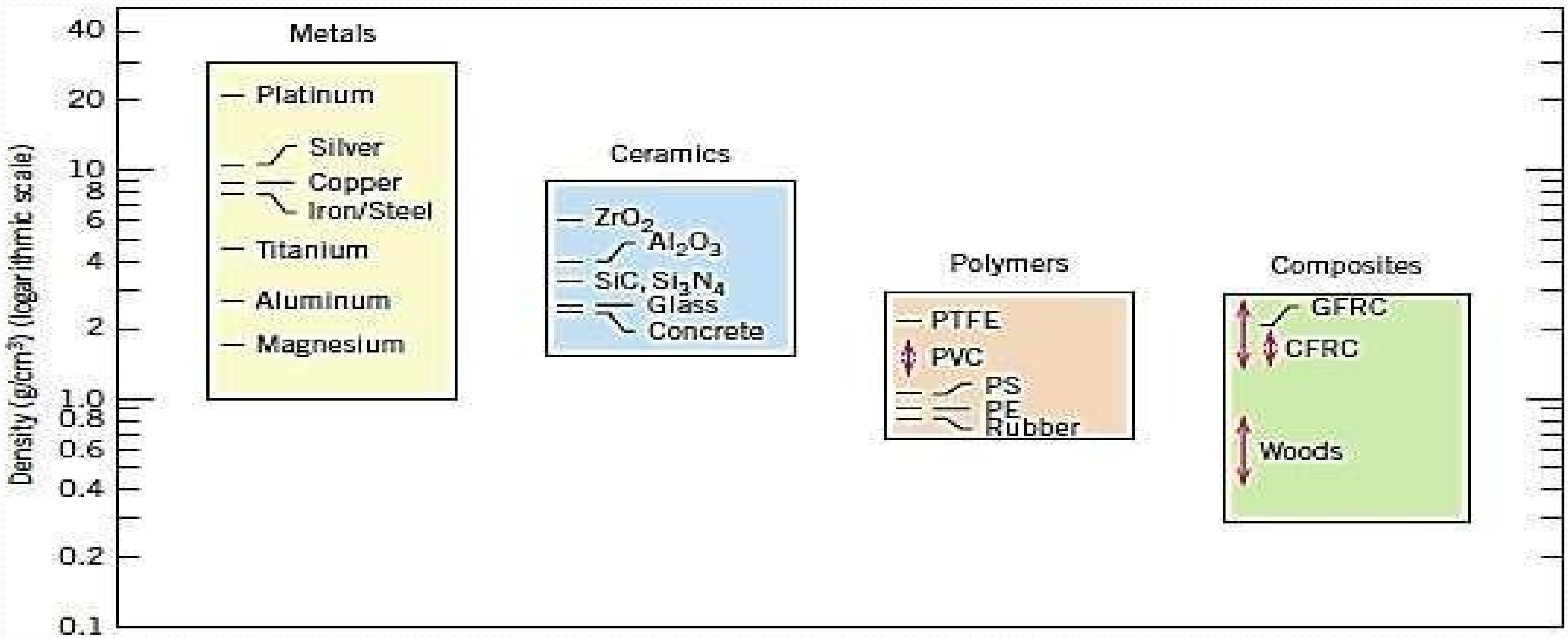


Fig 1.3 Bar chart of room-temperature density values for various metals, ceramics, polymers, and composite materials

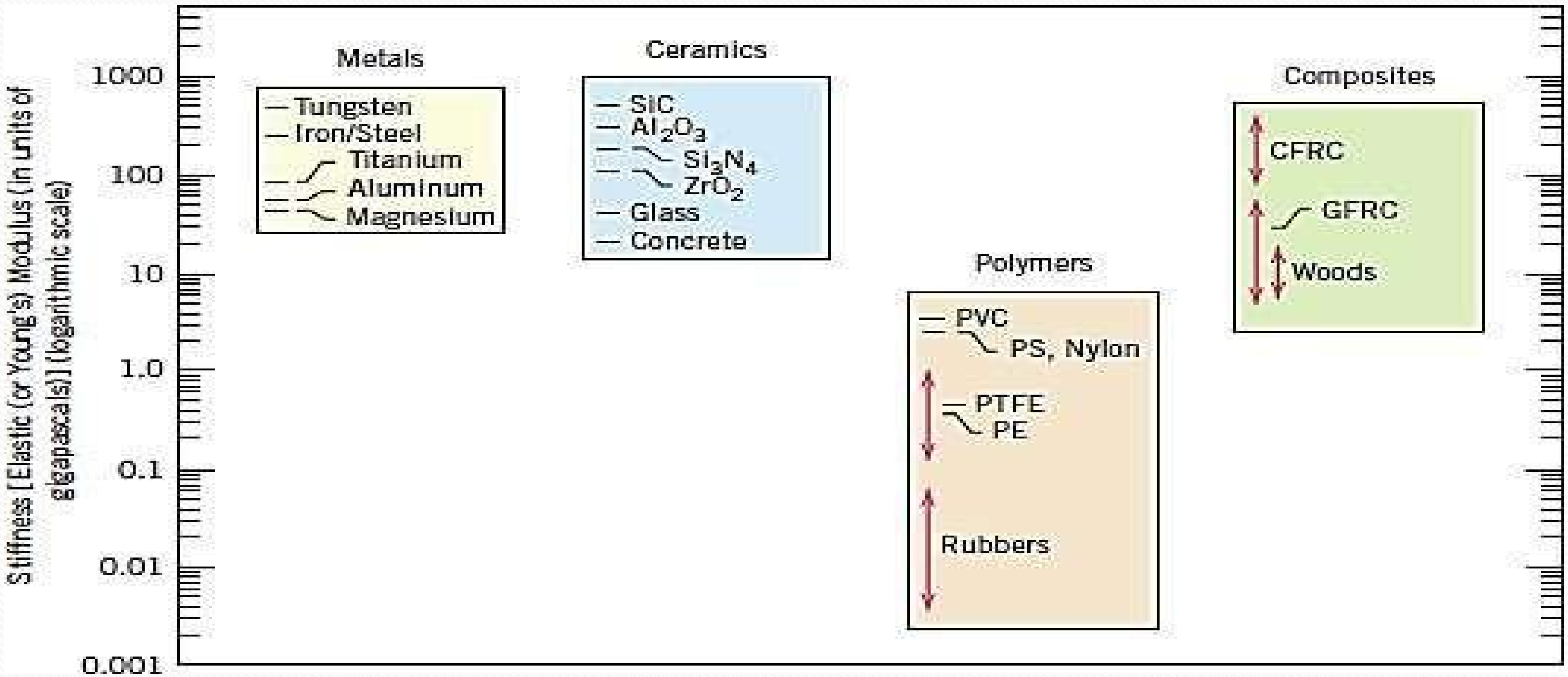


Fig 1.4 Bar chart of room-temperature stiffness values for various metals, ceramics, polymers, and composite materials

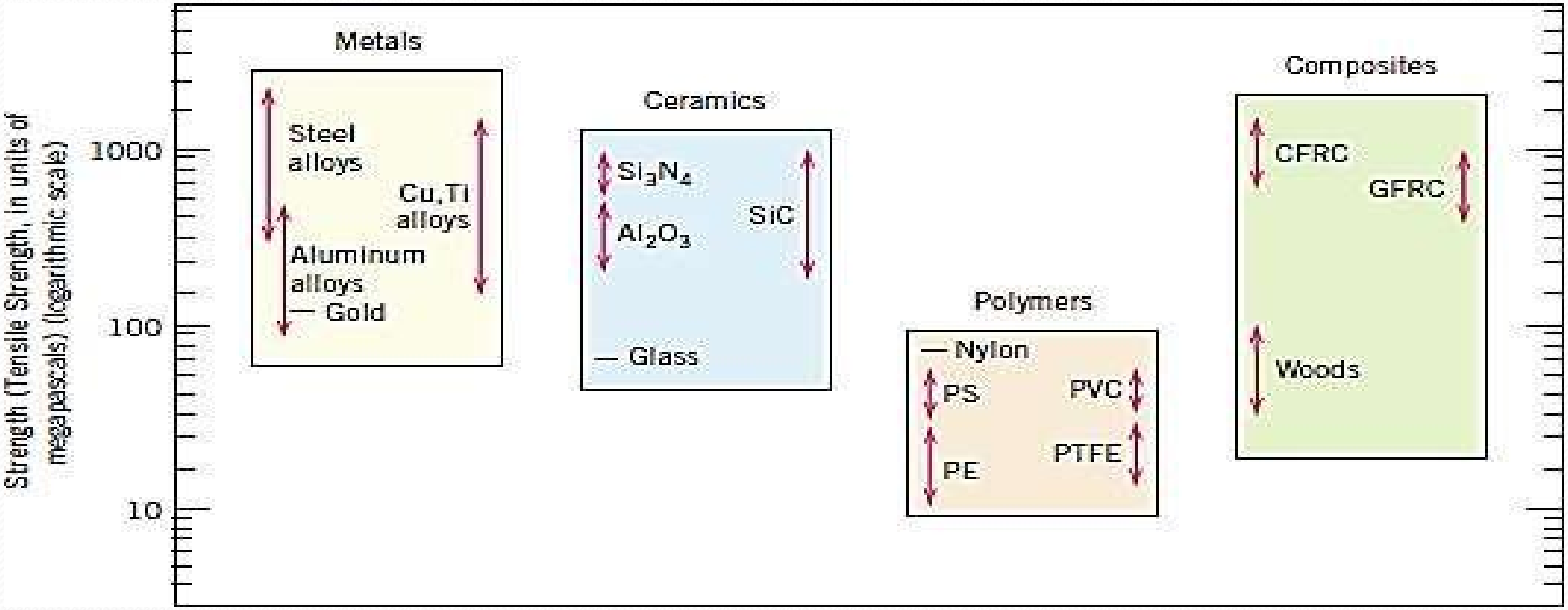


Fig 1.5 Bar chart of room-temperature strength (i.e. tensile strength) values for various metals, ceramics, polymers, and composite materials

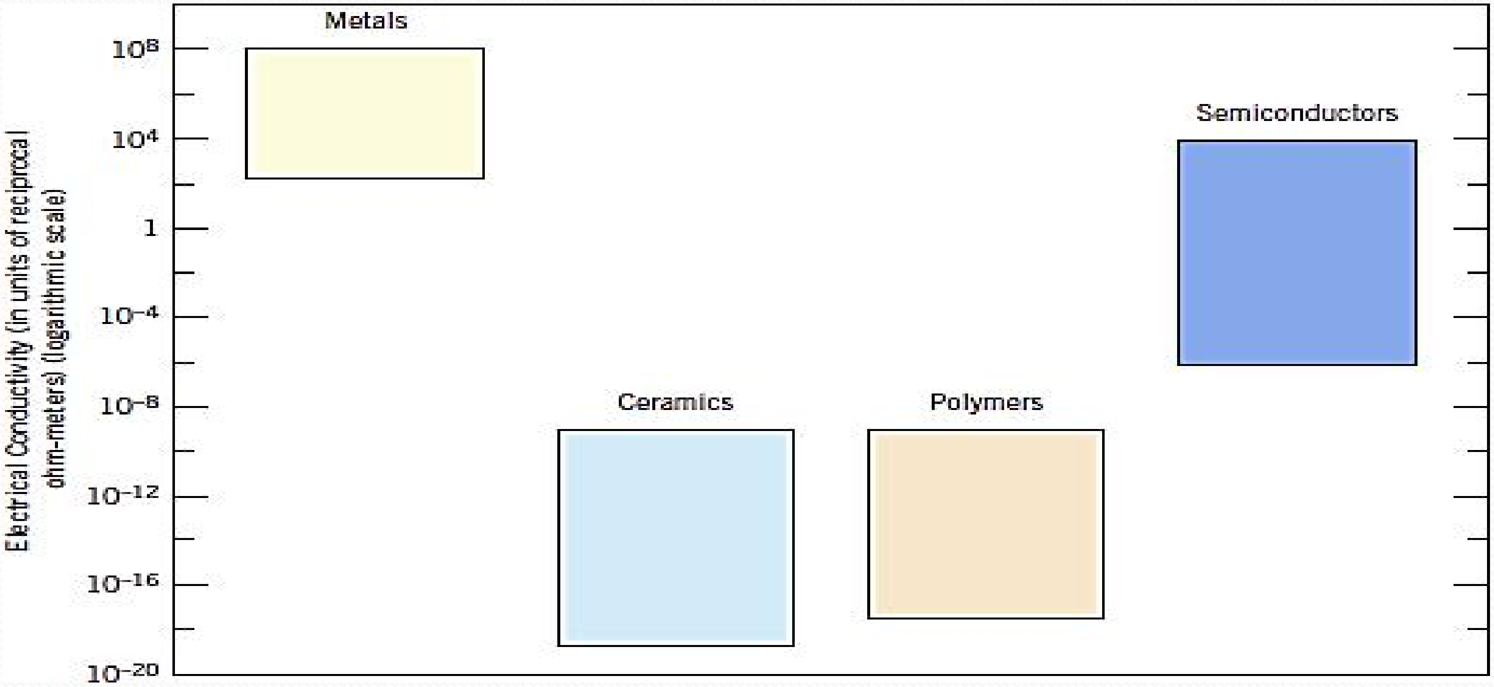


Fig 1.6 Bar chart of room-temperature resistance to fracture for various metals, ceramics, polymers, and composite materials

The Materials Selection Process

1. Pick Application → Determine required Properties
   - Properties: mechanical, electrical, thermal, magnetic, optical, deteriorative.
2. →
   - Properties → Identify candidate Material(s)
   - Material: structure, composition.

.

- Material → Identify required Processing
- Processing: changes *structure* and overall *shape*
- ex: casting, sintering, vapor deposition, doping
  - forming, joining, annealing.

STRUCTURE, PROCESSING, & PROPERTIES

- One aspect of Materials Science is the investigation of relationships that exist between the processing, structures, properties, and performance of materials.
- The performance of a material depends on its properties
- Properties depend on structure   ex: hardness vs structure of steel
- Processing can change structure

Ex: structure vs cooling rate of steel

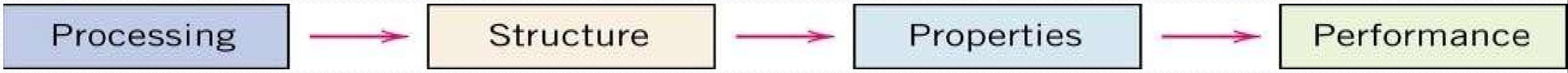
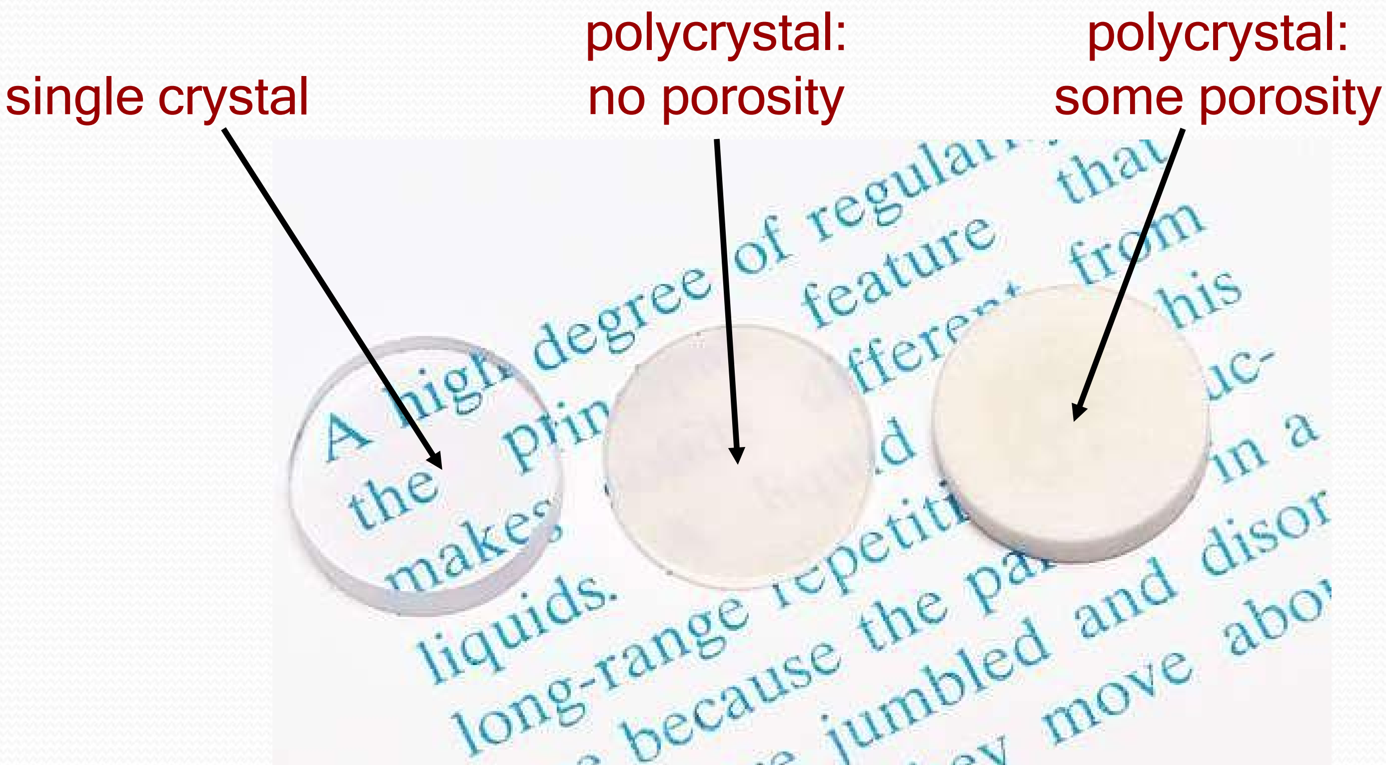


Fig 1.1 The four components of the discipline of materials science and engineering and thei interrelationship

- Transmittance:
  -- Aluminum oxide may be transparent, translucent, or opaque depending on the material’s structure (i.e., single crystal vs. polycrystal, and degree of porosity).



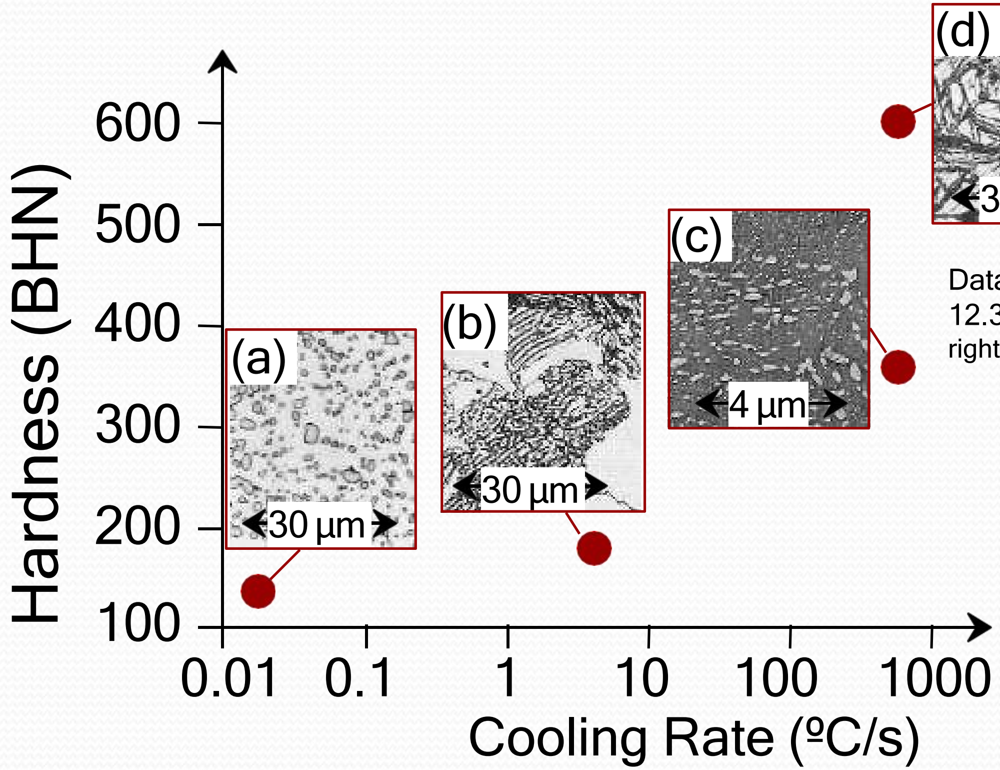
STRUCTURE OF MATERIALS

- **By structure we mean how some internal components of the material is (are) arranged.**
- **In terms of dimensionality, structural elements include subatomic, atomic, microscopic, and macroscopic**

Structure, Processing, & Properties

- Properties depend on structure

  ex: hardness vs structure of steel



Data obtained from Figs. 12.31(a) and 12.32 with 4 wt% C composition, and from right 1971 by United States Steel

- Processing can change structure

  ex: structure vs cooling rate of steel

ME6403 - ENGINEERING MATERIALS AND METALLURGY

UNIT I

ALLOYS AND PHASE DIAGRAMS

Constitu of alloys – Solid solutions, substitutional and interstitial equilibrium diagram. Classification of steel and cast Iron microstructure, properties and applicatio

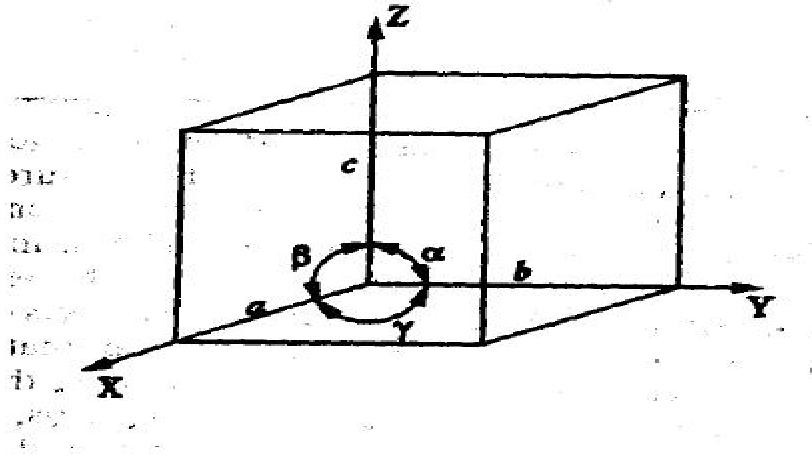
Introduction

- The matter is usually found to exist in solids and fluids.
- atoms molecules brittle ductile malleable strong weak good conductors of heat electricity magnetic non-magnetic their structure
- crystal geometry haviour of solids mechanical, metallurgical, electrical, magnetic and optical properties

Non-crystalline or Amorphous materials

Crystallographic terms

systematigeometricpatternperiodicarrangement of atomlattice array of points periodic fashion in three dimensional space exactly identical surroundings

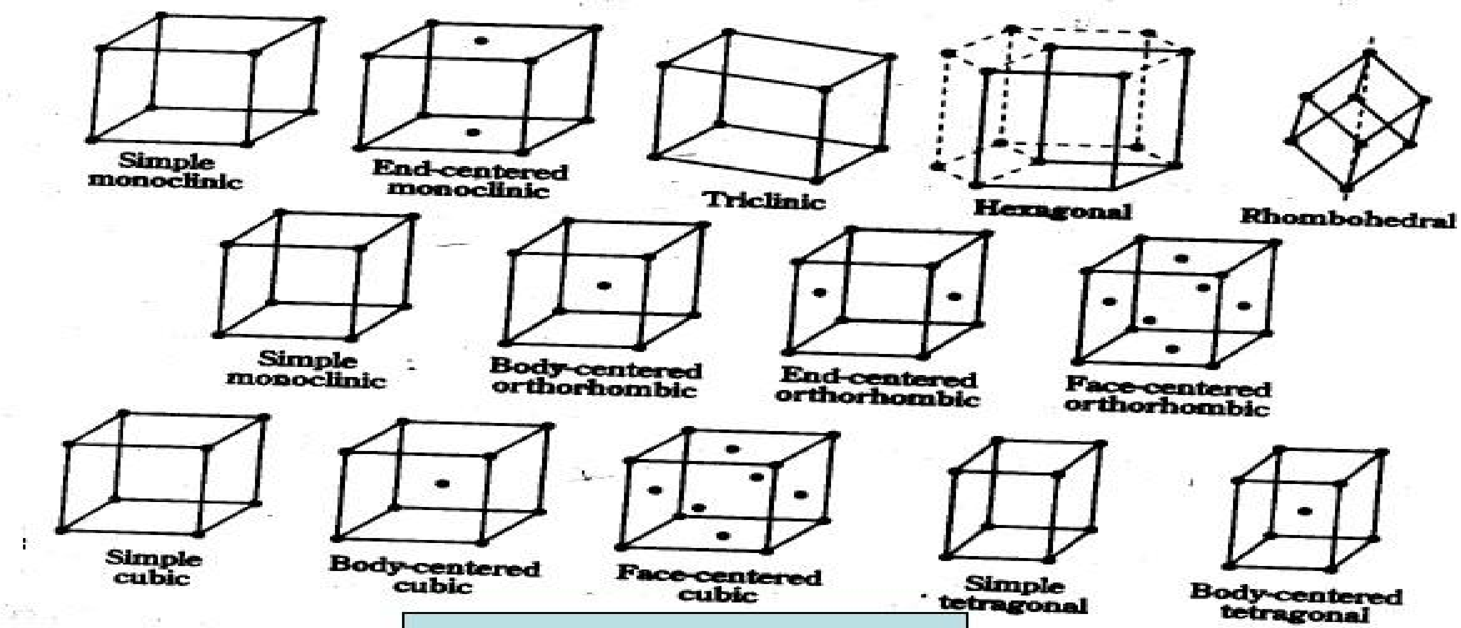


Three dimensional network of imaginary lines connecting the atoms called **SPACE LATTICE**

Smallest unit having the full symmetry of the crystal called- **UNIT CELL**

LATTICE PARAMETERS- edges of unit cell and angles

Crystal systems



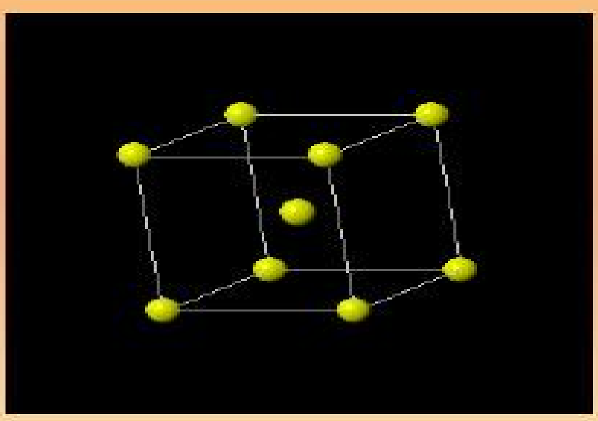
BRAVAIS LATTICES

14 possible different networks of lattice points

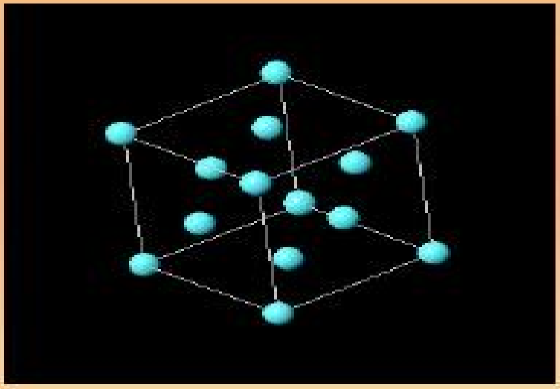
All crystals based on these possible space lattices

Crystal structure

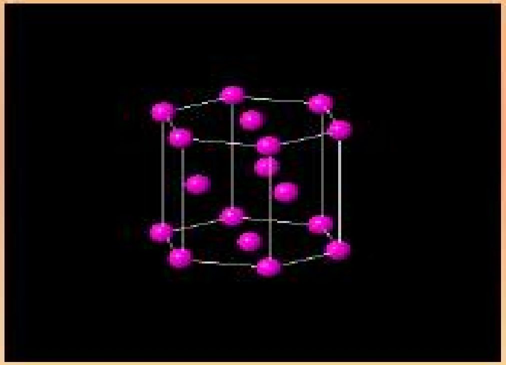
- Atoms are positioned in solids in an orderly arrangement. Imaginary lines drawn through the centre of adjacent atoms form geometric shapes



BCC

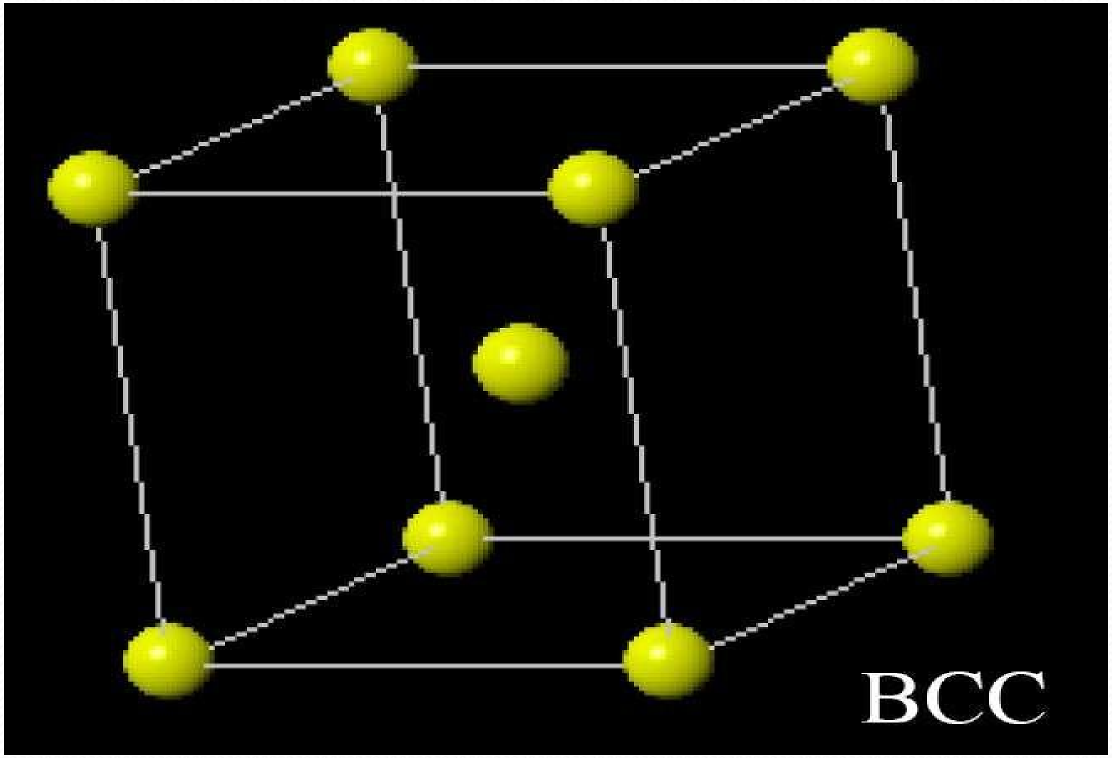


FCC



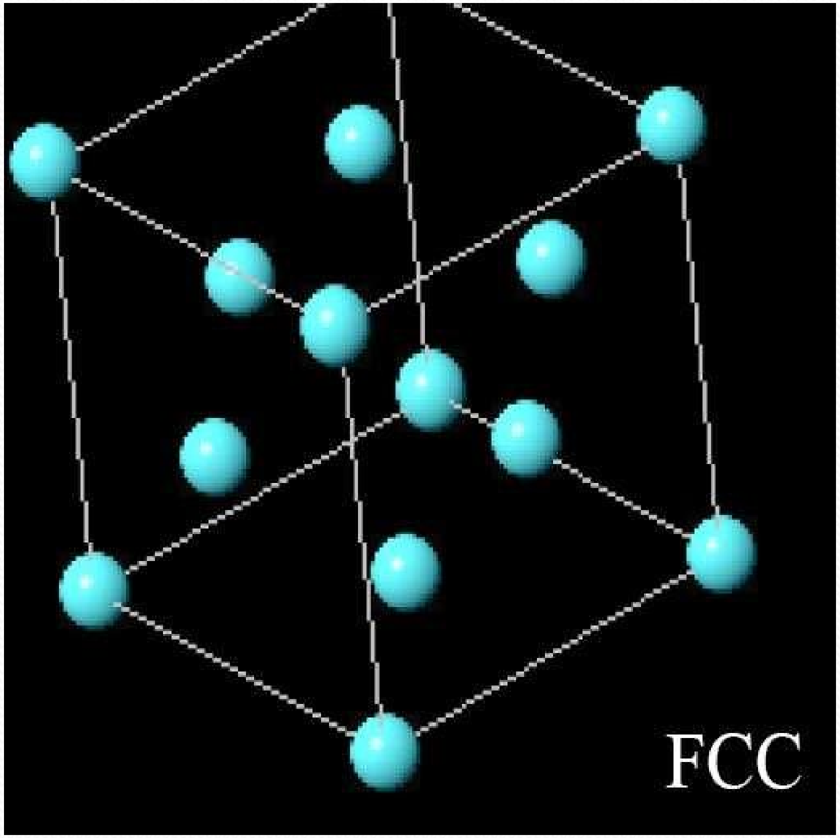
HCP

BCC (Body Centre Cubic)

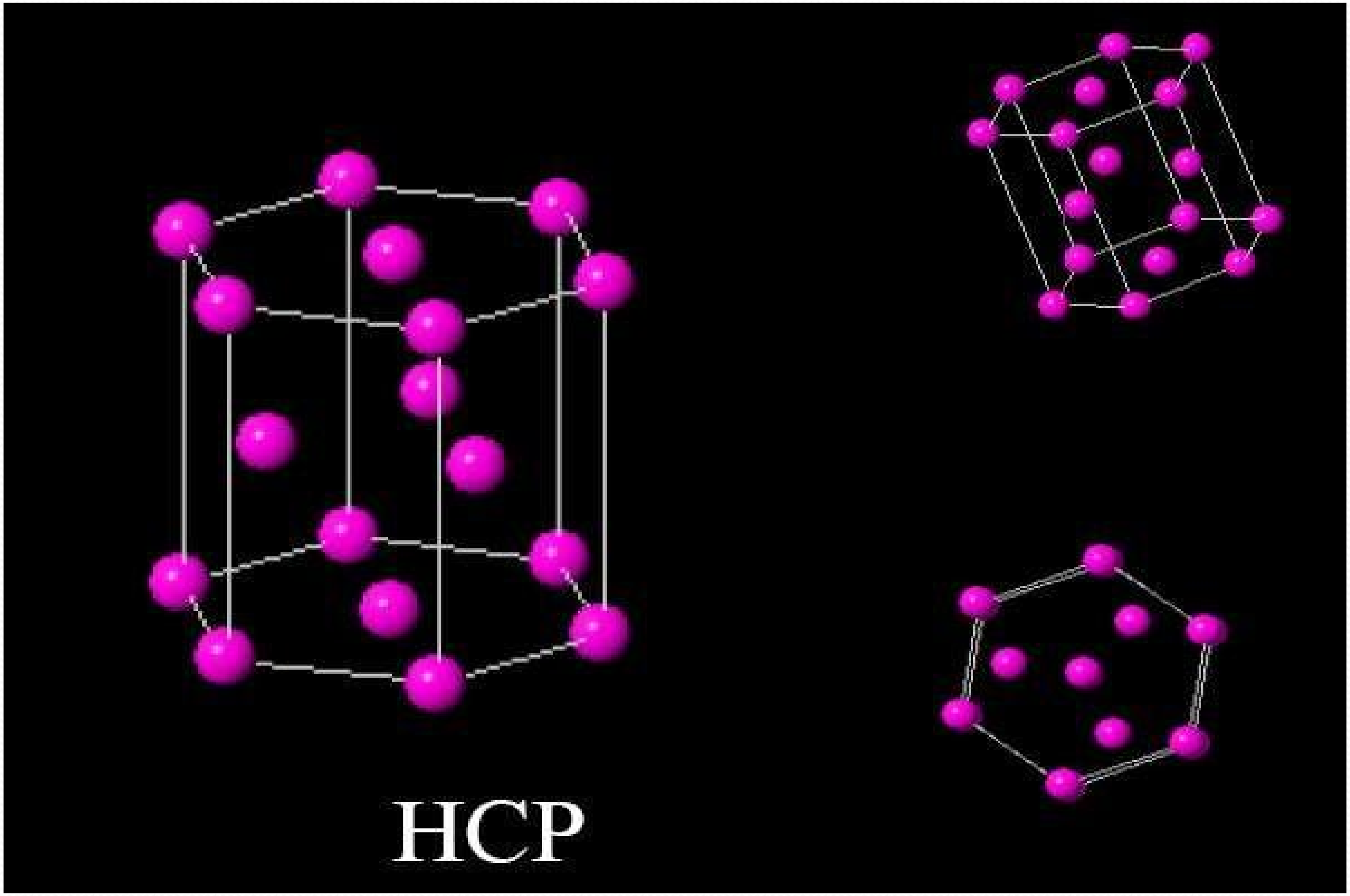


FCC (Face Centred Cubic)

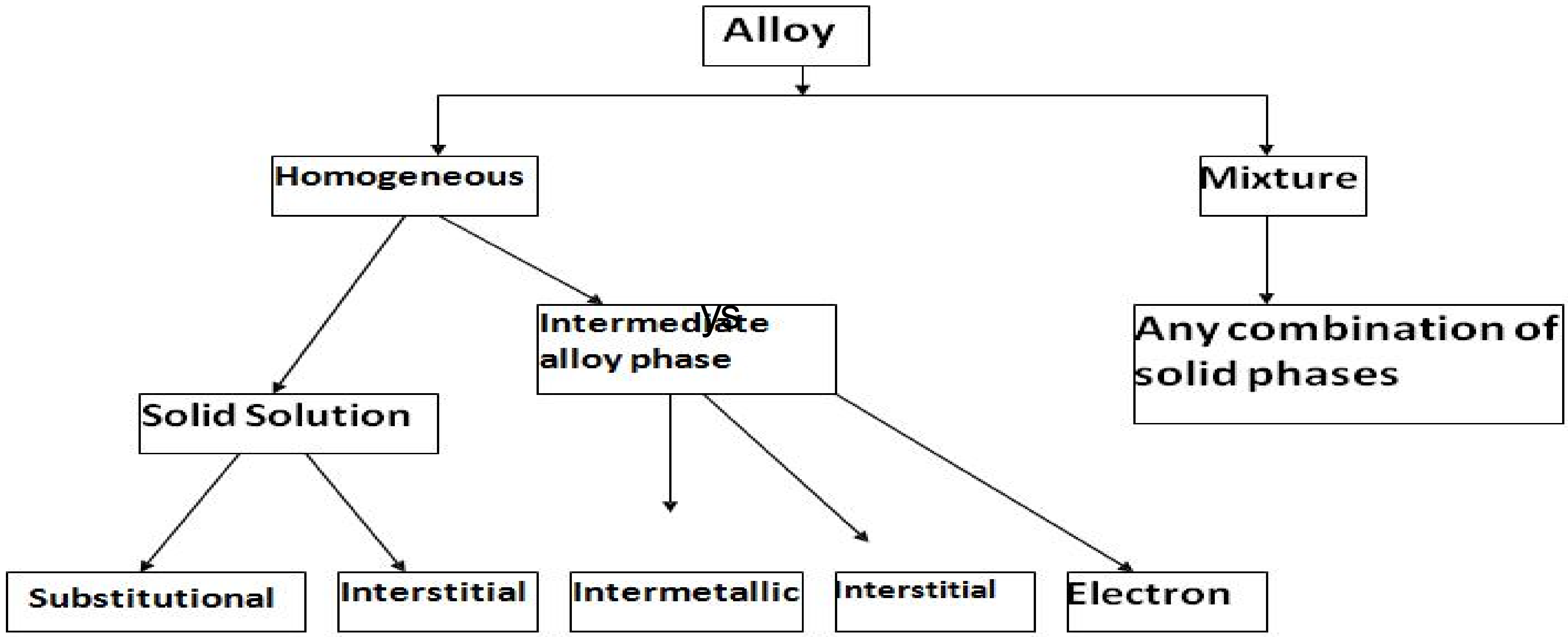
- Copper
- Silver
- Gold
- Aluminium
- Nickel
- Lead
- Platinum



HCP (Hexagonal Close Packed)



Based on the structure



Solid Solutions

- simplest type of alloy microscope only one type of crystal can be seen just like a pure metal similar properties to pure metals but with greater strength but are not as good as electrical conductors te and solvent

Types of Solid Solution

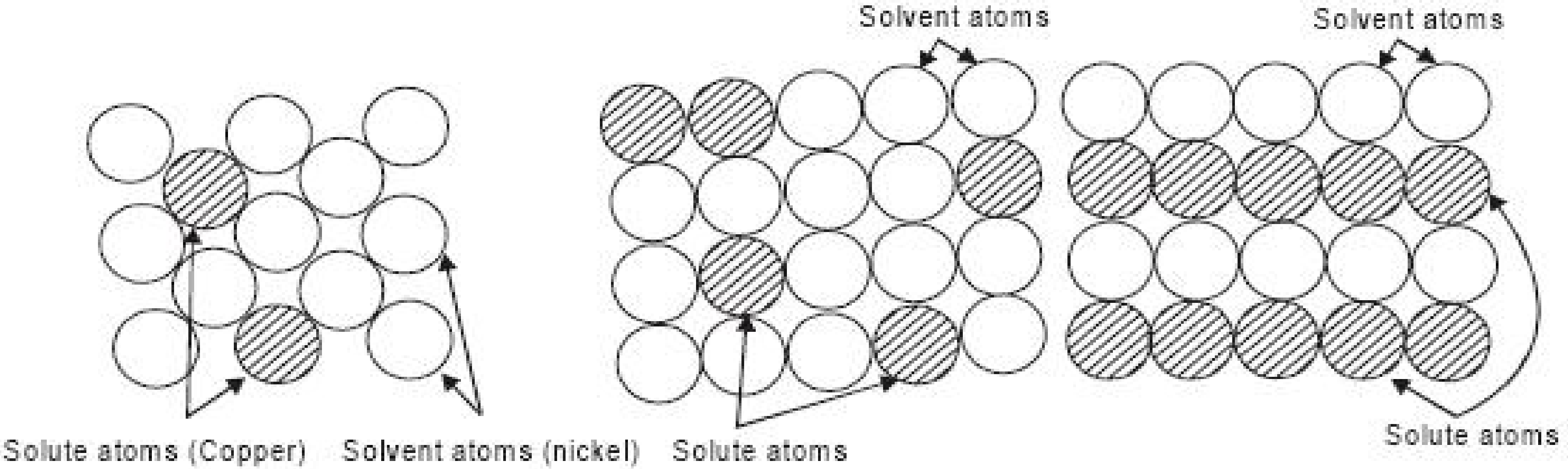
1. Substitutional

   a) Disordered or Random

   b) Ordered

2. Interstitial

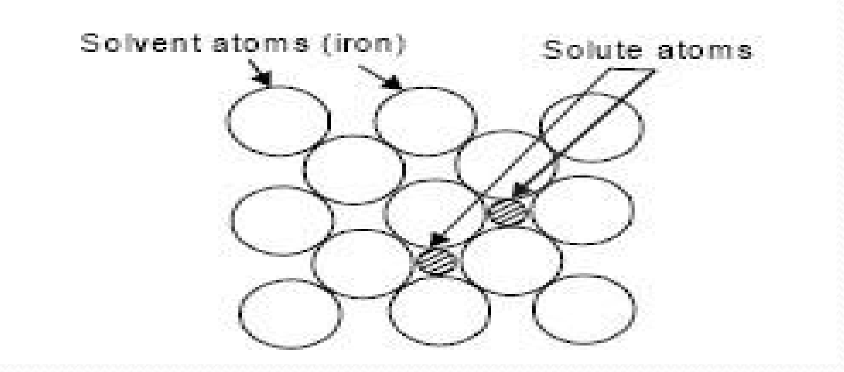
Substitutional Solid Solutions



(*a*) Substitutional solid solution (*b*) Disordered substitutional (*c*) Ordered substitutional

Interstitial Solid Solutions

- solute atom does not solvent atom enters one of the hole intersityen the solvent atoms.
- Interstitial solid solutions normally have a limited solu



Intermetallic Compounds

- Intermetallic compounds are generally formed when one metal (for example magnesium) has **chemical properties which are strongly metallic** and the other metal (for example antimony, tin or bismuth) has **chemical properties which are only weakly metallic.**
- Examples of intermetallic compounds are Mg2Sn, Mg2Pb, Mg3Sb2.
- These intermetallic compounds have higher melting point than either of the parent metal.
- This higher melting point indicates the high strength of the chemical bond in intermetallic compounds.

Intersitial compounds

Difference between interstitial solutions and interstitial compounds

- In interstitial solutions, the solute atoms are not in randomly solvent.

- In interstitial compounds, there is a regular pattern .

Hume Rothery's Rule

- The atoms must be of similar size, with less than a 15% difference in atomic

Crystal structure: The materials must have the same crystal structure.

- **Valence(electronic charge of an iron):** The atoms must have the same valence.
- **Electro negativity(ability of atom to attract an electron):** The atoms must have approximately the same electro negativity

Introduction to phase diagram

- The solidification of a metal or an alloy is clearly understood by means of phase diagram.
- **Component:** Pure metal or compound

(e.g., Cu, Zn in Cu-Zn alloy, sugar, water, in syrup.)

- **Solvent:** Host or major component in solution.
- **Solute:** Dissolved, minor component in solution.
- **System:** Set of possible alloys from same component (e.g., iron-carbon system.)
- **Solubility Limit:** Maximum solute concentration that can be dissolved at a given temperature.

Introduction to phase diagram

- **Phase:** Part with homogeneous physical and chelmicalcharacteristics
- One-phase systems homogeneous.

Phases:

- Systems with two or more phases are heterogeneous, or mixtures. This is the case of most metallic alloys, but also happens in ceramics and polymers.
- A two-component alloy is called binary. One with

Microstructure:

- The properties of an alloy do not depend only on concentration of the phases but how they are arranged structurally at the microscopy level. Thus, the microstructure is specified by the number of phases, their proportions, and their arrangement in space.

A binary alloy may be

- A single solid solution
- Two separated essentially pure components.
- Two separated solid solutions.
- A chemical compound, together with a solid

Phase diagram:

a given composition as a function of temperature.

- A plot with the temperature on the vertical scale and the percentage of composition by weight on the horizontal scale is termed a phase diagram.

Poly phase material:

- A material in which two or more phases are present.

Gibbs Phase Rule

- In a system under a set of conditions, the relationship between number of phases (P) exist can be related to the number of components (C) and degrees of freedom (F) by Gibbs phase rule.

$$P + F = C + 2$$

Where,

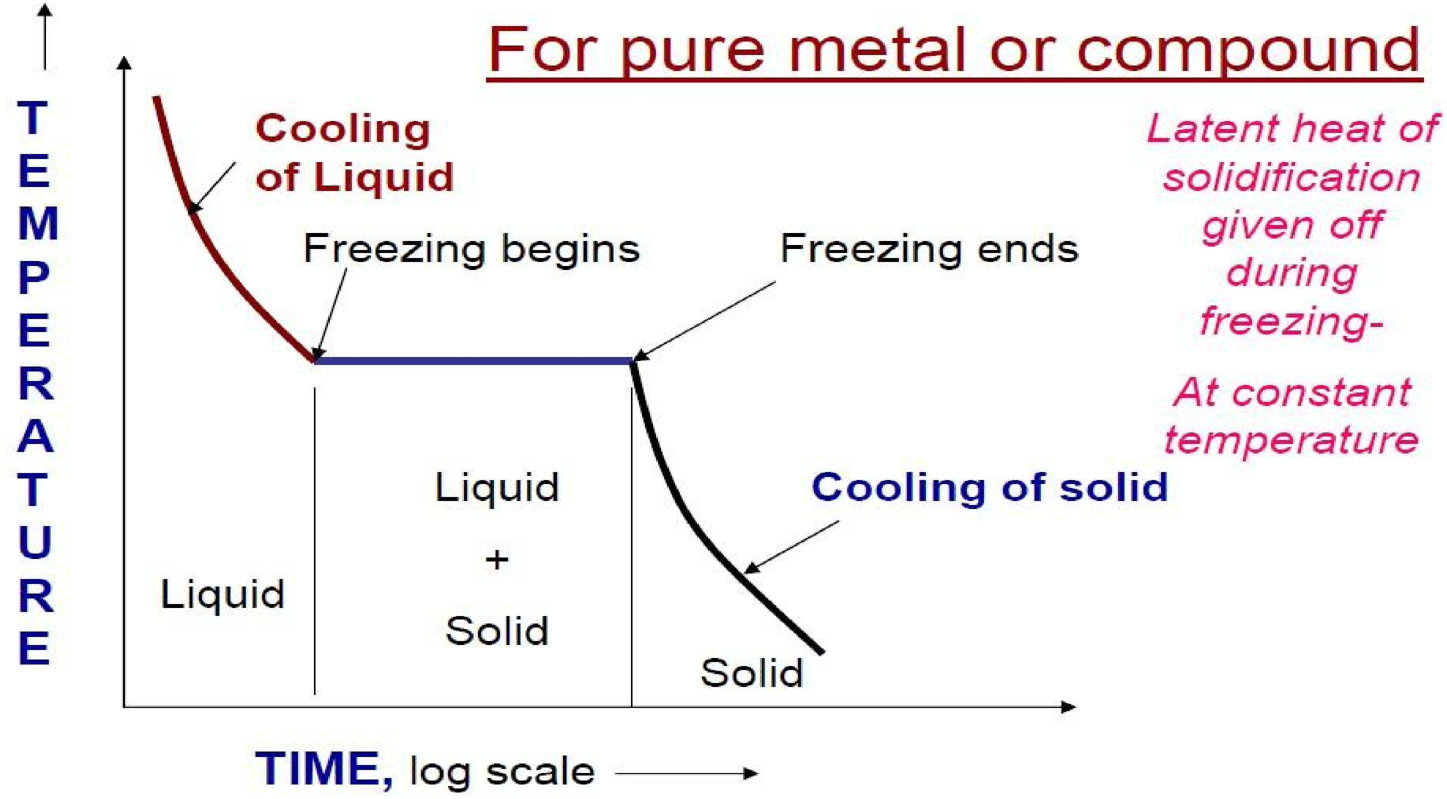
- P – no of phases (solid, liquid, Gaseous etc)
- C – No of components in the alloy
- F – Degrees of freedom refers to the number of independent variables (e.g.: pressure, temperature) that can be varied individually to effect changes in a system.

Gibbs Phase Rule

In practical conditions for metallurgical and materials systems, pressure can be treated as a constant (1 atm.). Thus ***Condensed Gibbs phase rule*** is written as:

- **P + F = C + 1**

COOLING CURVES



Cooling Curves

- Cooling curves are obtained by plotting the measured temperatures at equal intervals during the cooling period(time) of a metal
- It is useful for constructing the phase diagram.
- Apply Gibb's phase rule, for single phase

  $F = C-P+1$

  $= 1-1+1 = 1$ (one degree of freedom)

For two phases

  $F = C-P+1$

  $= 1-2+1 = 0$ (zero degree of freedom)

Equilibrium Phase Diagrams

- It is also known as equilibrium or constitutional diagram.
- Equilibrium phase diagrams represent the relationships between temperature and the compositions and the quantities of phases at equilibrium
- In general practice it is sufficient to consider only solid and liquid phases, thus pressure is assumed to be constant (1 atm.) in most applications.

- Important information, useful for the scientists and engineers materials development selection application product design,
- To show **phases** are present **at different compositions** and **temperatures** under slow cooling (equilibrium) conditions.
- To indicate **equilibrium solid solubility** of one element/compound in another.
- **To indicate temperature** at which an alloy starts to solidify and the **range of solidification**.
- To indicate the temperature at which different phases **start to melt.**
- Amount of each **phase in a two-phase mixture** can be obtained.

Types of equilibrium phase diagram

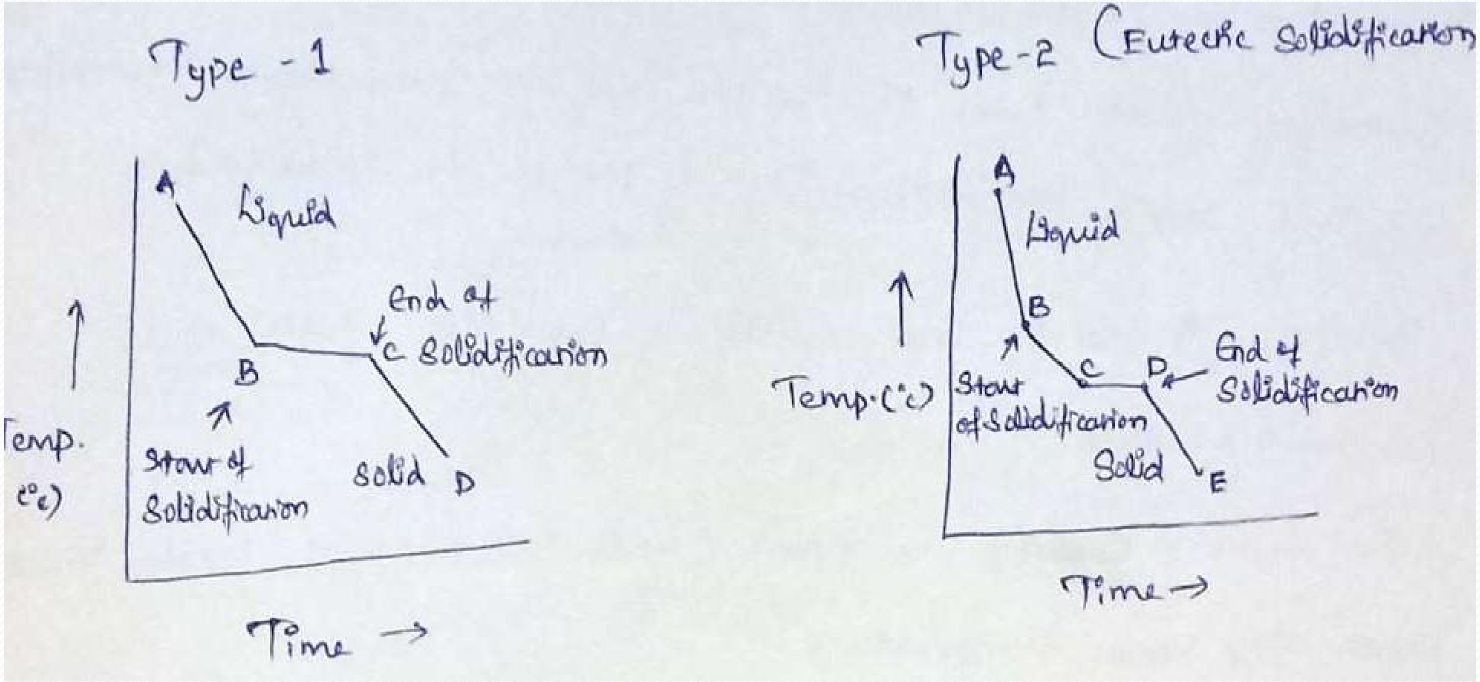
- Single component systems have unary diagrams
- Two-component systems have binary diagrams
- Three-component systems are represented by ternary diagrams, and so on

Construction of phase diagram

Liquidus line and Solidus line:

- The line obtained by joining thee points showing the beginning of solidification is called liquidus line.
- The liquidus line indicates the lowest temperature at which a given alloy of the series in the liquid start to freeze.
- The lower line of the diagram is known as the solidus.

Cooling curve for binary alloy



Eutectic reaction:

- For a mixture with two components at a fixed pressure, the eutectic reaction can only happen at a fixed chemical composition and temperature called eutectic point.
- It describes the thermodynamic equilibrium conditions where a liquid co exists with two solid phases.
- The microstructure of solid that results from the transformation consist of alternate layers of α and β phases that from simultaneously during the transformat

Eutectoid reaction:

It describes the phase changes reaction of an alloy in which on cooling, a single solid phase transforms into two other solid phases.

Peritectic reaction:

It describes the isothermal reversible reaction of a liquid phase and a solid phase to form a second solid phase during cooling.

Micro-constituents of Iron-Carbon alloys

The study of these micro- constituents is essential in order to understand iron-iron carbide ($Fe-Fe_3C$) equilibrium phase diagram

Various micro-constituents of iron-carbon alloys are:

1. Ferrite:

- Ferrite is a primary solid solution based on α iron having BCC structure.
- It is nothing but the interstitial solution of carbon in iron.

- Max. solubility of carbon in iron is 0.025% carbon at 723ºC.
- Ferrite is soft, ductile, and highly magnetic.
- It is used in cold working process.

2. Austenite or γ iron:

- Austenite is a primary solid solution based on γ iron having FCC structure.
- Max. solubility of carbon in iron is 2% at 1140ºC.
- It is soft, tough, highly ductile and non-magnetic.
- High electrical resistance and highcoefficient

3. Cementite:

- Cementite also called as carbide of iron (Fe_3C)
- It is hard, brittle, intermetallic compound of iron with 6.69% carbon
- The hardness and brittleness of cast iron is based on the presence of cementite.
- It is magnetic below 250ºC

4. Pearlite:

- Eutectoid mixture of ferrite (87.5%) and cementite (12.5%)
- It is formed when austenite decomposes during cooling. It contains 0.8% of carbon

5. Ledeburite:

- Eutectic mixture of austenite and cementite containing 4.3% carbon.
- It is forms at 1140ºC
- Pig iron, most important engineering materials are ledeburite

6. Martensite:

- Super saturated solid solution of carbon in α iron.
- It is formed when steel is rapidly cooled from the austentic state.
- It is very hard, more brittle and low ductility.

7. Troostite:

- A mixture of radial lamellae of ferrite and cementite
- It hardness is intermediate between martensite and sorbite.

8. Sorbite:

- A mixture of ferrite and finely divided cementite.
- Tensile and yield strength are high.

9. Bainite:

- Eutectoid of ferrite and cementite.
- It harness is between the pearlite and

METALLURGY AND MATERIALS SCIENCE

UNIT II
HEAT TREATMENT

Normalising, hardening and Tempering of steel. Isothermal transformation diagrams – cooling curves superimposed on I.T. diagram CCR – Hardenability, Jominy end quench test - Austempering, martempering – case hardening, carburizing, Nitriding, cyaniding, carbonitriding – Flame and Induction hardening – Vacuum and Plasma hardening

Introduction

- Most of the engineering properties of metals and alloys are related to their structure.
  - Varying the constituents properties. micro- change the mechanical

- In practice, change in mechanical properties can be achieved by a process called heat treatment.
- Heat treatment can be defined as a heating and cooling operation applied to metals and alloys in solid state so as to obtain the desired

Purposes of Heat Treatment:

- Improvement in ductility
- Improvement in machinability
- Relieving internal stress
- Refinement of grain
- Alternation in magnetic and electrical properties
- Increasing the hardness
- Improvement in toughness

Heat Treatment Process

- Annealing
- Surface hardening
- Spheroidizing
- Normalizing
- Hardening
- Tempering

Annealing

- In the process of annealing, the steel is exposed to an elevated temperature and soaked at this temperature for some time and then very slowly cooled so as to relieve stresses, to increase ductility and toughness and to produce desired micro structure.

purpose

- To improve mechanical properties
- To improve machinability
- To restore ductility, particularly after the steel has been subjected to cold working
- To remove or minimize segregation of the

- To alter the microstructure to make it suitable for hardening.
- To relieve internal stresses

Full Annealing:

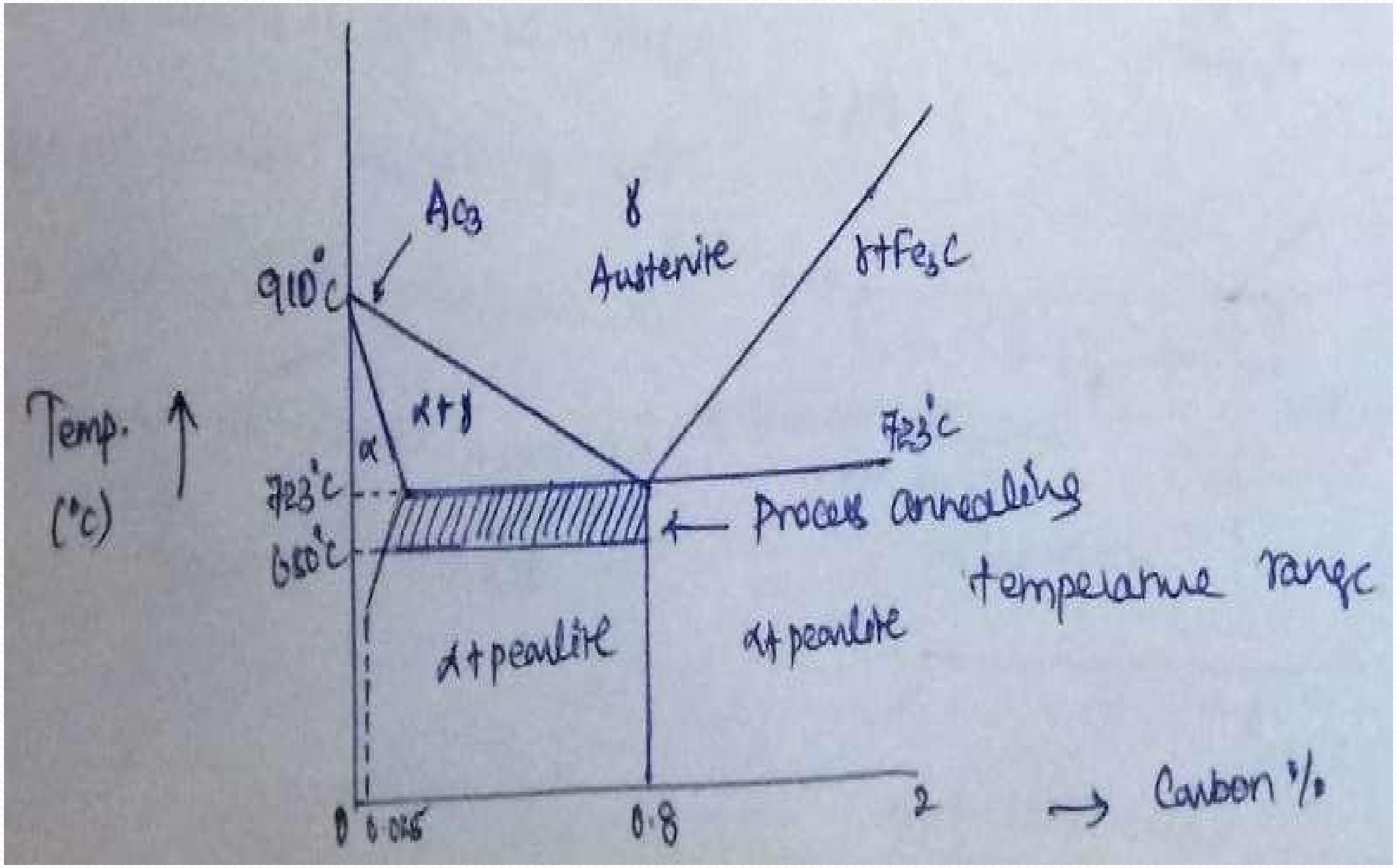
The main objective of full annealing is to soften the metal, to refine its grain structure, to relive the stresses and to remove gases trapped in the metal

- This process consist of heating the steel 30^{o} to 50^{o} above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature for hypereutectoid steel.
- The steel is then held at this temperature for sometime to enable the internal changes to take place.
- The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of the langest section, and then slowly cooled in the furnace.
- The rate of cooling varies from $30^{o}C$ to $200^{o}C$ per hour, depending upon the composition of steel.
- Also, full annealing process removes all structural

Process Annealing

- Process annealing is usually carried out to remove the effects of cold working and to soften the steel.
- Process annealing consists of heating steel uniformly to a temperature of 650ºC – 723ºC and holding at that temperature for sufficient time, followed by slow cooling.
- This process is very useful for mild steel, low carbon steel for removing cold working effects.

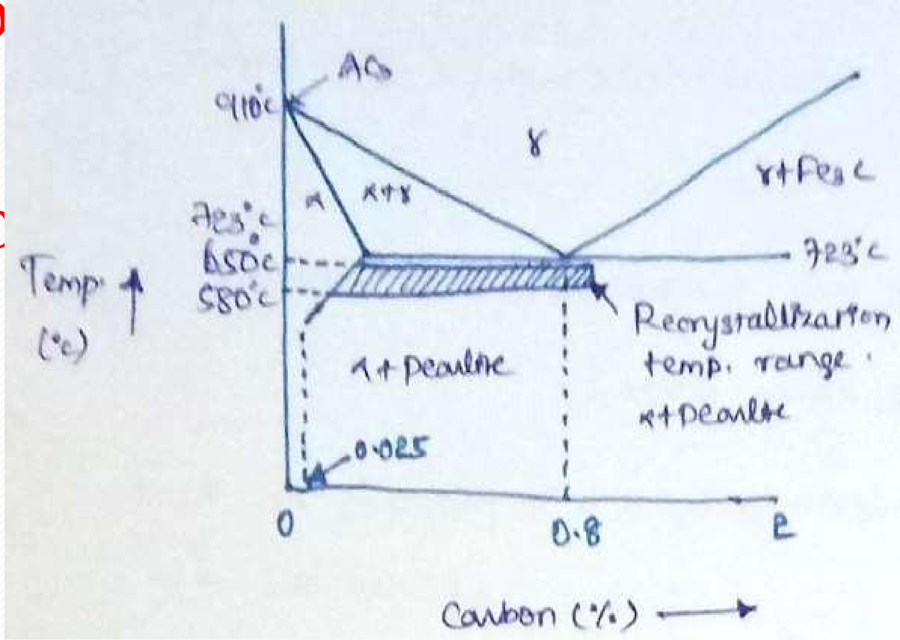
Process Annealing



Recrystallization or stress-relieving annealing

- This process is used to relieve internal stress which develops during different operations like welding, solidification of casting, machining etc.
- This process of recrystallization annealing consists of heating steel uniformly to a temperature 50ºC to 80ºC below 723ºC as shown in figure and holding at this temperature for sufficient time followed by slow cooling.

- Uniform cooling is most important as non-uniform cooling results in the development of internal stress.
- Recrystallization or stress-relieving annealing is widely used fo
sheets, etc.
- It can be used for bo
metals and alloys.



Spheroidal annealing or spheroidizing

- In spheroidal annealing graphite with iron in the granular form is produced.
- The prolonged heating causes the cementite to course into spheres, completely destroying the pearlitic formation.
- The actual structure is a matrix of ferrite with Fe_3C in the form of spheroidal globules. The heat treatment that follows after machining should be done easily.

Continue…

- This process is usually applied to high carbon steel which is difficult to machine.
- The process consist of heating steel between 650ºC and 723ºC holding at this temperature and then cooling very slowly.
- The rate of cooling in furnace is 25ºC to 30ºC per hour.

END