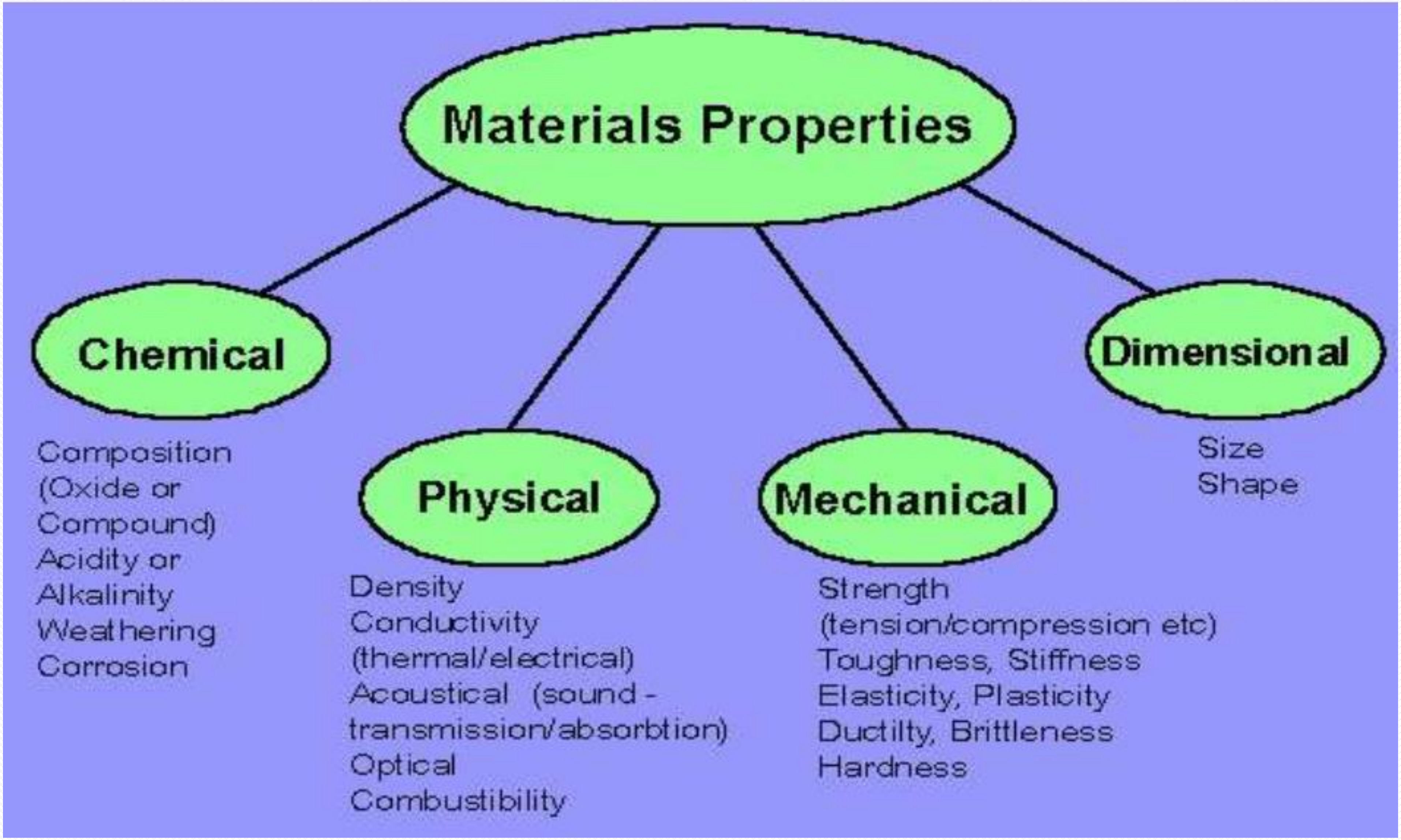
Unit-1

Introduction

INTRODUCTION:

- The practical application of engineering materials in manufacturing engineering depends upon a thorough knowledge of their particular properties under a wide range of conditions.
- The term ***"property"*** is a qualitative or quantitative measure of response of materials to externally imposed conditions like forces and temperatures.
- However,the range of properties found in different classes of materials is very large.

Classification of material property:



Materials Properties

Chemical

- Composition (Oxide or Compound)
- Acidity or Alkalinity
- Weathering
- Corrosion

Physical

- Density
- Conductivity (thermal/electrical)
- Acoustical (sound - transmission/absorbtion)
- Optical
- Combustibility

Mechanical

- Strength (tension/compression etc)
- Toughness, Stiffness
- Elasticity, Plasticity
- Ductilty, Brittleness
- Hardness

Dimensional

- Size
- Shape

MECHANICAL PROPERTIES:

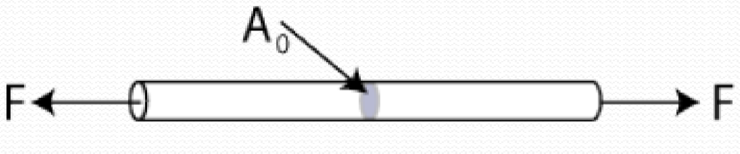
- The properties of material that determine its behaviour under applied forces are known as mechanical properties.
- They are usually related to the elastic and plastic behaviour of the material.
- These properties are expressed as functions of stress-strain,etc.
- A sound knowledge of mechanical properties of materials provides the basis for predicting behaviour of materials under different load conditions and designing the components out of them.

STRESS AND STRAIN

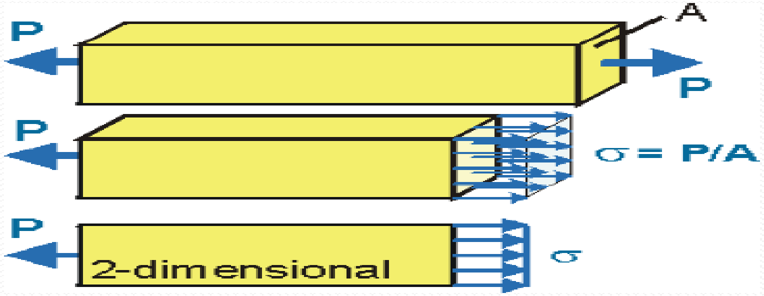
- Experience shows that any material subjected to a load may either deform, yield or break, depending upon the
  - The Magnitude of load
  - Nature of the material
  - Cross sectional dime.

CONTI..

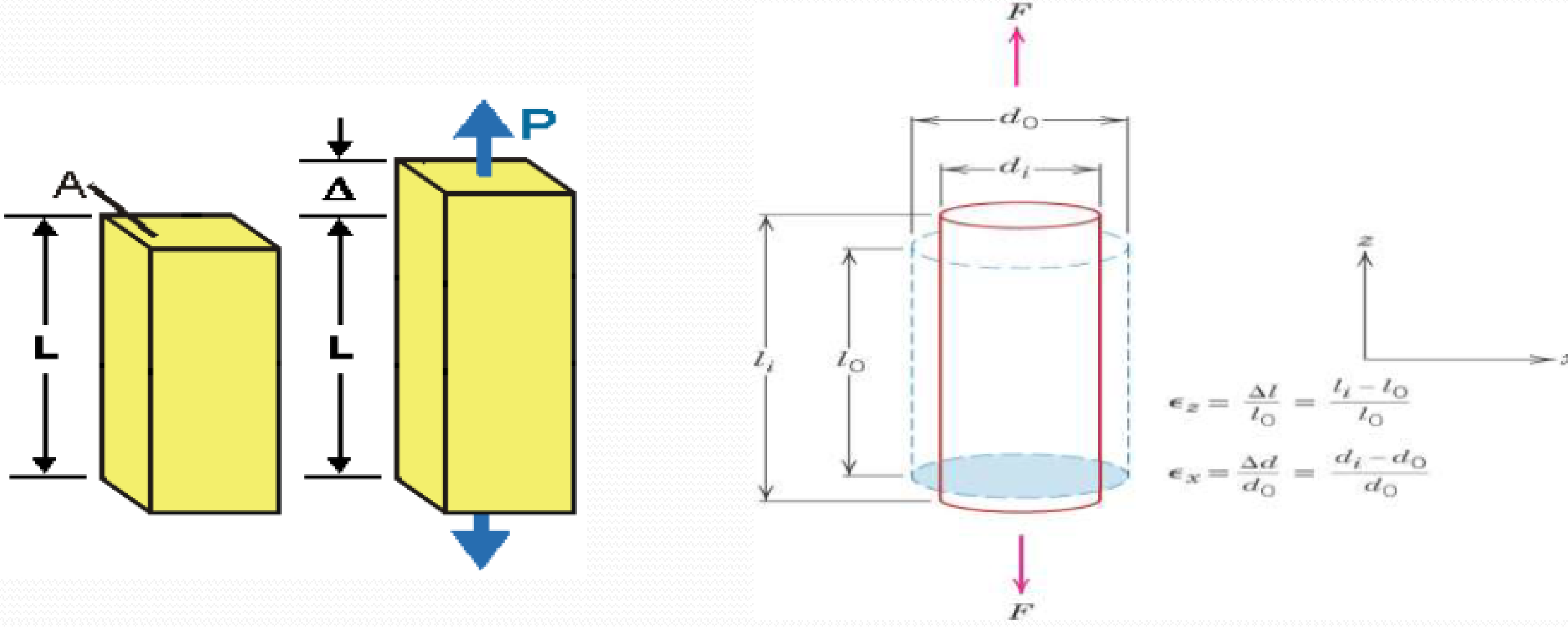
- The sum total of all the elementary interatomic forces or internal resistances which the material is called upon to exert to counteract the applied load is called stress.
- Mathematically, the stress is expressed as force divided by cross-sectional area.



$$\text{Stress, } \sigma = \frac{\text{Force}}{\text{Cross-Sectional Area}} = \frac{F}{A_0}$$



- Strain is the dimensional response given by material against mechanical loading/Deformation produced per unit length.
- Mathematically Strain is change in length divided by original length.

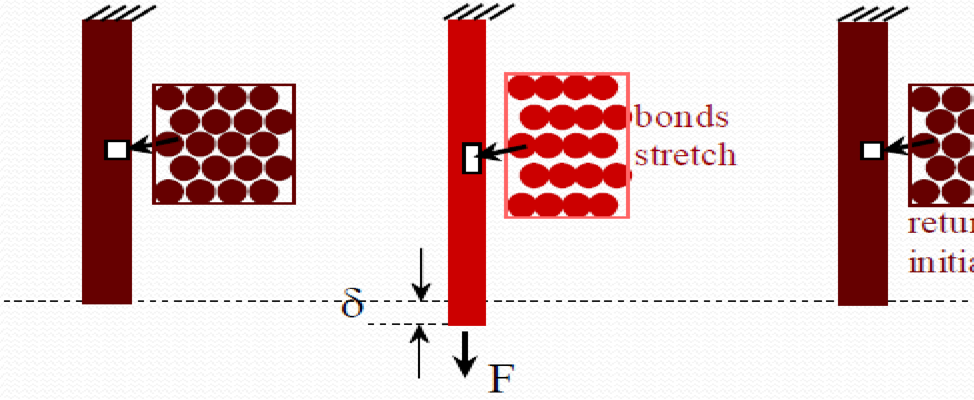


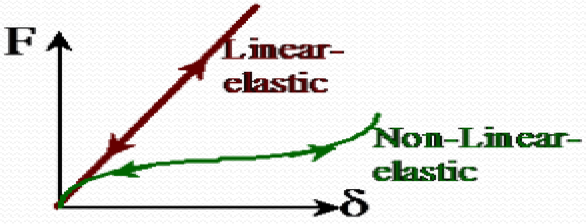
STRENGTH

- The strength of a material is its capacity to withstand destruction under the action of external loads.
- It determines the ability of a material to withstand stress without failure.
- The maximum stress that any material will withstand before destruction is called ultimate strength.

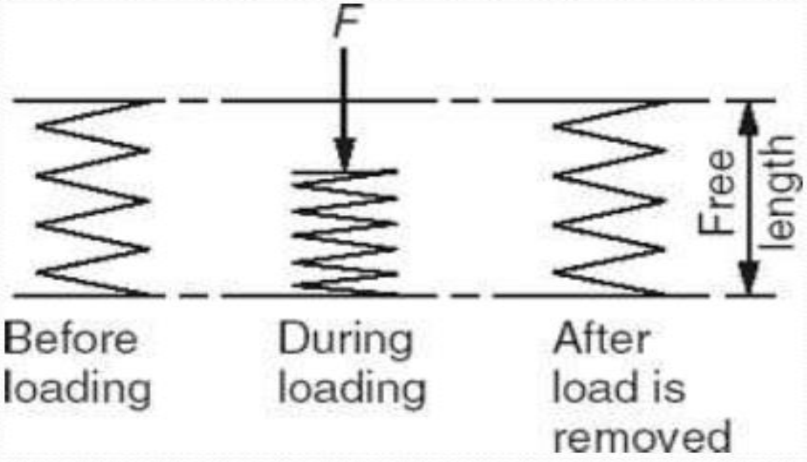
ELASTICITY:

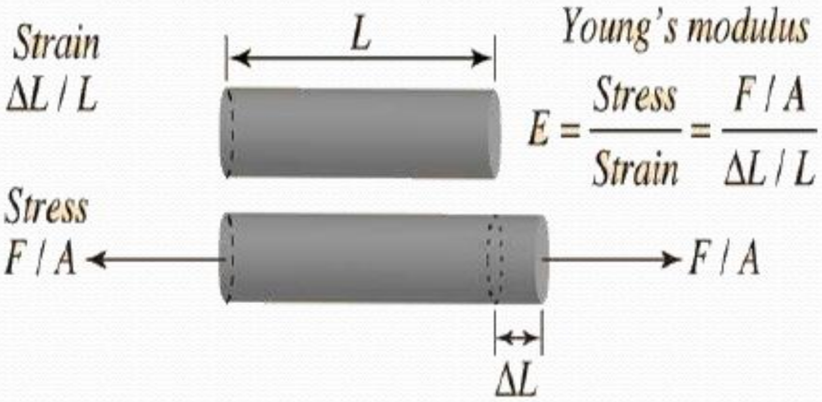
- The property of material by virtue of which deformation caused by applied load disappears upon removal of load.
- Elasticity of a material is the power of coming back to its original position after deformation when the stress or load is removed.





Elastic means reversible.

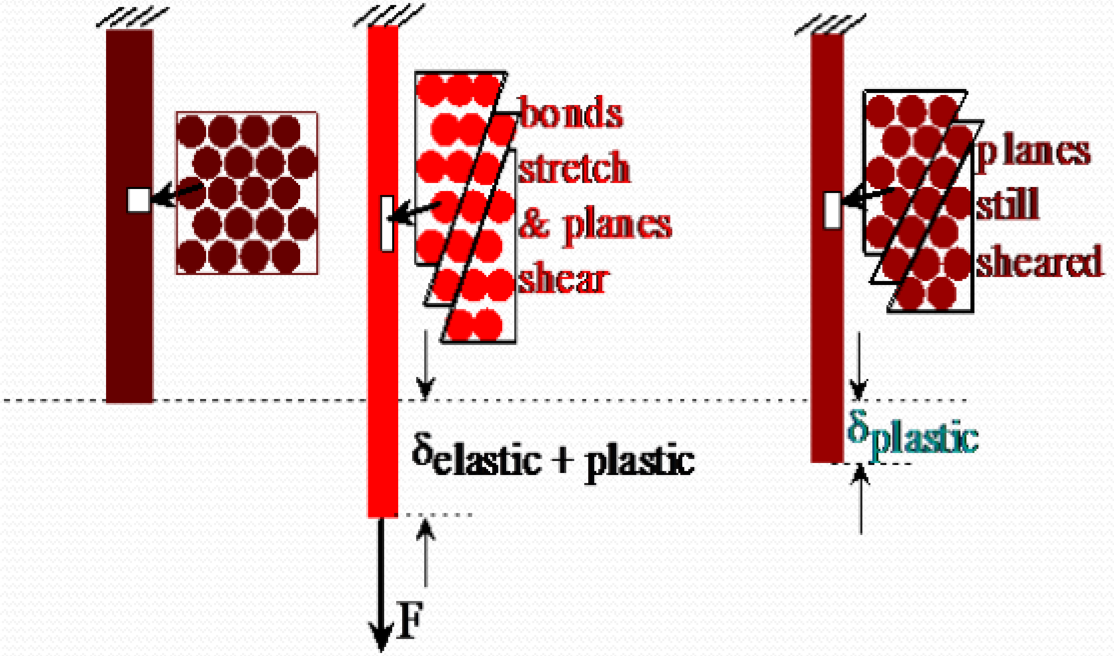


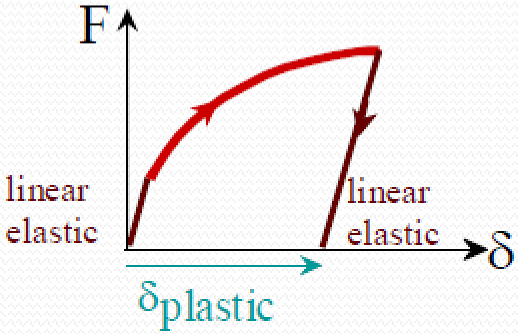


$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F / A}{\Delta L / L}$$

PLASTICITY:

- The plasticity of a material is its ability to undergo some degree of permanent deformation without rupture or failure.
- Plastic deformation will take only after the elastic limit is exceeded.
- It increases with increase in temperature.





Plastic means permanent.

STIFFNESS:

- The resistance of a material to elastic deformation or deflection is called stiffness or rigidity.
- A material which suffers slight deformation under load has a high degree of stiffness or rigidity.
- E.g. Steel beam is more stiffer or more rigid than aluminium beam.

DUCTILITY:

- It is the property of a material which enables it to draw out into thin wires.
- E.g., Mild steel is a ductile material.
- The percent elongation and the reduction in area in tension is often used as emperical measures of ductility.

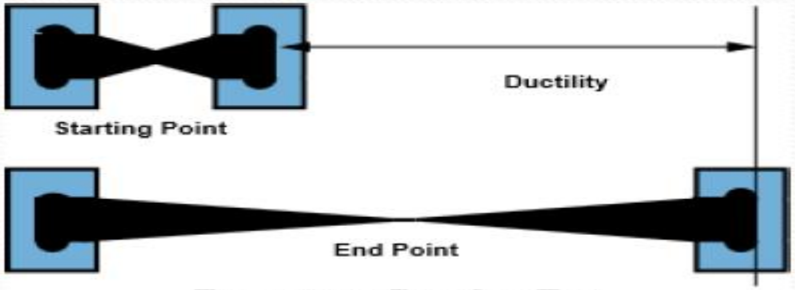
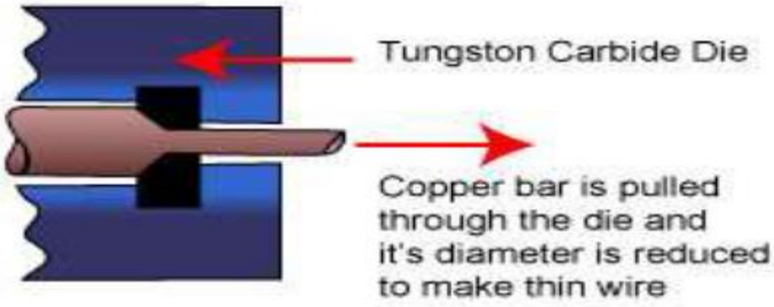
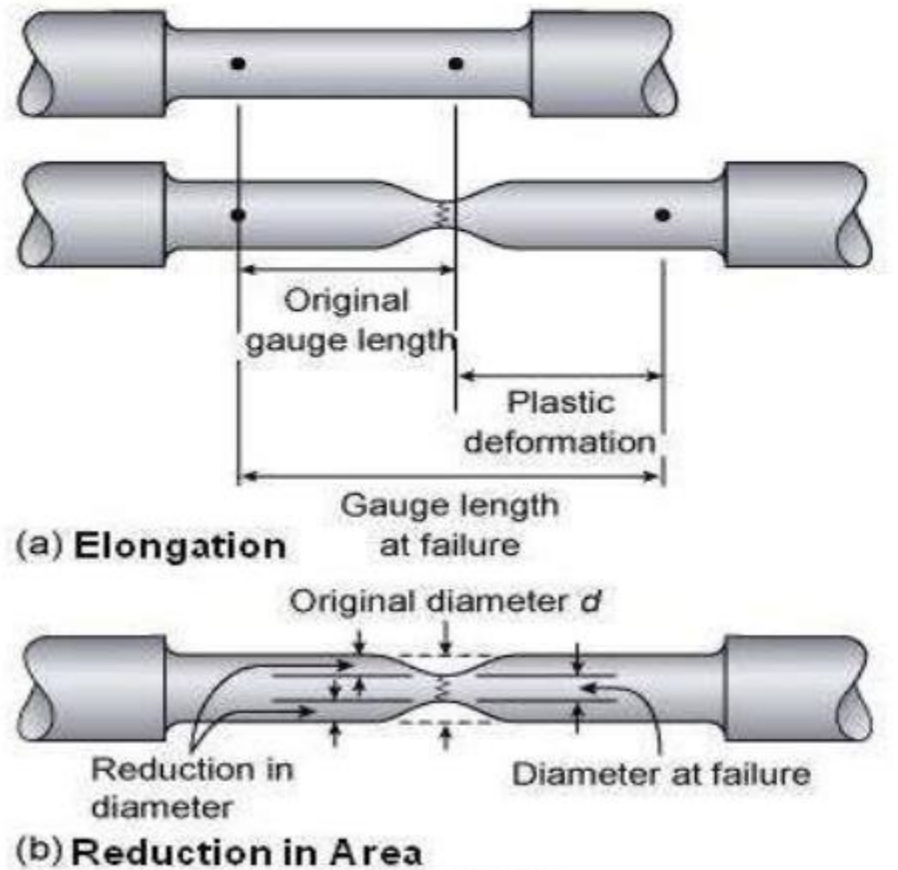


Figure 23:2: Ductility Test

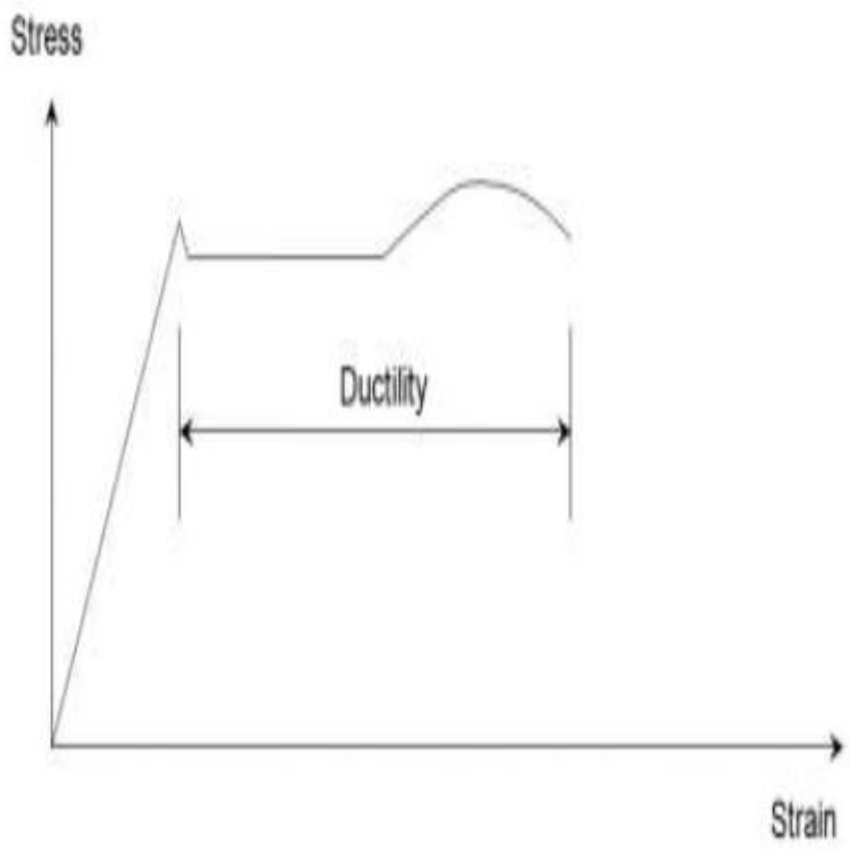




(a) **Elongation**

(b) **Reduction in Area**

Ductility



Malleability:

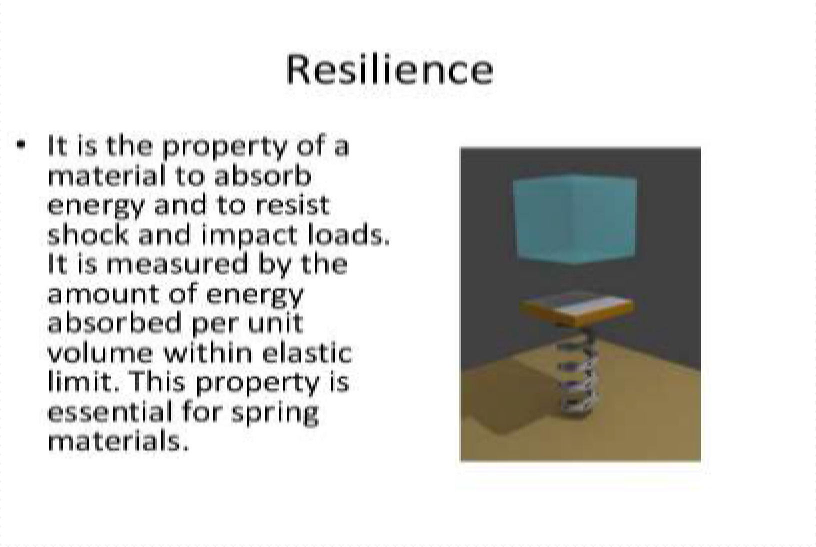
- Malleability of a material is its ability to be flattened into thin sheets without cracking by hot or cold working.
- E.g Lead can be readily rolled and hammered into thin sheets but can be drawn into wire.

Comparision of ductility and malleability

- Ductility and Malleability are frequently used interchangeably many times.
- Ductility is ***tensile quality, while*** malleability is ***compressive quality.***

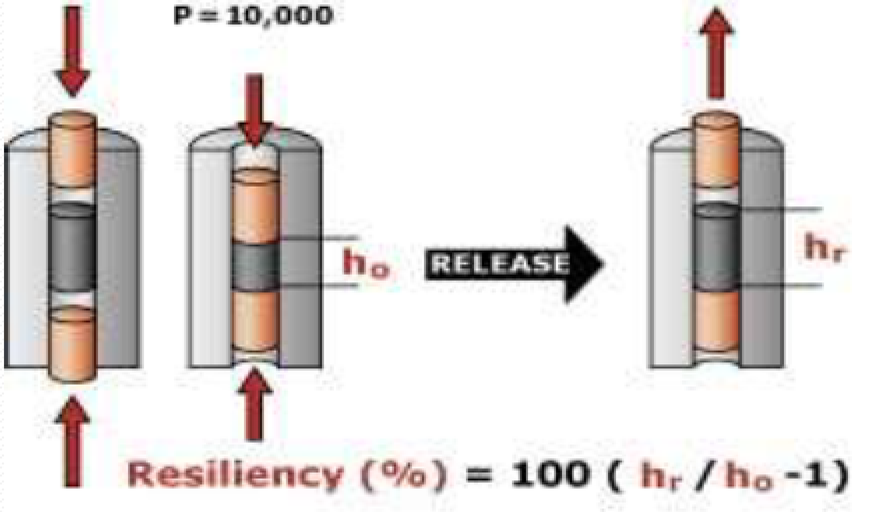
RESILIENCE:

- It is the capacity of a material to absorb energy elastically.
- The maximum energy which can be stored in a body upto elastic limit is called the ***proof resilience, and*** the proof resilience per unit volume is called ***modulus of resilience***.
- The quantity gives capacity of the material to bear shocks and vibrations.



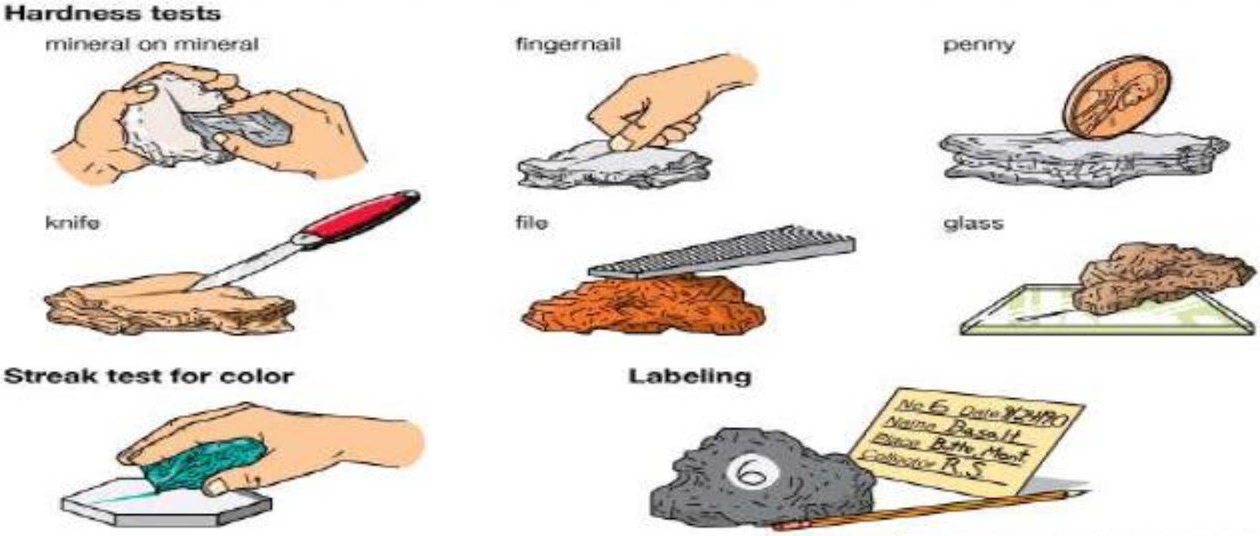
Resilience

- It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for spring materials.



HARDNESS:

- Hardness is a fundamental property which is closely related to strength.
- Hardness is usually defined in terms of the ability of a material to resist to ***scratching, abrasion, cutting, identation,or penetration.***
- Methods used for determining hardness: Brinel, Rockwell ,Vickers.



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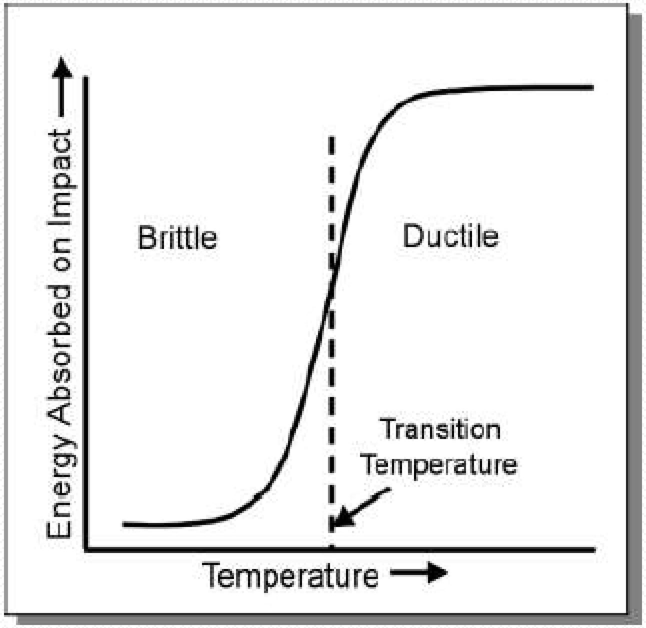
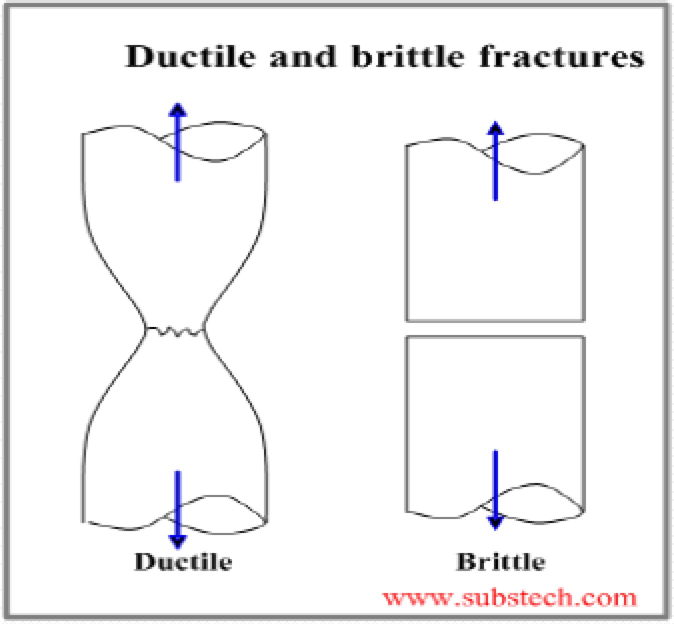
BRITTLENESS:

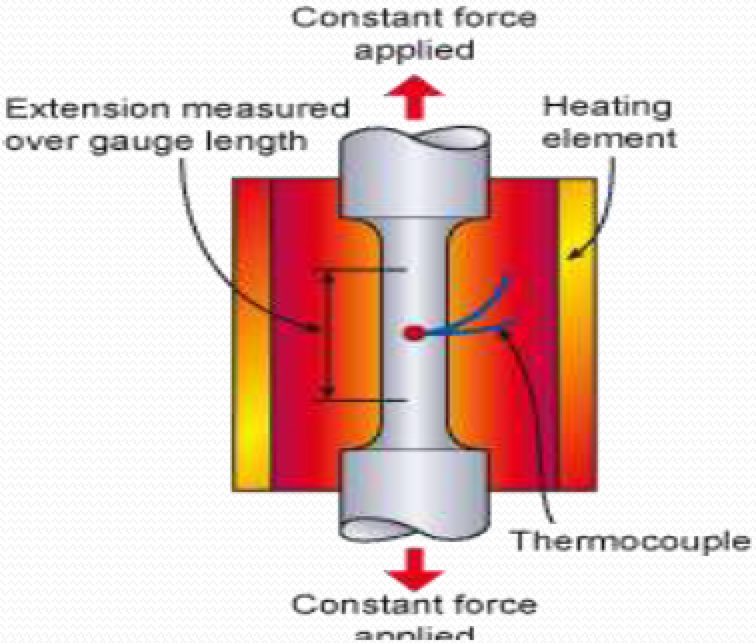
- It is the property of breaking without much permanent distortion.
- Non-Ductile material is considered to be brittle material.
- E.g, Glass, Cast iron,etc.





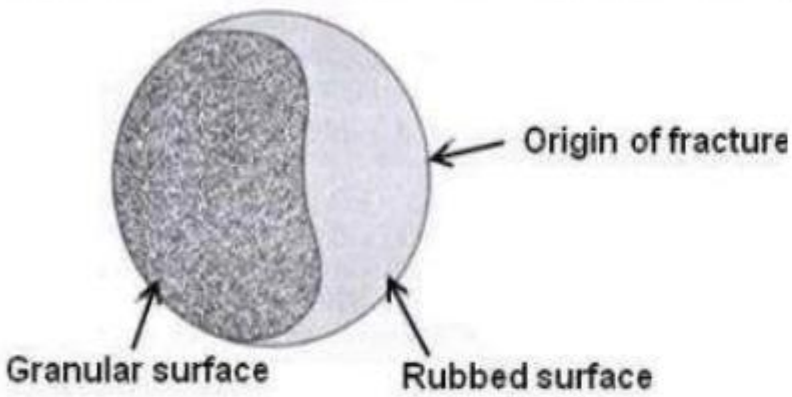
CREEP:

- The slow and progressive deformation of a material with time at constant stress is called creep.
- Depending on temperature, stresses even below the elastic limit can cause some permanent deformation.
- It is most generally defined as time-depndent strain occuring under stress.



FATIGUE:

- This phenomenon leads to fracture under repeated or fluctuating stress.
- Fatigue fractures are progressive beginning as minute cracks and grow under the action of fluctuating stress.
- Many components of high speed aero and turbine engines are of this type.



Surface of a Fatigue Fracture

Unit-2

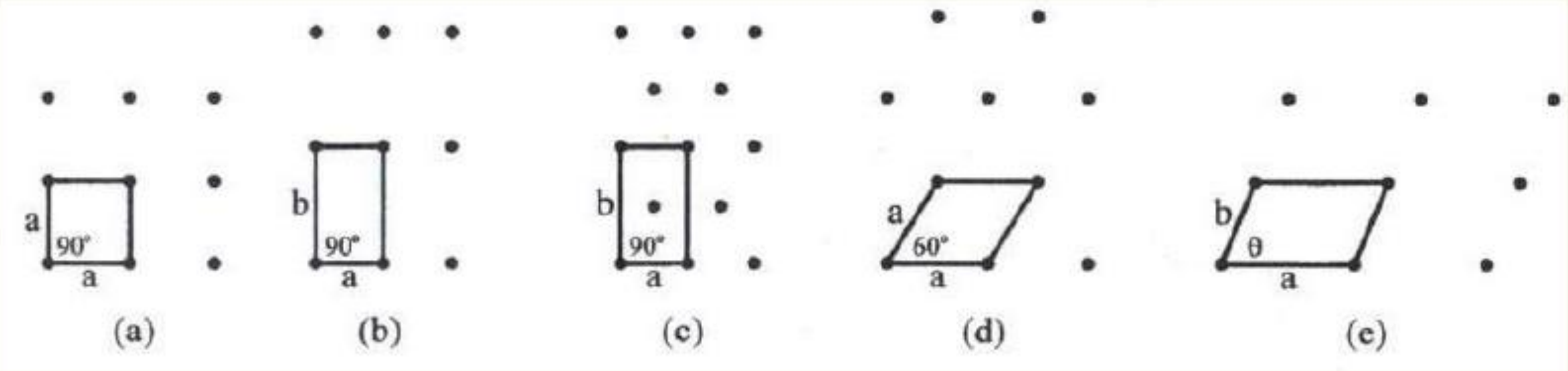
Crystllography

Introduction to Crystallography:

Crystal Structures

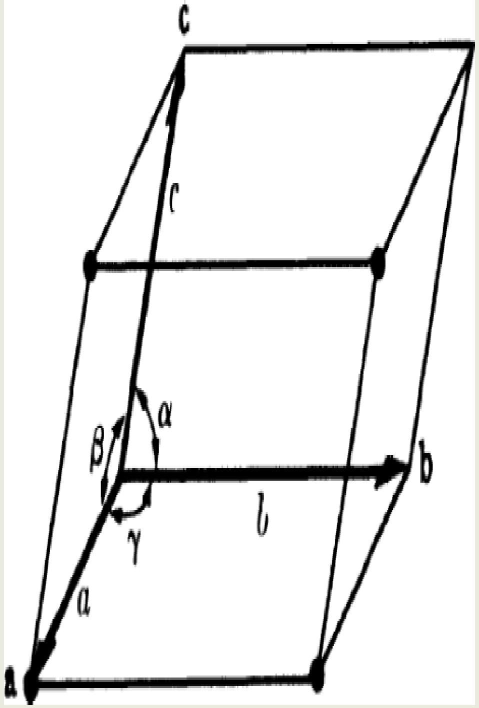
- Five regular arrangements of lattice points that can occur in two dimensions.

(a) square; (b) primitive rectangular;
(c) centered rectangular; (d) hexagonal;
(e) oblique.

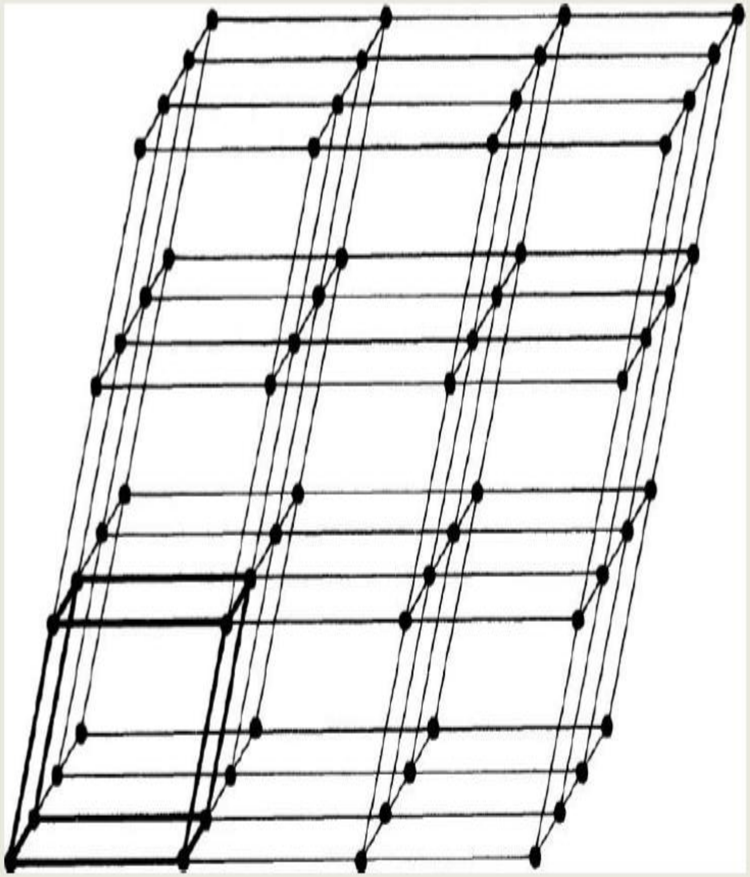


Unit cell

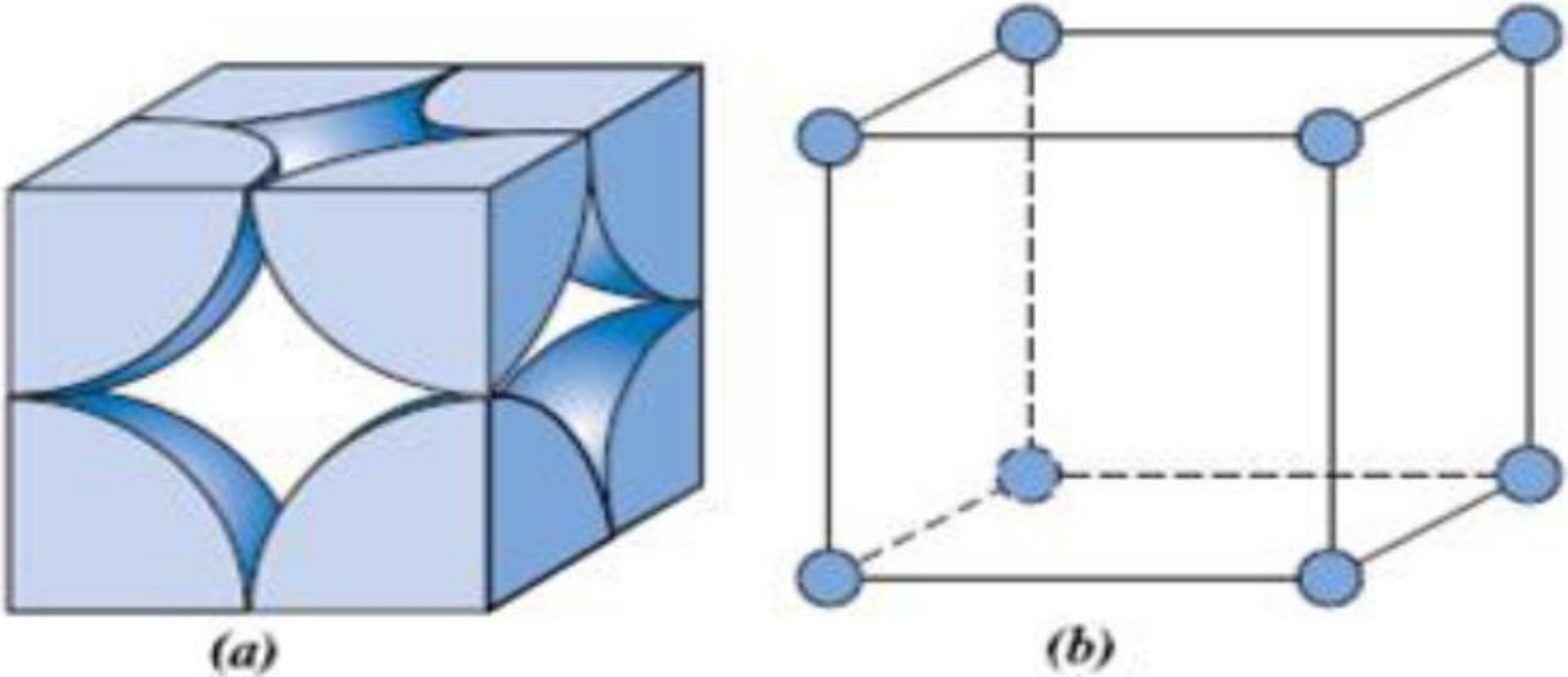
- Lattice parameters: **a, b, c,** α, β and γ



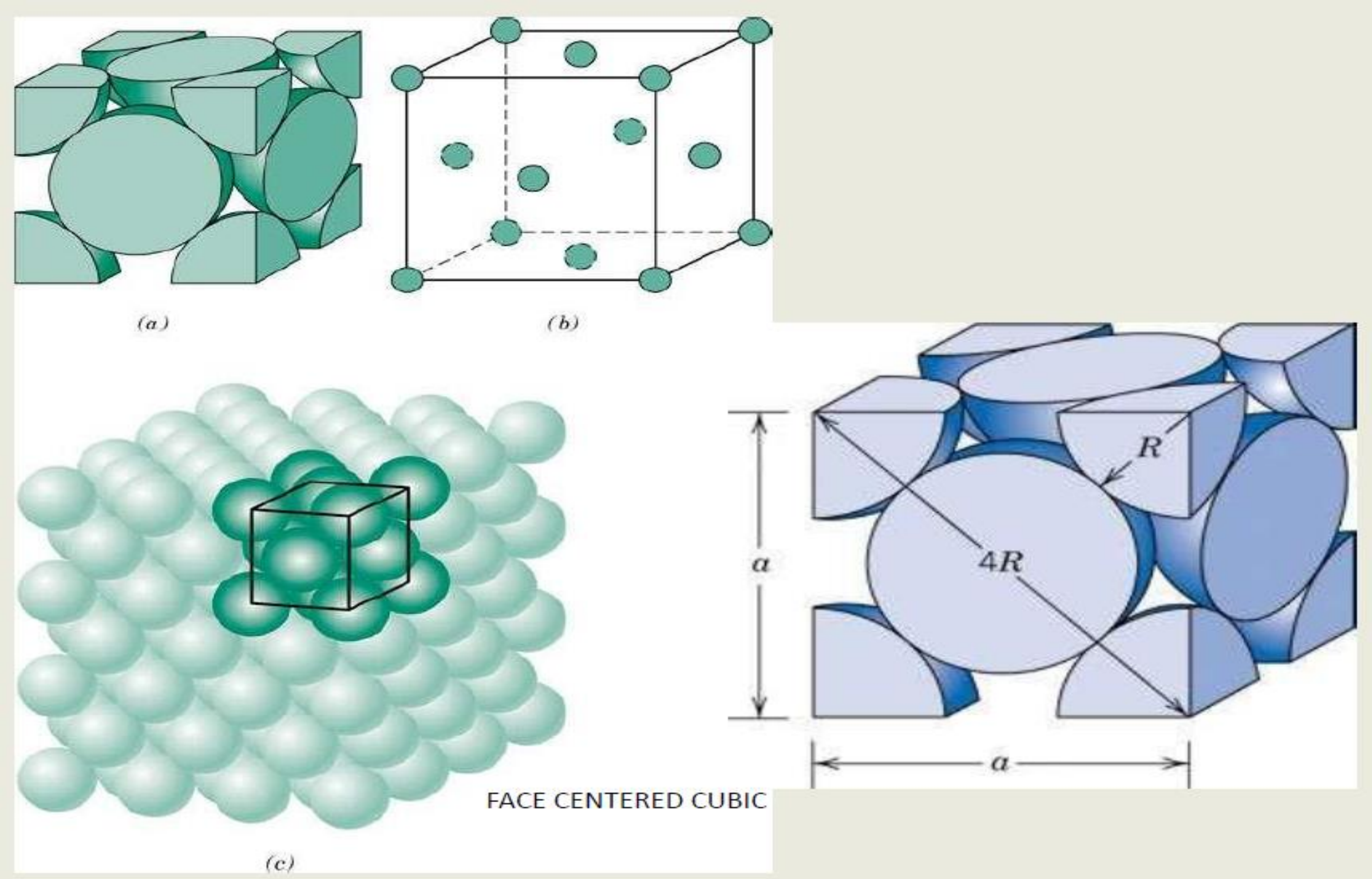
Space lattice



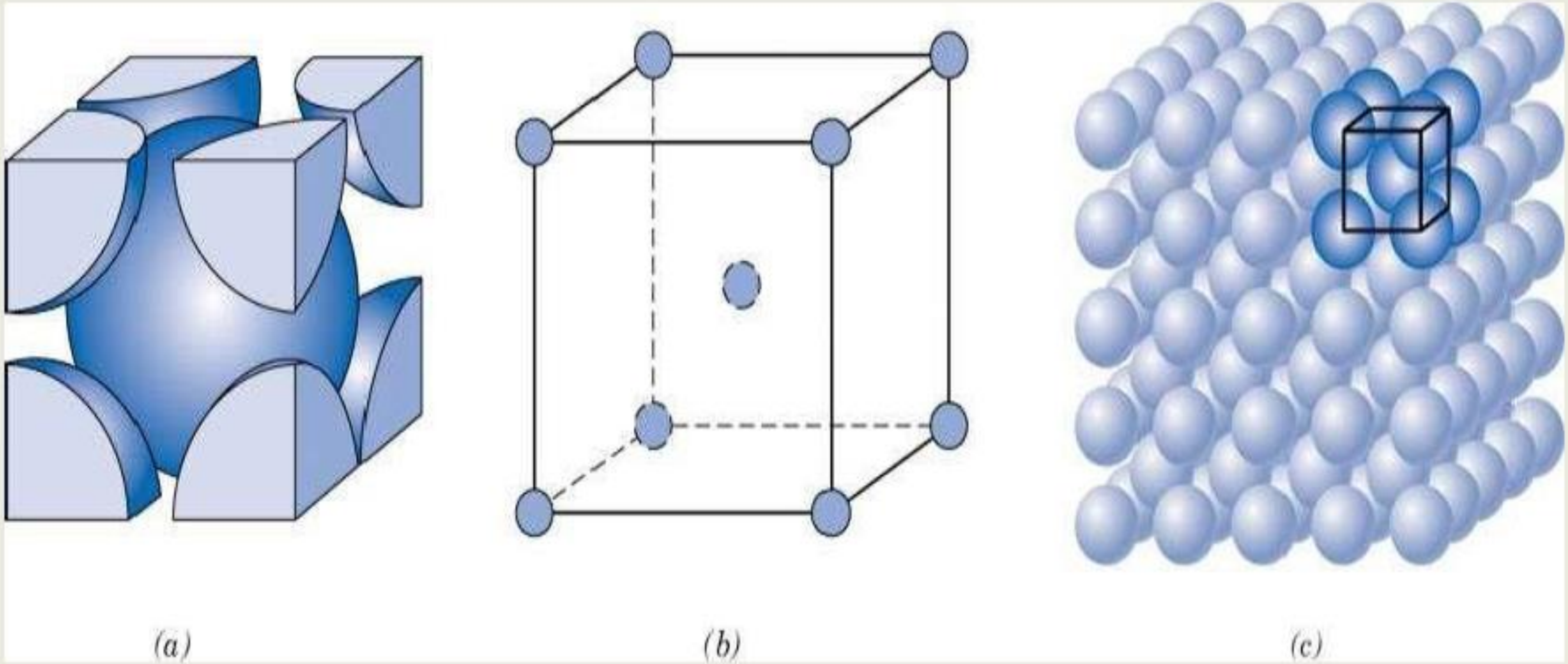
ARRENGEMENT OF ATOMS



- SIMPLE CUBIC STRUCTURE

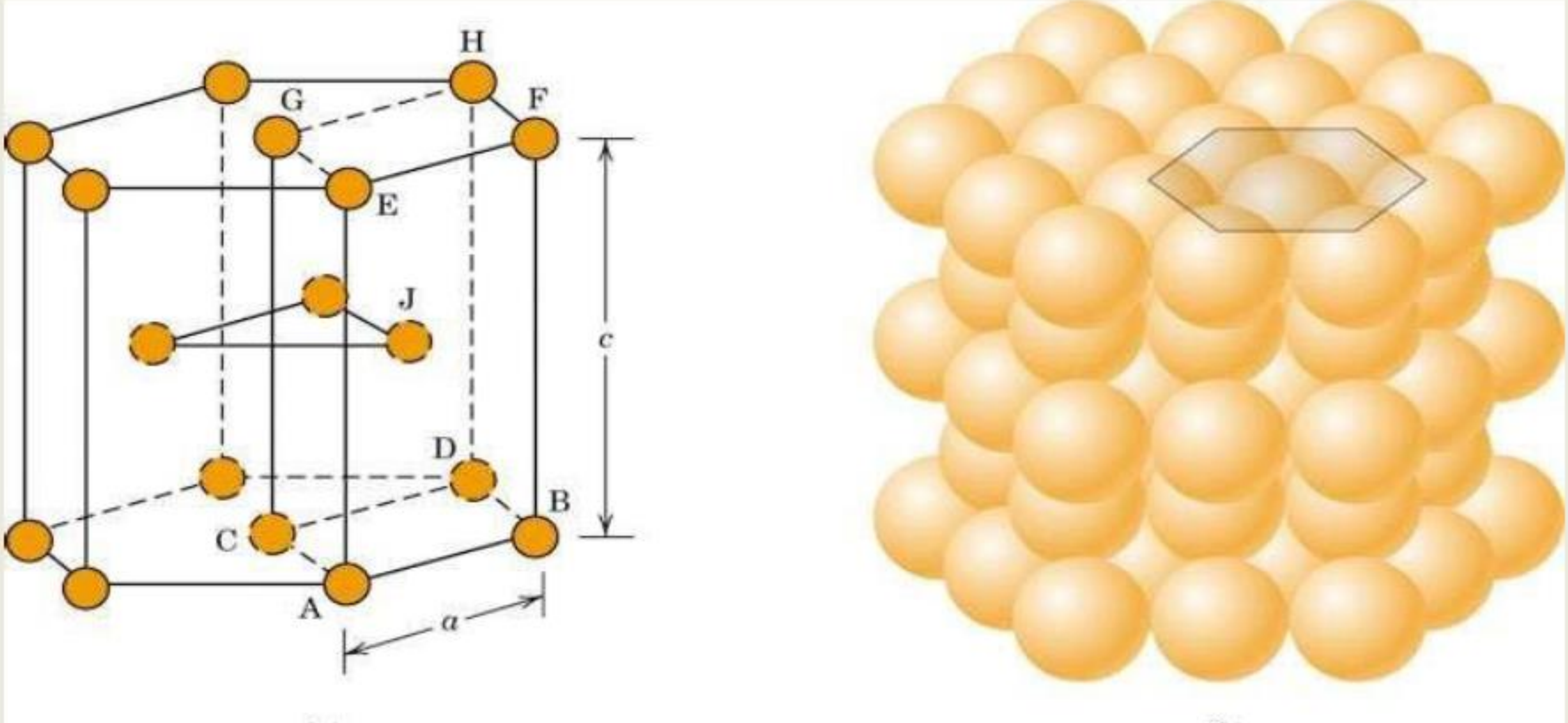


FACE CENTERED CUBIC



(a) (b) (c)

Body Centred Cubic



(a) (b)

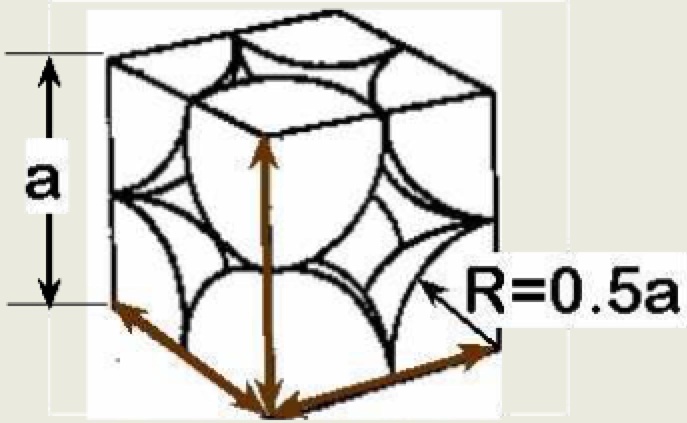
Hexagonal Close Packed

ATOMIC PACKING FACTOR

$$\text{APF} = \frac{\text{Volume of atoms in unit cell*}}{\text{Volume of unit cell}}$$

*assume hard spheres

- APF for a simple cubic structure = 0.52



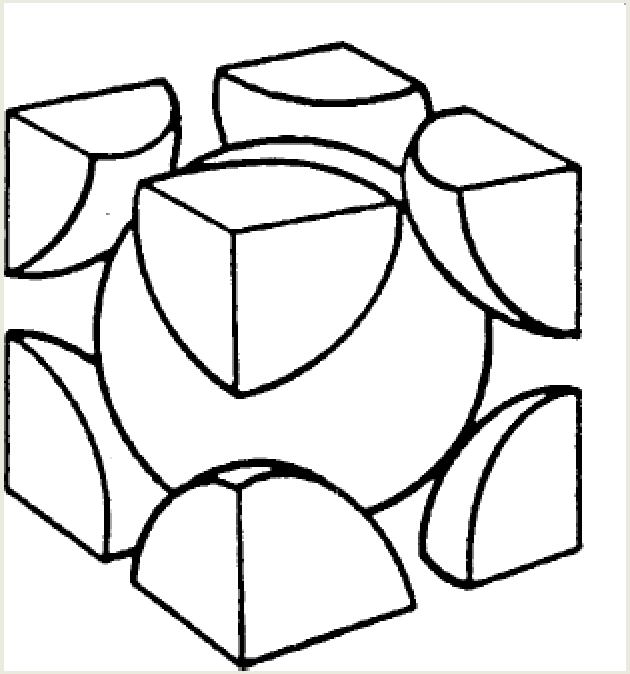
close-packed directions

contains 8 x 1/8 =
1 atom/unit cell

$$\text{APF} = \frac{\underbrace{1}_{\frac{\text{atoms}}{\text{unit cell}}}\ \underbrace{\frac{4}{3}\pi\,(0.5a)^3}_{\frac{\text{volume}}{\text{atom}}}}{\underbrace{a^3}_{\frac{\text{volume}}{\text{unit cell}}}}$$

ATOMIC PACKING FACTOR: BCC

- APF for a body-centered cubic structure = 0.68



Close-packed directions:

length = 4R

$= \sqrt{3}\, a$

Unit cell contains:

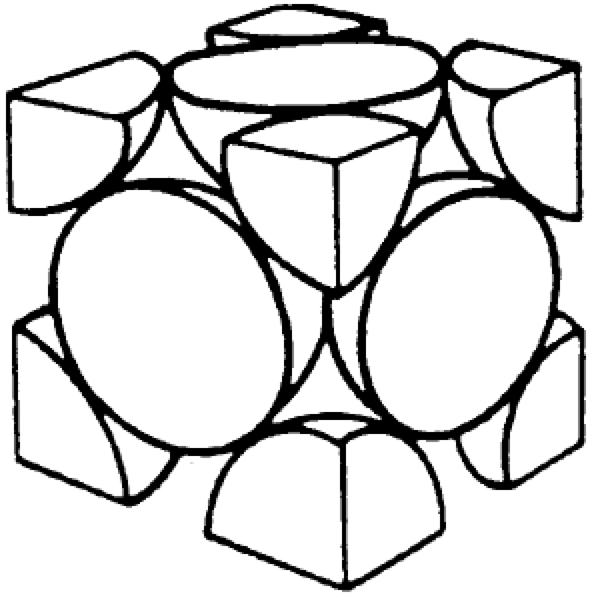
1 + 8 x 1/8

= 2 atoms/unit cell

$$\text{APF} = \frac{\overbrace{2}^{\frac{\text{atoms}}{\text{unit cell}}} \;\; \overbrace{\frac{4}{3}\pi\left(\sqrt{3}a/4\right)^3}^{\frac{\text{volume}}{\text{atom}}}}{\underbrace{a^3}_{\frac{\text{volume}}{\text{unit cell}}}}$$

ATOMIC PACKING FACTOR: FCC

- APF for a body-centered cubic structure = 0.74



Close-packed directions:
length = 4R
$= \sqrt{2}\, a$

Unit cell contains:
6 x 1/2 + 8 x 1/8
= 4 atoms/unit cell

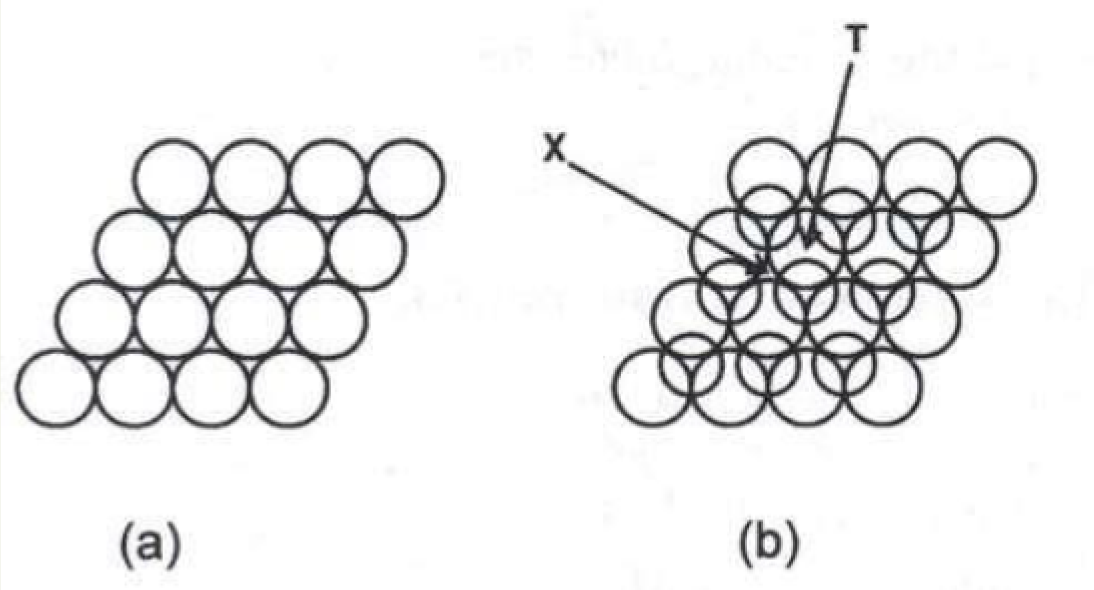
$$\frac{\text{atoms}}{\text{unit cell}} \rightarrow \qquad \leftarrow \frac{\text{volume}}{\text{atom}}$$

$$\text{APF} = \frac{4 \quad \frac{4}{3}\pi\left(\sqrt{2}a/4\right)^3}{a^3}$$

$$a^3 \leftarrow \frac{\text{volume}}{\text{unit cell}}$$

Atomic packing

- In two dimensions the most efficient way to pack identical circles is equilateral triangle arrangement shown in figure (a).
- A second hexagonal layer of spheres can be placed on top of the first to form the most efficient packing of two layers, as shown in figure (b).
- For efficient packing, the third layer can be placed either above the first layer with an atom at the location indicated by T or in the third possible arrangement with an atom above the position marked by X on the figure.
- In the first case a hexagonal lattice with a hexagonal close packed (HCP) structure is generated
cubic lattice results.



(a) (b)

Coordination number

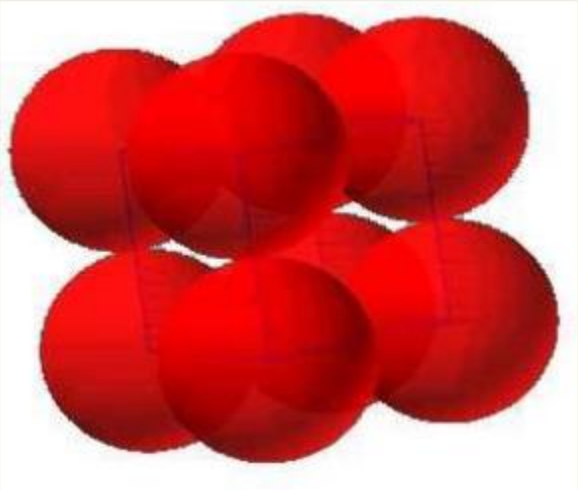
Number of nearest neighbors of an atom in the crystal lattice

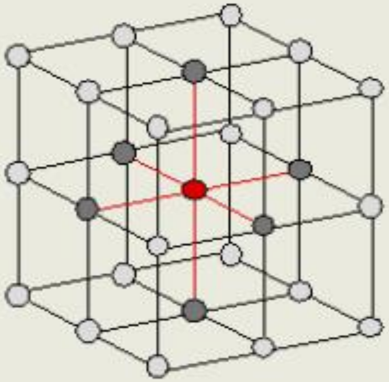
SIMPLE CUBIC STRUCTURE (SC)

- Rare due to poor packing (only Po has this structure)
- Close-packed directions are cube edges.

Polonium is a chemical ***element*** with the symbol ***Po*** and atomic number 84, discovered in 1898 by Marie

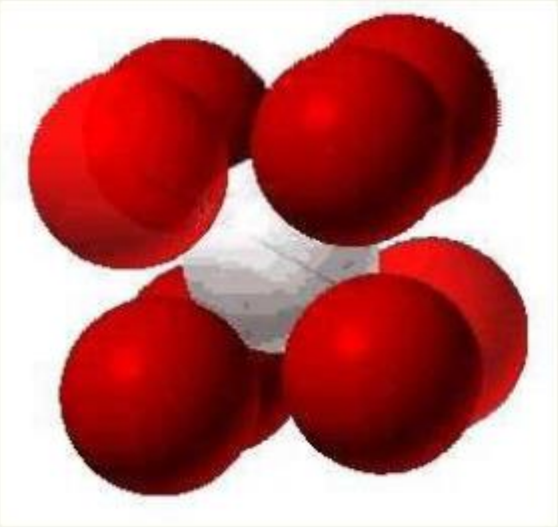
- Coordination # = 6
  (# nearest neighbors)



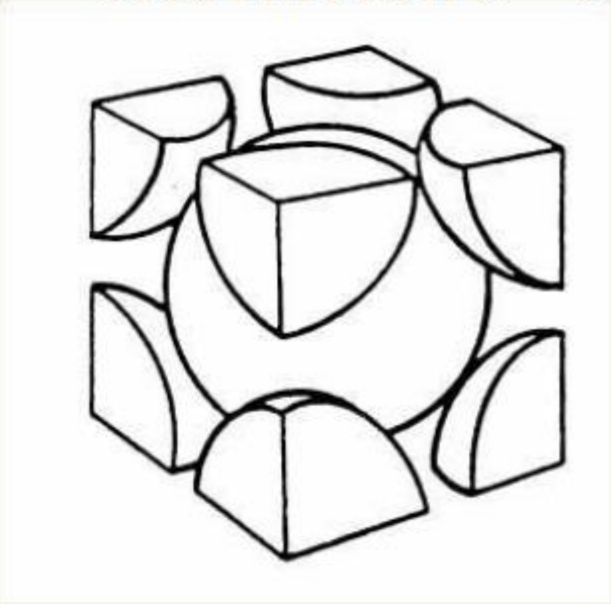


BODY CENTERED CUBIC STRUCTURE (BCC)

- Close packed directions are cube diagonals.
  - --Note: All atoms are identical; the center atom is shaded differently only for ease of viewing.



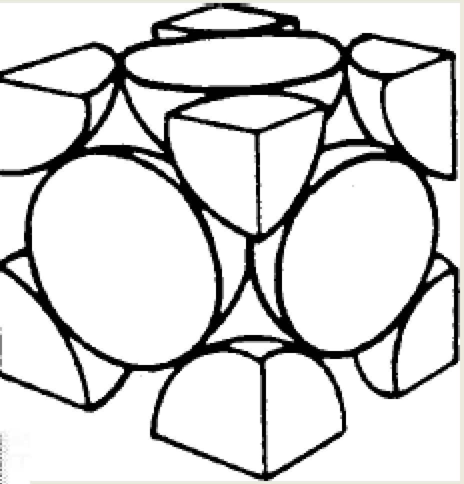
- Coordination # = 8

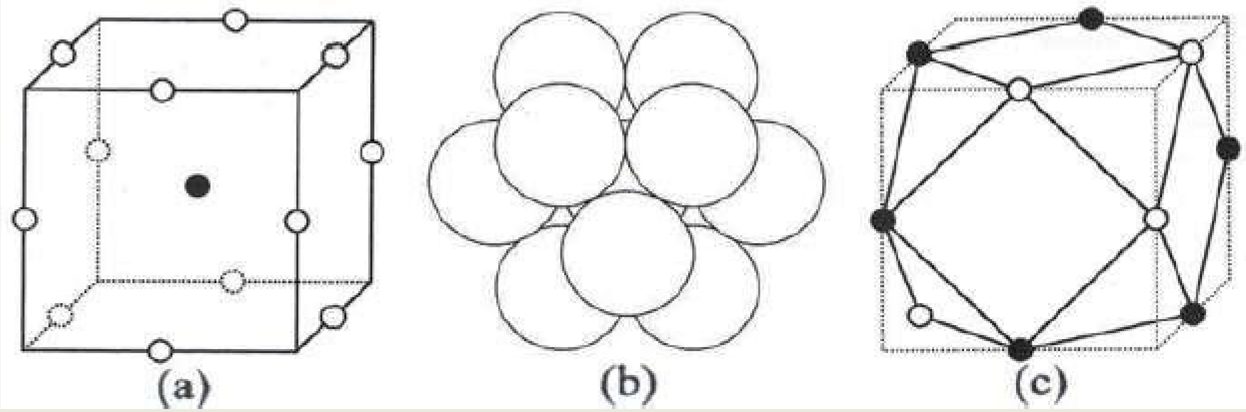


FACE CENTERED CUBIC STRUCTURE (FCC)

- Close packed directions are face diagonals.
  - --Note: All atoms are identical; the face-centered atoms are shaded differently only for ease of viewing.

- **Coordination # = 12**





DEFECTS IN CRYSTALS

Crystals are like people, it is the defects in them which tend to make them interesting!" - Colin Humphreys

Crystal defects

1. Point defect-
   - Vacancy,
   - Impurity atoms (substitutional and interstitial)
   - Frankel and Schottky defect (ionic solids & nonstochiometric)
2. Line defect-
   - Edge dislocation
   - Screw dislocation,
   - Mixed dislocation
3. Surface defects-
   - Grain boundaries
   - Twin boundary
   - Surfaces, stacking faults
   - Interphases

INTRODUCTION

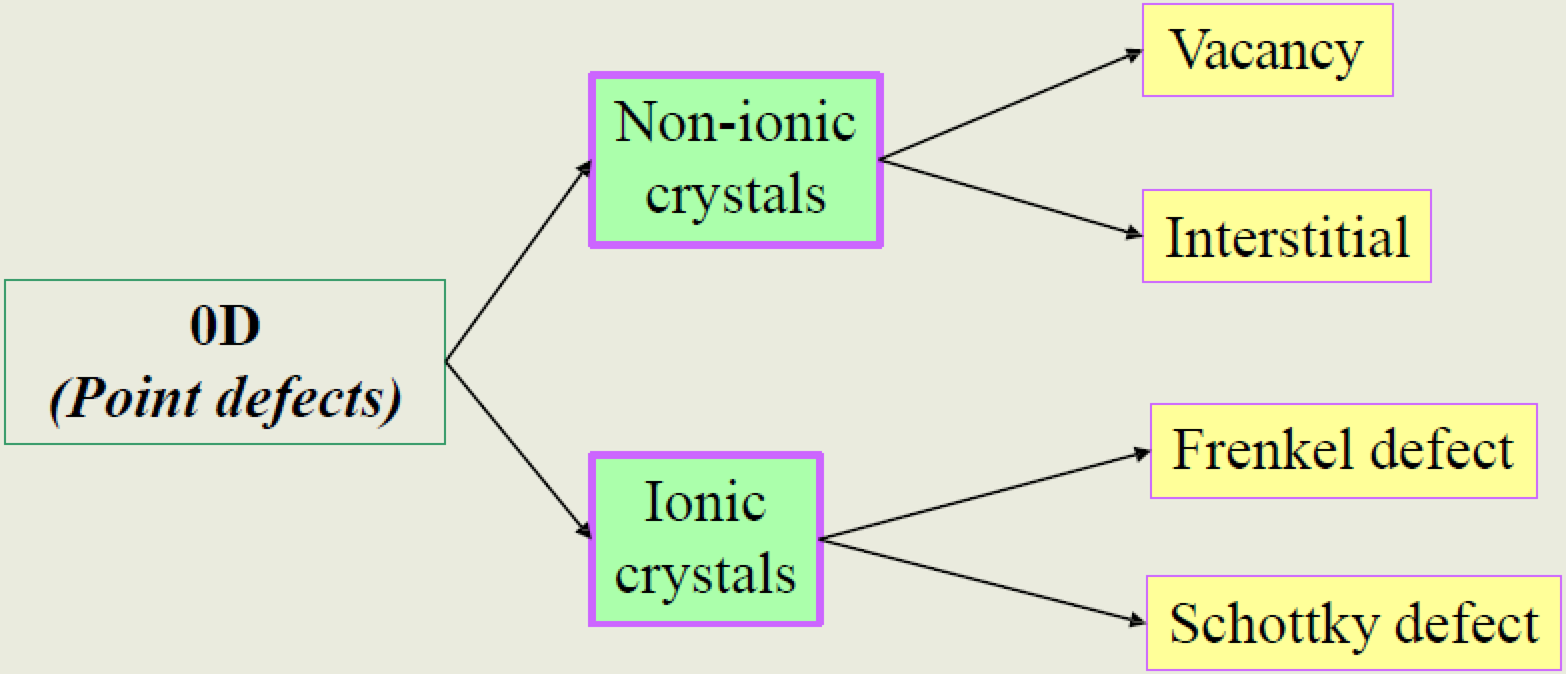
- Crystalline material has a crystal structure in which the atoms are positioned in perfect ordered pattern which is repetitive over large atomic distance.
- Defects have a profound impact on the macroscopic properties of materials.
- Sometimes defects are deliberately created to improve properties of crystal.

CLASSIFICATION OF DEFECTS BASED ON DIMENSIONALITY

- **0D** ***(Point defects)***
  - Vacancy
  - Interstitial
  - Frenkel defect
  - Schottky defect
- **1D** ***(Line defects)***
  - Edge Dislocation
  - Screw Dislocation
- ***2D*** ***(Surface / Interface)***
  - Grain boundary
  - Twin boundary
  - Stacking faults

POINT DEFECTS

Point Defects are the irregularities or deviations from ideal arrangement around a point or an atom in a crystalline substance.



- **0D** *(Point defects)*
  - Non-ionic crystals
    - Vacancy
    - Interstitial
  - Ionic crystals
    - Frenkel defect
    - Schottky defect

VACANCY DEFECT

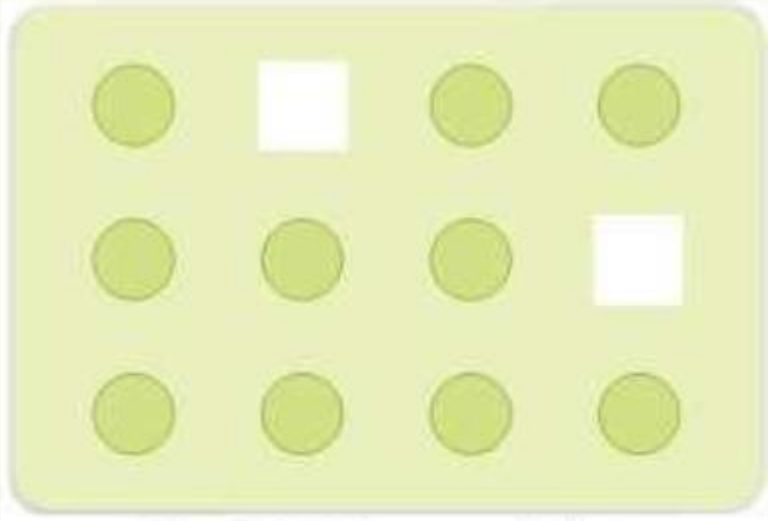
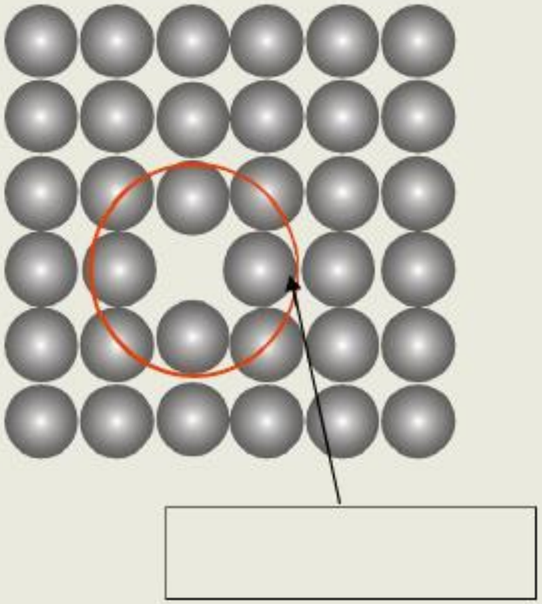
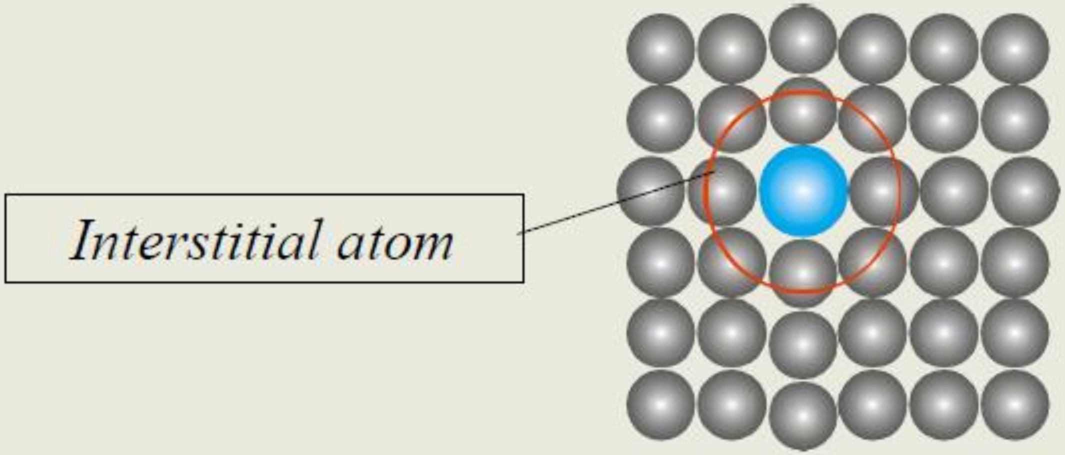


Fig. 1.23: Vacancy defects



- Atom missing from an atomic site
- Occur due to imperfect packing during crystallisation
- This results in decrease in density of the substance
- Number of vacancy defects depend on temperature

INTERSTITIALS DEFECT



- Addition of an extra atom within a crystal structure
- This defect increases the density of the substance
- Causes atomic distortion
- Vacancy and interstitials are inverse phenomena

SCHOTTKY DEFECT

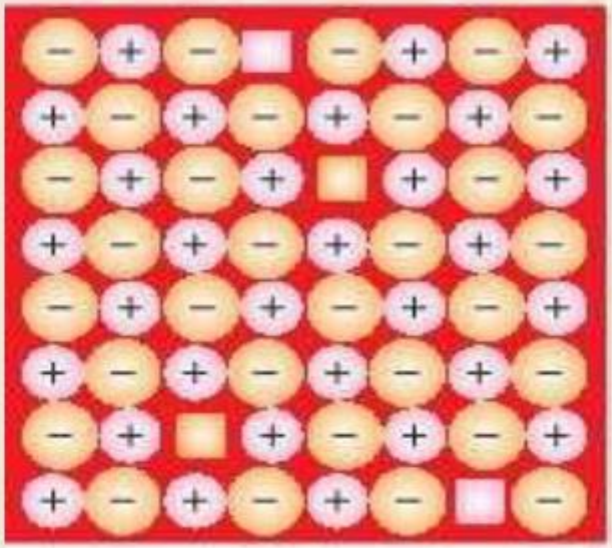
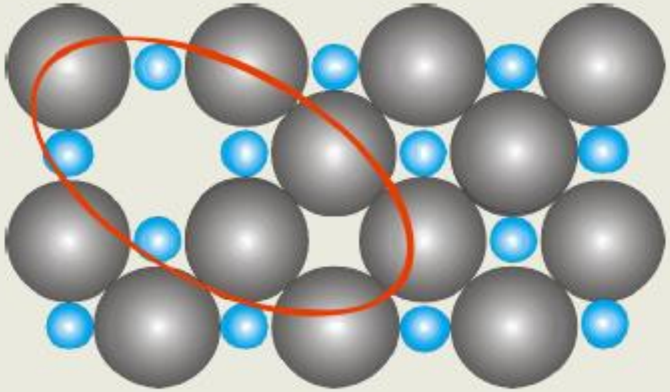


Fig. 1.26: Schottky defects



- Pair of anion and cation vacancies
- In order to maintain electrical neutrality, the number of missing cations and anions are equal
- It also decreases the density of crystal
- E.g. Alkali halides such as NaCl, KF, etc.

FRENKEL DEFECTS

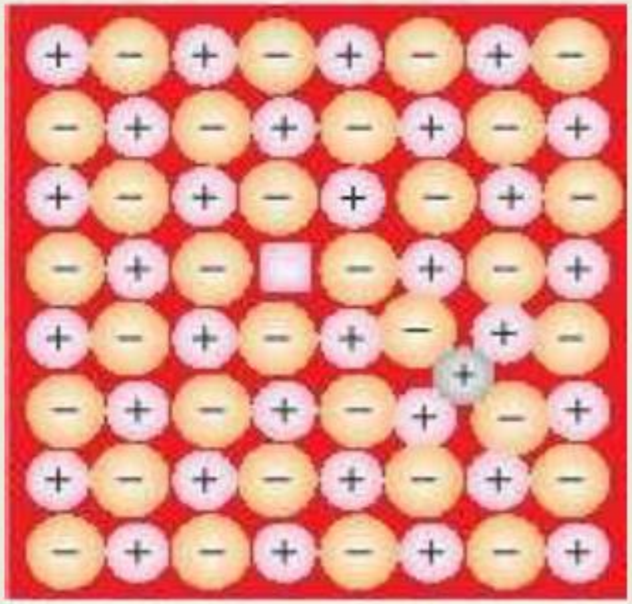
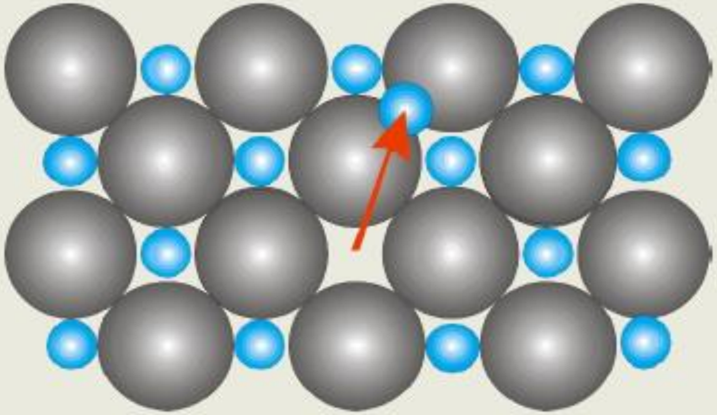


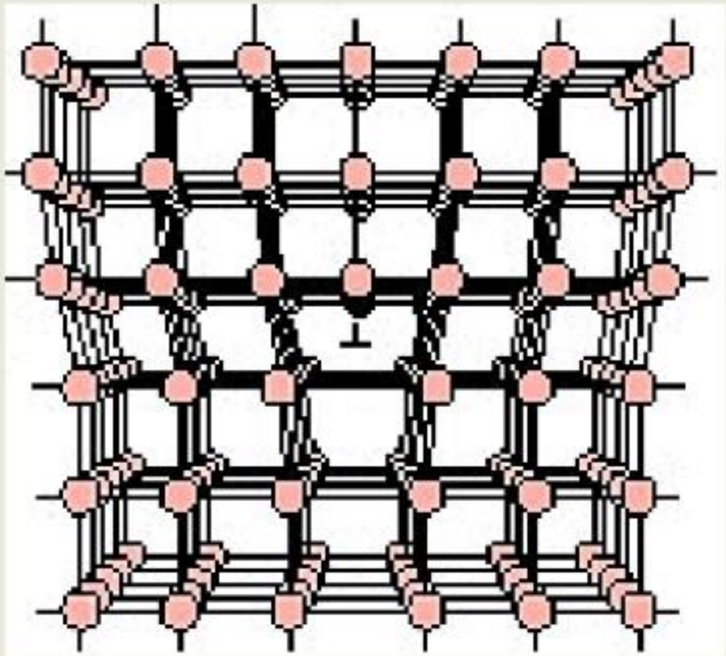
Fig. 1.25: Frenkel defects



- Cation (being smaller get displaced to interstitial voids
- Combination of vacancy and interstitial atom
- No change in the density
- E.g. AgI, CaF_2

LINE DEFECTS

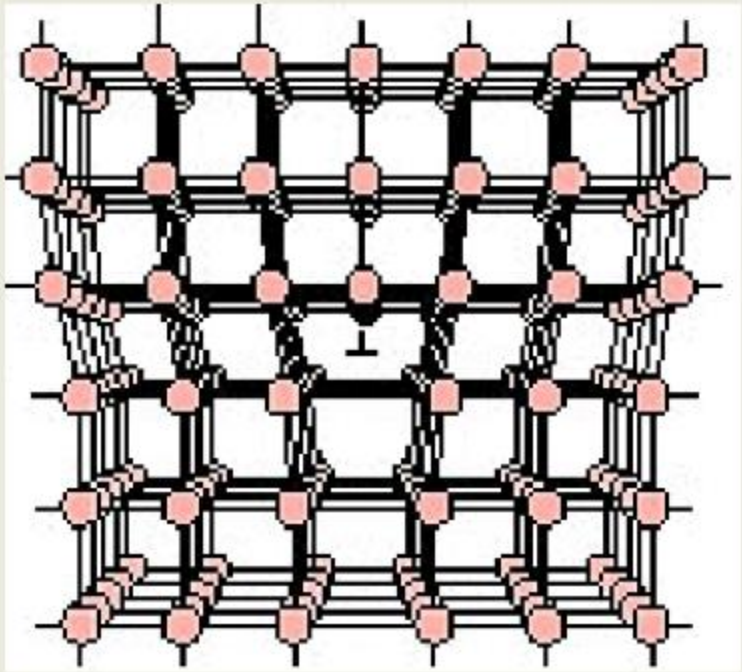
- Line defects are the irregularities or deviations from ideal arrangement in entire rows of lattice points.



- Interatomic bonds significantly distorted in immediate vicinity of dislocation line.
- Dislocation affects the mechanical properties.

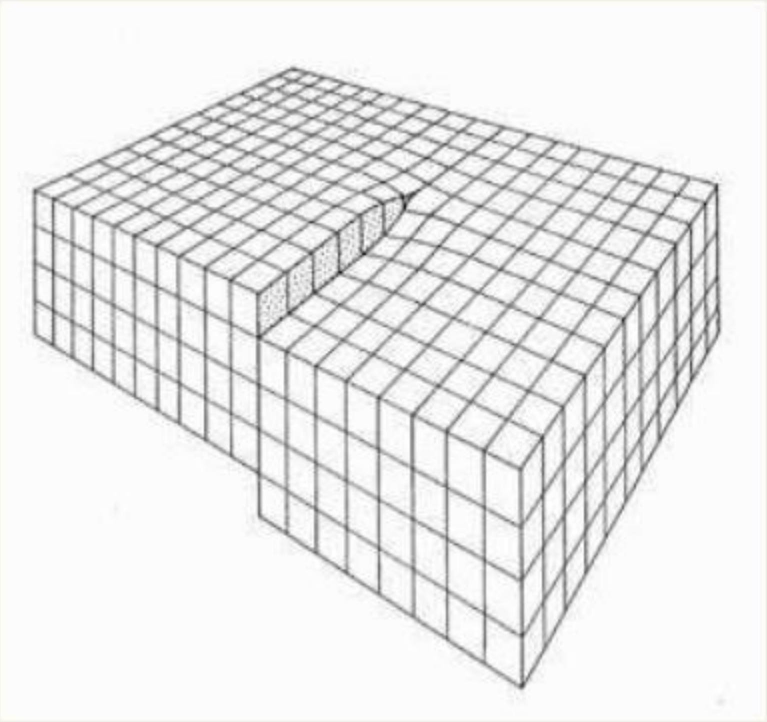
EDGE DISLOCATION

- POSITIVE DISLOCATION
- NEGATIVE DISLOCATION



SCREW DISLOCATION

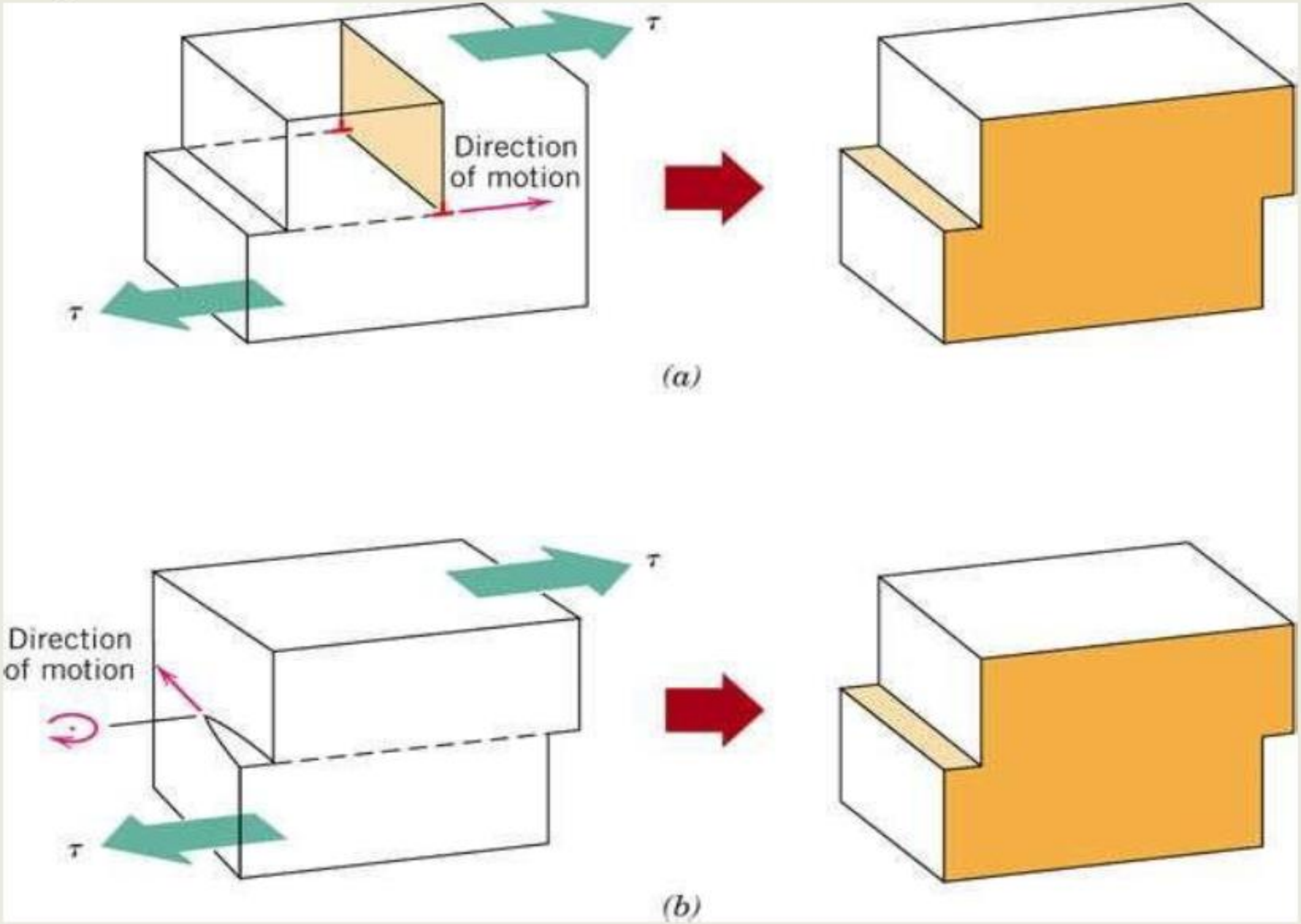
The lattice/atomic planes follow helical or spiral along the dislocation line.



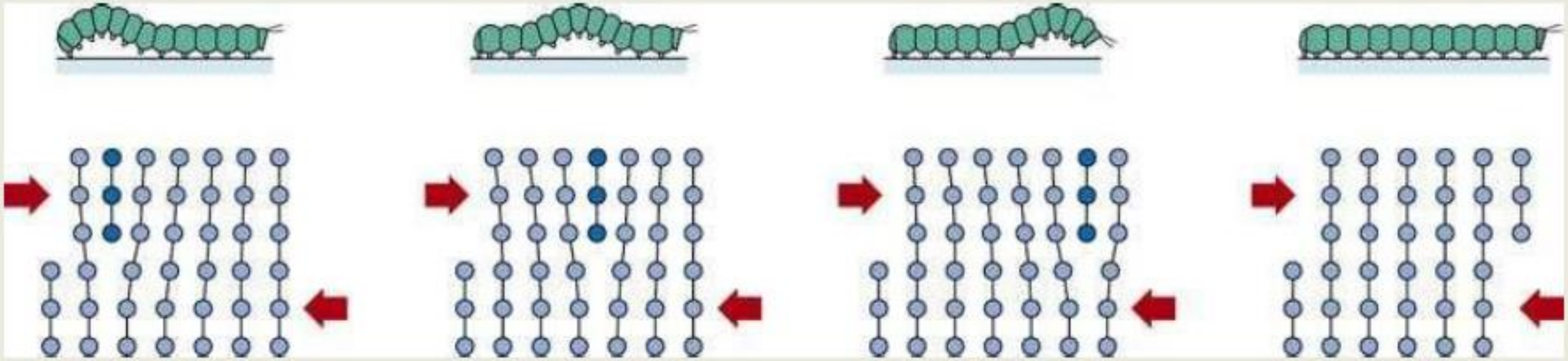
SURFACE DEFECTS

- Surface defects are associated with boundaries that are separate regions of the materials and have different crystal structure.
- Two Dimensional defect.
- Due to change in orientation of the atomic planes and stacking sequence of atomic planes.
- Caused during solidification or mechanical or thermal treatment of material.
- Effect the mechanical properties, electrical resistance and corrosion resistance.

Slip



Cause of slip



STRESS SRAIN CURVE FOR DUCTILE MATERIAL

HOOKE'S LAW & ELASTIC MODULI

- Hooke's law states that: " When a body is loaded within elastic limit, the stress is proportional to strain developed" or "Within the elastic limit the ratio of stress applied to strain developed is a constant"
- The constant is known as Modulus of elasticity or Elastic modulus or Young's modulus
- Mathematically within elastic limit

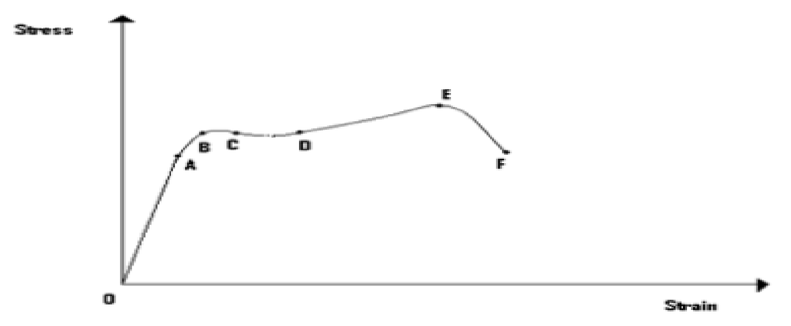
  Stress/Strain=$\sigma/e=E$

  $\sigma= P/A$; $e =\Delta L/L$

  $E=PL/A\,\Delta L$

stress is a physical quantity that expresses the internal forces that neighboring particles of a continuous

strain is the measure of the deformation of the **material**.



Stress - Strain Curve for Ductile materials

The relationship between the stress and strain that a particular **material** displays is known as that particular **material's** stress–strain **curve**. It is unique for each **material and is found by recording the amount of deformation (strain) at distinct intervals of tensile or compressive loading (stress).**

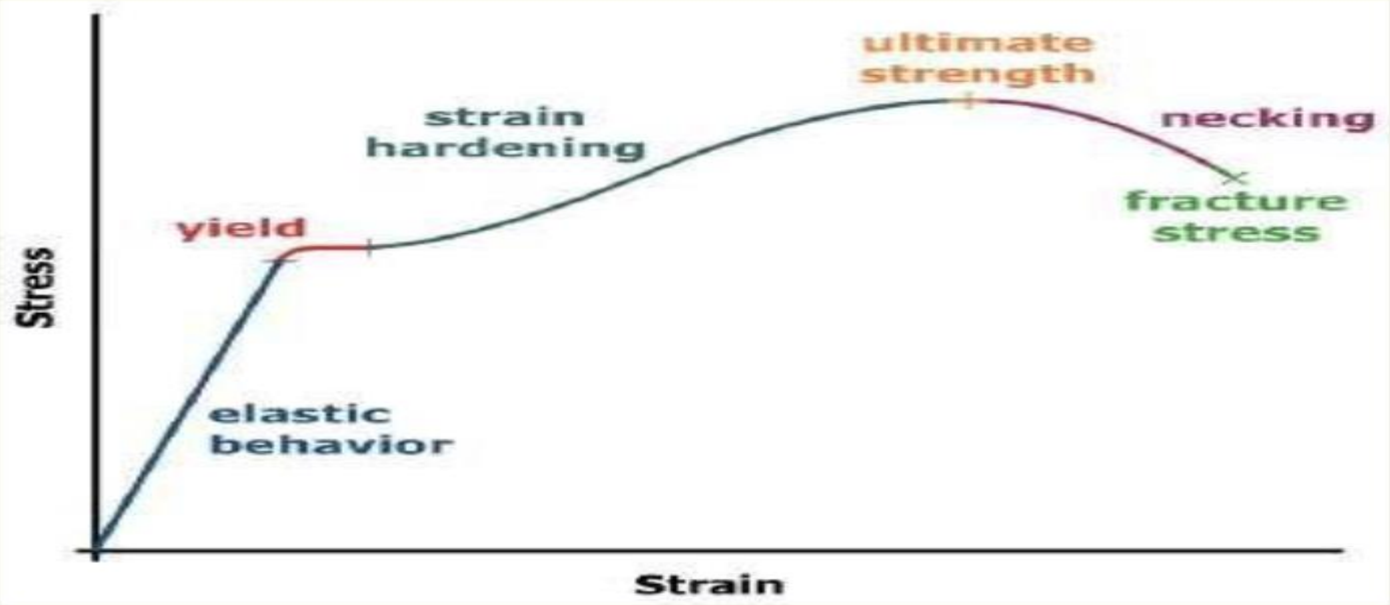
Ductile Materials:

>Ductile materials will withstand large strains before the specimen ruptures.

>Ductile materials often have relatively small Young's moduli and ultimate stresses.

>Ductile materials exhibit large strains and yielding before they fail.

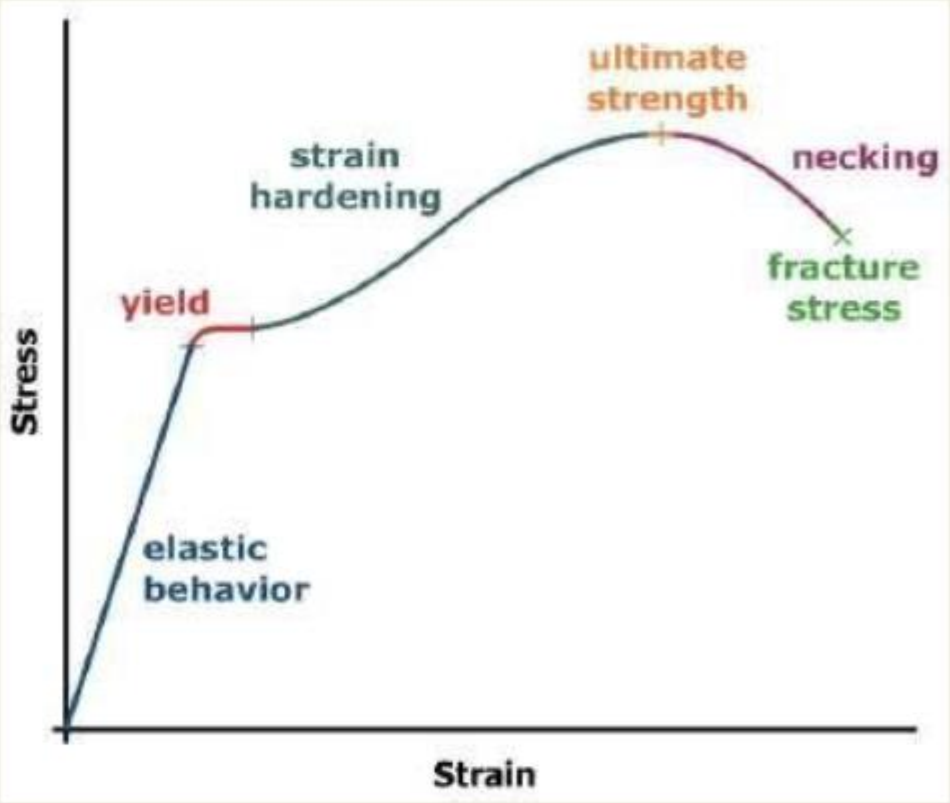
>Steel and aluminum usually fall in the class of Ductile Materials



Steel generally exhibits a very linear stress-strain relationship up to a well defined **yield point**

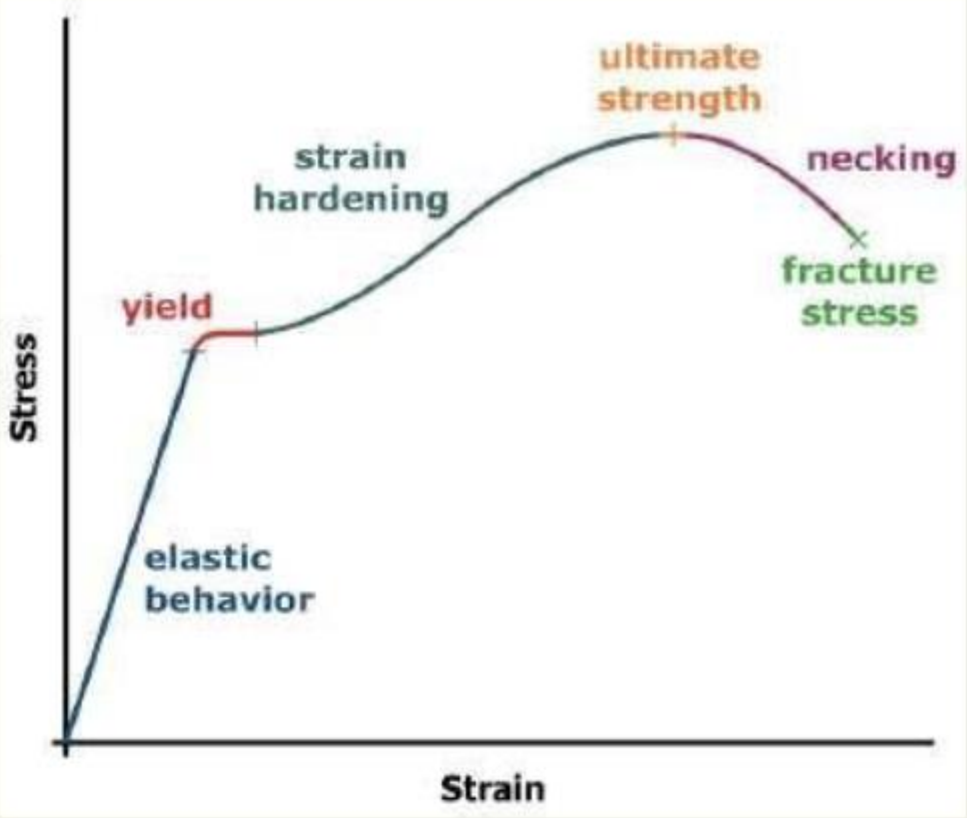
Elastic Behavior

If the specimen returns to its original length when the load acting on it is removed, it is said to response elastically



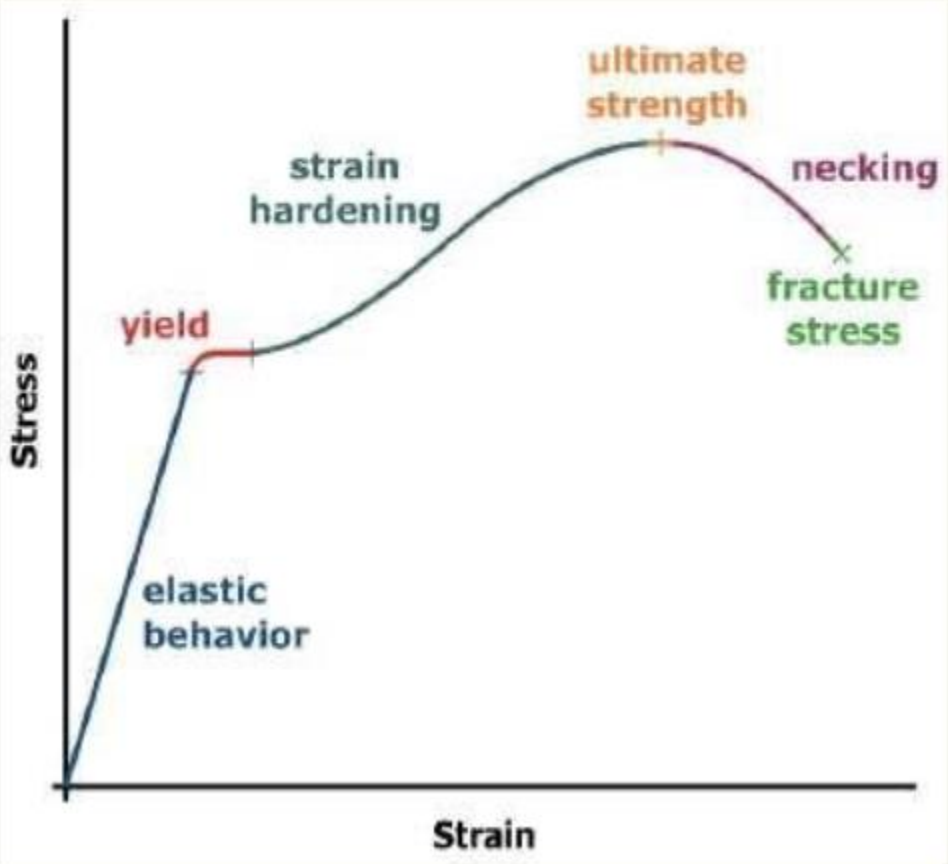
Yielding

- A slight increase in stress above the elastic limit will result in permanent deformation. This behavior is called **yielding**
- The stress that causes yielding is called **yield stress σ_y**.
- The deformation that occurs is called **plastic deformation**



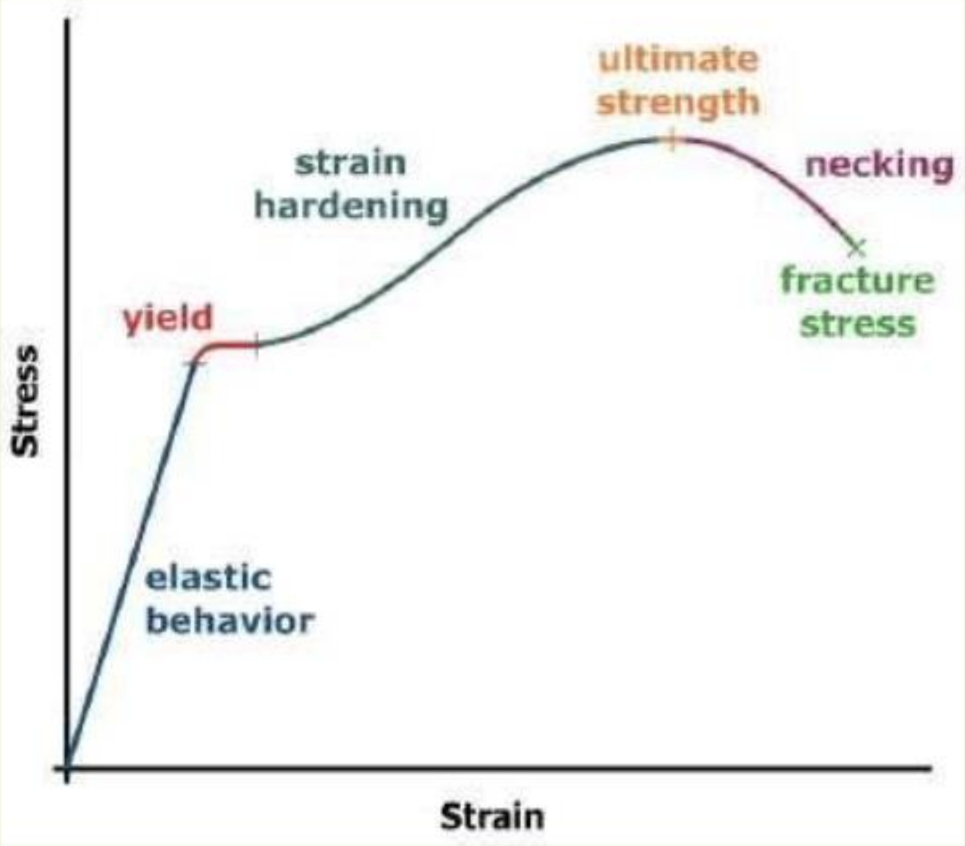
Strain Hardening

- When yielding has ended, a further load can be applied to the specimen, resulting in a cure that rises continuously but becomes flatter until it reaches a maximum stress referred to as **ultimate stress, σ_u.**
- The rise in the curve is called **Strain Hardening**



Necking & Fracture

- After the ultimate stress, the cross-sectional area begins to decrease in a localized region of the specimen, instead of over its entire length. The load (and stress) keeps dropping until the specimen reaches the fracture point.



Unit -3

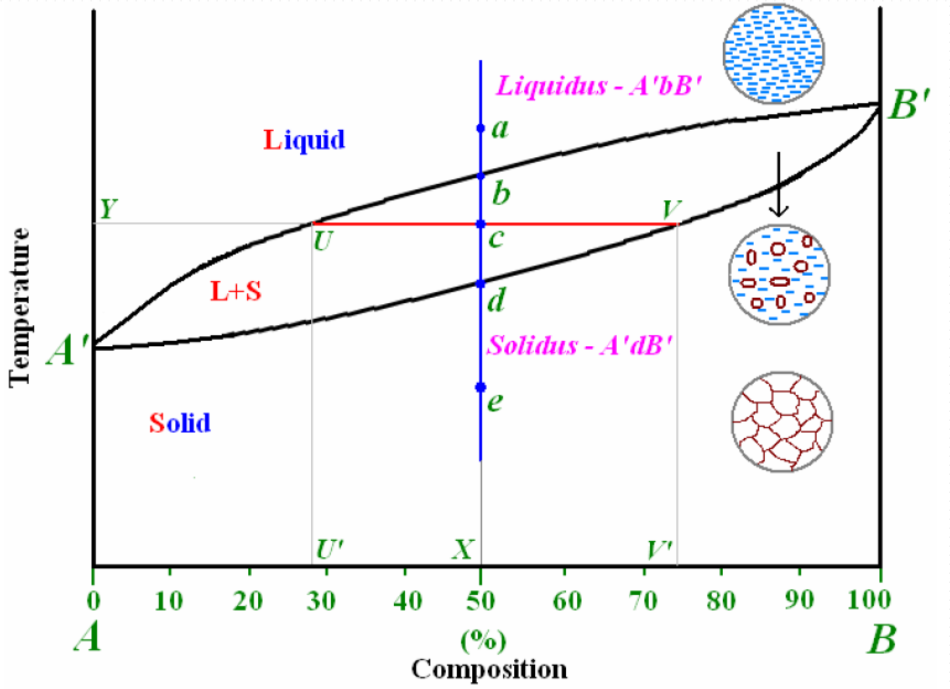
Metallurgy

Lever Rule

- At a point in a phase diagram, phases present and their composition (tie-line method) along with relative fraction of phases (lever rule) can be computed.
- Relative amount of liquid and solid phases is given respectively by:

$$C_L = \frac{cV}{UV} \qquad C_S = \frac{Uc}{UV} \qquad C_L + C_S = 1$$

- Therefore it is not restricted to solid phases only.



Example

- In a binary system of A and B, if a liquid of 35% A (65% B) is co-exists with a solid of 75% A (25% B), for an overall composition of 40% A, the fraction of the liquid is given by

$$C_L = \frac{75-40}{75-35} = 0.875$$

Example: If the alloy content 60 gm of Cr_2O_3 and 40 gm of Al_2O_3 at top 2150°C. Find liquid and solid phase present in the sable.

Solution: Tie line corresponded to 2150°C intersects the liquidus of 40% $^{w}/_{o}$ Cr_2O_3 and solid at 67 $^{w}/_{o}$ Cr_2O_3

Hence

$$^{w}/_{o}\ \text{Liquid} = \frac{67-60}{67-40}\times 100 = 25.93\%$$

and $$^{w}/_{o}\ \text{solid} = \frac{60-40}{67-40}\times 100 = 74.07\%$$

Fe-C alloy classification

- Fe-C alloys are classified according to wt.% C present in the alloy for technological convenience as follows:

Commercial pure irons	% C < 0.008
Low-carbon/mild steels	0.008 - %C - 0.3
Medium carbon steels	0.3 - %C - 0.8
High-carbon steels	0.8- %C - 2.11
Cast irons	2.11 < %C

Gibbs phase rule

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

$$P + F = C + 2$$

- 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:

$$P + F = C + 1$$

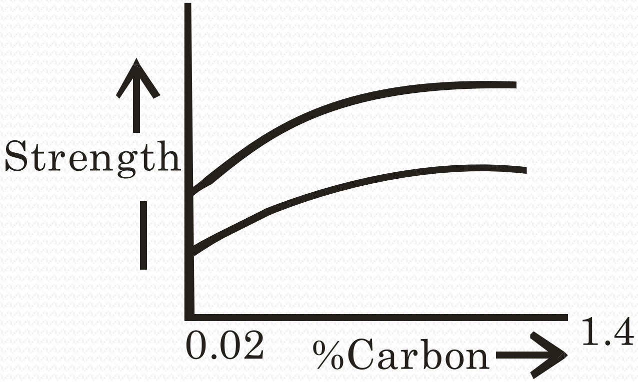
Unit -4

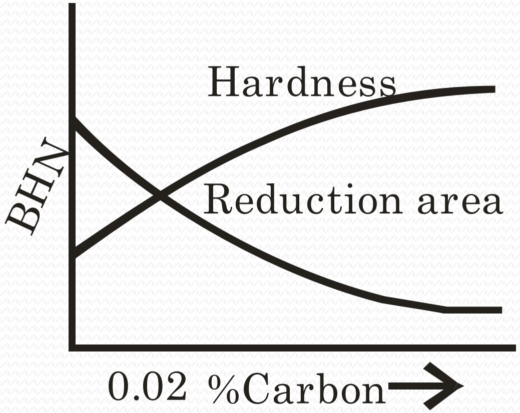
Metals and Alloys

Plain Carbon Steel

Plain-Carbon steel

- Due to lack of tensile strength and hardness pure iron is not used.
- Most important alloy’s element is carbon.
- Maximum amount of carbon that can be alloyed with iron is 6.67%.
- Alloy containing upto 2% carbon is steel and above 2% are caused cost Iron.





Low-carbon steel: (less than 0.3%C)

- Good formability and weld ability but lack hardenability
- Used in hot-forming, cold-forming etc.

Medium carbon steel or Mild steel (0.3% to 0.8 % carbon)

- high toughness & ductility
- Most widely used steel
- Heat treatable (austenitizing, quenching and tempering).
- Hardenability is increased by adding Ni, Cr, Mo.
- Used in various tempered conditions.
- Typical applications: gears, railway tracks, machine parts.

High carbon steel (more the 0.8 %C)

- Hardness & wear resistance are high but Toughness & formability is very low

Note⇒ purest form of Iron i.e. wrought iron has least carbon content.

Alloying Element of Steel and alloy Steel

Alloy Steel

- **Definition:** A steel to which one or more alloying elements other than carbon have been deliberately added (e.g. chromium, nickel, molybdenum) to achieve a particular physical property.

1. Nickel

- It increases the strength and toughness of the steel.
- These steels contain 2 to 5% nickel and from 0.1 to 0.5% carbon.
- In this range, nickel contributes great strength and hardness with high elastic limit, good ductility and good resistance to corrosion.
- An alloy containing 25% nickel possesses maximum toughness and offers the greatest resistance to rusting, corrosion and burning at high temperature.

Contd...

- It has proved to be of advantage in the manufacture of boiler tubes, valves for use with superheated steam, valves for I.C. engines and spark plugs for petrol engines.
- A nickel steel alloy containing 36% of nickel is known as **invar.** It has nearly zero coefficient of expansion. So it is in great demand for measuring instruments and standards of lengths for everyday use.

2. Chromium

- It is used in steels as an alloying element to combine hardness with high strength and high elastic limit.
- It also imparts corrosion-resisting properties to steel.
- The most common chrome steels contains from 0.5 to 2% chromium and 0.1 to 1.5% carbon.
- The chrome steel is used for balls, rollers and races for bearings.
- A **nickel chrome steel** containing 3.25% nickel, 1.5% chromium and 0.25% carbon is much used for armour plates. Chrome nickel steel is extensively used for motor car crankshafts, axles and gears requiring great strength and hardness.

3. Tungsten

- It prohibits grain growth, increases the depth of hardening of quenched steel and confers the property of remaining hard even when heated to red colour.
- It is usually used in conjunction with other elements.
- Steel containing 3 to 18% tungsten and 0.2 to 1.5% carbon is used for cutting tools.
- The principal uses of tungsten steels are for cutting tools, dies, valves, taps and permanent magnets.

4. Vanadium

- It aids in obtaining a fine grain structure in tool steel.
- The addition of a very small amount of vanadium (less than 0.2%) produces a marked increase in tensile strength and elastic limit in low and medium carbon steels without a loss of ductility.
- The **chrome-vanadium steel** containing about 0.5 to 1.5% chromium, 0.15 to 0.3% vanadium and 0.13 to 1.1% carbon have extremely good tensile strength, elastic limit, endurance limit and ductility.
- These steels are frequently used for parts such as springs, shafts, gears, pins and many drop forged parts.

5. Manganese

- It improves the strength of the steel in both the hot rolled and heat treated condition.
- The manganese alloy steels containing over 1.5% manganese with a carbon range of 0.40 to 0.55% are used extensively in gears, axles, shafts and other parts where high strength combined with fair ductility is required.
- The principal uses of manganese steel is in machinery parts subjected to severe wear. These steels are all cast and ground to finish.

6. Silicon

- The silicon steels behave like nickel steels.
- These steels have a high elastic limit as compared to ordinary carbon steel.
- Silicon steels containing from 1 to 2% silicon and 0.1 to 0.4% carbon and other alloying elements are used for electrical machinery, valves in I.C. engines, springs and corrosion resisting materials.

7. Cobalt

- It gives red hardness by retention of hard carbides at high temperatures.
- It tends to decarburise steel during heat-treatment.
- It increases hardness and strength and also residual magnetism and coercive magnetic force in steel for magnets.

8. Molybdenum

- A very small quantity (0.15 to 0.30%) of molybdenum is generally used with chromium and manganese (0.5 to 0.8%) to make molybdenum steel.
- These steels possess extra tensile strength and are used for air-plane fuselage and automobile parts. It can replace tungsten in high speed steels.

9. Boron

- Boron (not exceeding 0.003%) is a very powerful hardenability agent, being from 250 to 750 times as effective as nickel, 75 to 125 times as effective as molybdenum, and about 100 times as powerful as chromium.
- Only a few thousandths of a percent are sufficient to produce the desired effect in low-carbon steels, but the results diminish rapidly with increasing carbon content.
- Since no carbide formation or ferrite strengthening is produced, improved machinability and cold-forming capability often result from the use of boron in place of other hardenability additions.
- It has no effect on tensile strength of steel.

10. sulphur

- It is an undesirable impurity in steel because its forms iron sulphide, which can result in cracking.
- However, in the presence of proper amount of Mn, it forms Mn S which improves the machinability of steels.
- Its content may very from 0.06 - 0.30%.

11. Copper

- Copper has been known to resist atmospheric corrosion for centuries, but only recently has it been used as an addition to steel (in amounts from 0.10 to 0.50%) to provide this property.
- Low-carbon steel sheet and structural steels often contain a copper addition to enhance corrosion resistance, but surface quality and hot-working behavior tend to deteriorate somewhat.

Alloy Steel at a glance

Do-not form carbide: nickel, Silicon, Aluminium

Carbide forming ↑order: Manganese, chromium, Tungsten, Molybdenum, vanadium, titanium, niobium.

(1)	Manganese:	↑ Toughness & ductility
		↑ Machinability with sulphur
(2)	Chromium:	↑ Corrosion resistance
		↑ Wear resistance , hardness
(3)	Nickel:	↑ toughness

Contd…

(4) Tungsten, Molybdenum, Vanadium: → ↑ hot hardness
Tungsten → ↑wear resistance,
Vanadium: → ↑endurance limit
Molybdenum→ ↑creep property
(5) Si & Al → deoxidizer, restrict grain growth
Si →↑ Magnetic permissibility
(6) Cobalt: ↓ hardenability
↑ Impact strength
(7) Phosphorus: reduce strength to impact ↓ conductivity of copper
(8) Copper: Raises yield point
(9) Magnesium: because light weight it is used where weight is important.

Super alloy: Is for high temperature use [jet engine, gas turbine blade etc]

Ex: Hastelloy X

C – 0.1%
Mn – 1 %
Cr – 21.8%
Si – 1%
Ni – balance
Co – 2.5%
Mo – 9%
W – 0.6 %
Fe – 18.5%

Stainless Steel

- They typical consists min.12% Cr along with other alloying elements, thus highly corrosion resistant owing to presence of chromium oxide.
- Three kinds - ferritic & hardenable Cr steels, austenitic and precipitation hardenable (martensitic, semi-austenitic) – based on presence of prominent micro-structural constituent.
- Typical applications – cutlery, surgical knives, storage tanks, domestic items.
- *Ferritic steels* are principally Fe-Cr-C alloys with 12-14% Cr. And small additions of Mo, V, Nb, Ni.

Contd…

- Austenitic steels contain 18% Cr and 8% Ni plus minor alloying elements. Ni stabilizes the austenitic phase assisted by C and N.
- For, martensitic steels Ms is made to be above the room temperature. These alloys are heat treatable. Major alloying elements are: Cr, Mn and Mo.
- Ferritic and austenitic steels are hardened and strengthened by cold work because they are not heat treatable.
- Austenitic steels are non-magnetic as against ferritic and martensitic steels, which are magnetic.

Contd…

- Austenitic stainless steels are non-magnetic and are highly resistant to corrosion 304 alloy is 18-8 when 18% chromium & 8% nickel used costly material.
- Austenitic stainless steels usually contain 18% Cr and 8% Ni in addition to other minor alloying elements. Ni stabilizes the austenitic phase assisted by C and N. Other alloying additions include Ti, Nb, Mo (prevent weld decay), Mn and Cu (helps in stabilizing austenite).
- These steels are very tough and can be forged and rolled but offer great difficulty in machining.
- These steels cannot be hardened by quenching, in fact they are softened by rapid cooling from about 1000°C.

DESIGNATION OF STEEL, (INDIAN STANDARD)

- Two systems of notation are recommended by IS :

  (a) Based on ultimate tensile strength.

  (b) Based on chemical composition.

  (a) Based on Ultimate Tensile Strength: This is applicable to carbon and low alloy steels.

- The symbol consists of the letter St followed by the number representing the ultimate tensile strength in kgf/mm2 , for example, St 32. The new coding consists of the letter Fe followed by the number representing the ultimate tensile strength in N/mm2 , for example, Fe 410.

Contd…

(b) Based on Chemical Composition: This type of designation is preferred if subsequent heat treatment is carried out.

1. Plain Carbon Steels: These are designated by letter C followed by a number representing the average percentage carbon content, for example, C 14 - carbon steel with 0.14%, C.

- Its new designation is 14 C4. Here, the first figure indicates 100 times the average of Carbon content, then letter C, and the last figure indicates 10 times the average percentage of Mn content rounded off to the next integer.

Contd...

2. Alloy Steels: Here the letter C is omitted and the numbers representing the carbon content are followed by chemical symbols for one or more of the predominant alloying elements followed by numbers indicating their average contents, for example, 15 Cr 65 - chromium steel with 0.15°%,C and 0.65% Cr.

- 20 Cr 18 Ni 2 - Nickel - chromium steel with 0.2% C, 18% Cr and 2% Ni.
- The coding of the alloy steels is given below :- The average alloy content upto 1 per cent, Alloy index number will be : - Average alloy content upto two decimal places, underlined by a bar. For average alloy content one per cent and above, alloy index number will be : rounded to the nearest whole number upto 0.5 rounded down and above rounded up.

Cast Iron

Cast Iron

- The cast iron is obtained by re-melting pig iron with coke and limestone in a furnace known as cupola.
- It is primarily an alloy of iron and carbon.
- The carbon content in cast iron varies from more than 2 per cent to 4.5 per cent.
- The carbon in a cast iron is present in either of the following two forms:

1. Free carbon or graphite, and
2. Combined carbon or cementite.

Contd…

- The properties of cast iron which make it a valuable material for engineering purposes are its low cost, good casting characteristics, high compressive strength, wear resistance and excellent machinability.
- The compressive strength of cast iron is much greater than the tensile strength.

Types of Cast Iron

- Cast irons that were slowly cooled to room temperature consist of cementite, look whitish – white cast iron.
- If it contains graphite, look grayish – gray cast iron.
- It is heat treated to have graphite in form of nodules – malleable cast iron.
- If inoculants are used in liquid state to have graphite nodules – spheroidal graphite (SG) cast iron.

Contd…

1. Grey cast iron

- Carbon = 3 to 3.5%;
- The grey colour is due to the fact that the carbon is present in the form of free graphite.
- It has a low tensile strength, high compressive strength and no ductility.
- It can be easily machined.
- A very good property of grey cast iron is that the free graphite in its structure acts as a lubricant. Due to this reason, it is very suitable for those parts where sliding action is desired.

Contd...

- The grey iron castings are widely used for machine tool bodies, automotive cylinder blocks, heads, housings, fly-wheels, pipes and pipe fittings and agricultural implements.
- The grey cast iron is designated by the alphabets 'FG' followed by a figure indicating the minimum tensile strength in MPa or N/mm^2. For example, 'FG 150' means grey cast iron with 150 MPa or N/mm^2 as minimum tensile strength.

2. White cast iron

- Carbon = 1.75 to 2.3%.
- The white colour is due to fact that it has no graphite and whole of the carbon is in the form of carbide (known as cementite) which is the hardest constituent of iron.
- The white cast iron has a high tensile strength and a low compressive strength.

3. Chilled cast iron

- It is a white cast iron produced by quick cooling of molten iron.
- The quick cooling is generally called chilling and the cast iron so produced is called chilled cast iron.
- Chills are used on any faces of a casting which are required to be hard to withstand wear and friction.

4. Mottled cast iron

- It is a product in between grey and white cast iron in composition, colour and general properties.
- It is obtained in castings where certain wearing surfaces have been chilled.

5. Malleable cast iron

- The malleable iron is a cast iron-carbon alloy which solidifies in the as-cast condition in a graphite free structure, *i.e.* total carbon content is present in its combined form as cementite (Fe_3C).
- It is ductile and may be bent without breaking or fracturing the section.
- The tensile strength of the malleable cast iron is usually higher than that of grey cast iron and has excellent machining qualities.

Contd...

- It is used for machine parts for which the steel forgings would be too expensive and in which the metal should have a fair degree of accuracy, *e.g.* hubs of wagon wheels, small fittings for railway rolling stock, brake supports, parts of agricultural machinery, pipe fittings, door hinges, locks etc.
- In order to obtain malleable iron castings, it is first cast into moulds of white cast iron. Then by a suitable heat treatment (*i.e.* annealing), the combined carbon of the white cast iron is separated into nodules of graphite.
- There are two process:
  1. Black-heart process,
  2. White-heart process

Contd...

1. Black-heart process

- In this process the white iron castings are heated in airtight boxes out of contact with air at 850-950 deg C for 50-170 hours, depending upon the mass and thickness of the castings.
- The effect of this prolonged heating is to break down the iron carbide (cementite) of the white cast iron into small rosettes of graphite.
- The name 'black-heart' comes from the darkened appearance of the iron, when fractured, resulting from the formation of free graphite.
- It is used in the wheel hubs, break drums, conduit fitting control levers and pedals.

2. White-heart process

- In this process the castings are packed into airtight boxes with iron oxide in the form of high-grade ore.
- They are then heated to about 1000 deg C for between 70 and 100 hours, depending upon the mass and thickness of the castings.
- The ore oxidises the carbon in the castings and draws it out, leaving a ferritic structure near the surface and a pearlitic structure near the centre of the casting.
- There will also be some fine rosettes of graphite.
- White-heart castings behave much as expected of a mild steel casting, but with the advantage of a very much lower melting point and higher fluidity at the time of casting.
- It is used in the wheel hubs, bicycle and motor cycle frame fittings, gas, water and steam pipe fittings.

6. Nodular or spheroidal graphite cast iron

- The nodular or spheroidal graphite cast iron is also called ***ductile cast iron*** or ***high strength cast iron***.
- This type of cast iron is obtained by adding small amounts of magnesium (0.1 to 0.8%) to the molten grey iron.
- The addition of magnesium causes the graphite to take form of small nodules or spheroids instead of the normal angular flakes.

Contd…

- It has high fluidity, castability, tensile strength, toughness, wear resistance, pressure tightness, weldability and machinability.
- It is generally used for castings requiring shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads, rolls for rolling mill and centrifugally cast products.
- SG 400/15 means spheroidal graphite cast iron with 400 MPa as minimum tensile strength and 15 percent elongation.

Wrought Iron

- It is the purest iron which contains at least 99.5% iron but may contain upto 99.9% iron.
- The wrought iron is produced from pig iron by remelting it in the puddling furnace of reverberatory type.
- The wrought iron is a tough, malleable and ductile material.
- It can be easily forged or welded. It is used for chains, crane hooks, railway couplings, water and steam pipes.

Effect of Impurities on Cast Iron

1. **Silicon.** It may be present in cast iron upto 4%. It provides the formation of free graphite which makes the iron soft and easily machinable. It also produces sound castings free from blow-holes, because of its high affinity for oxygen.

2. **Sulphur.** It makes the cast iron hard and brittle. Since too much sulphur gives unsound casting, therefore, it should be kept well below 0.1% for most foundry purposes.

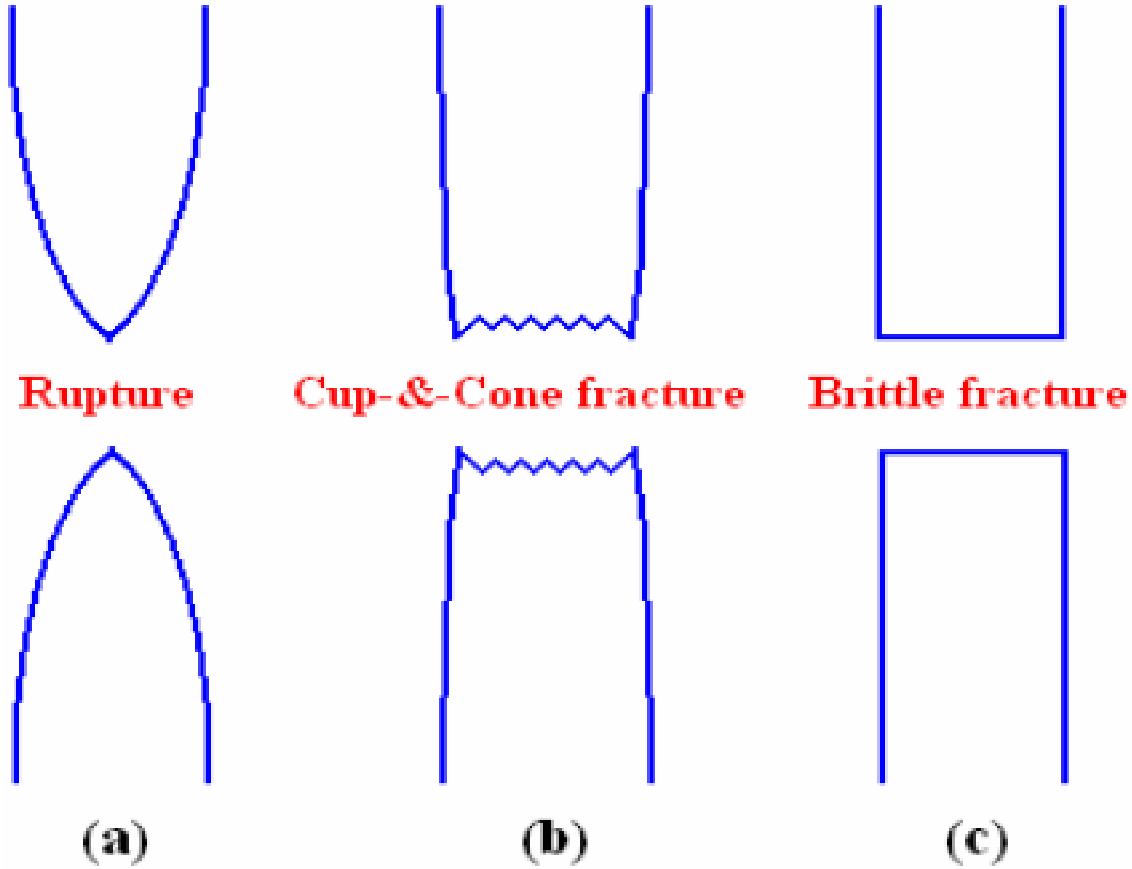
Contd...

3. **Manganese.** It makes the cast iron white and hard. It is often kept below 0.75%. It helps to exert a controlling influence over the harmful effect of sulphur.

4. **Phosphorus.** It aids fusibility and fluidity in cast iron, but induces brittleness. It is rarely allowed to exceed 1%. Phosphoric irons are useful for casting of intricate design and for many light engineering castings when cheapness is essential.

Fracture modes

- ➢ Ductile and Brittle are relative terms.
- ➢ Most of the fractures belong to one of the following modes: (a) rupture, (b) cup-&-cone and (c) brittle.



Ductile fracture Vs Brittle fracture

Parameter	***Ductile fracture***	***Brittle fracture***
Strain energy required	Higher	Lower
Stress, during cracking	Increasing	Constant
Crack propagation	Slow	Fast
Warning sign	Plastic deformation	None
Deformation	Extensive	Little
Necking	Yes	No
Fractured surface	Rough and dull	Smooth and bright
Type of materials	Most metals (not too cold)	Ceramics, Glasses, Ice

Use of Materials

Duralumin

- It is an important and interesting wrought alloy.
- Its composition is as follows:
- Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and the remainder is aluminium.
- This alloy possesses maximum tensile strength (upto 400 MPa) after heat treatment and age hardening. After working, if the metal is allowed to age for 3 or 4 days, it will be hardened. This phenomenon is known as **age hardening.**
- It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets.

Magnalium

- It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum or under a pressure of 100 to 200 atmospheres.
- It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

Hindalium

- It is an alloy of aluminium and magnesium with a small quantity of chromium.

Copper-zinc alloys (Brass)

- The most widely used copper-zinc alloy is brass.
- There are various types of brasses, depending upon the proportions of copper and zinc.
- This is fundamentally a binary alloy of copper with zinc each 50%.
- By adding small quantities of other elements, the properties of brass may be greatly changed.
- Applications of Cu alloys include: costume jewellery, coins, musical instruments, electronics, springs, bushes, surgical and dental instruments, radiators, etc.

Contd…

- The addition of zinc strengthens the material and incidentally changes the colour to a yellow or gold effect.
- The ratio of copper and zinc can be varied for advantages and the addition of other elements gives still more variety of combinations of properties such as machinability, strength, hardness, ductility (hot or cold), conductivity and corrosion resistance as well as many others.
- Lead additions are used to improve machinability. The lead is insoluble in the solid brass and segregates as small globules that help the swarf to break up in to small pieces and may also help to lubricate the cutting tool action.

Copper-tin alloys (Bronze)

- The alloys of copper and tin are usually termed as bronzes.
- The useful range of composition is 75 to 95% copper and 5 to 25% tin.
- The metal is comparatively hard, resists surface wear and can be shaped or rolled into wires, rods and sheets very easily.
- In corrosion resistant properties, bronzes are superior to brasses.

Contd…

- The hardness and strength of bronze increase with an increase in tin content.
- The ductility is also reduced with the increase in tin percentage above 5.
- When aluminium is also added (4 to 11%), the resulting alloy is termed **aluminium bronze**, which has a considerably higher corrosion resistance.
- Bronzes are comparatively costly compared to brasses due to the presence of tin which is an expensive metal.
- The colour of aluminium bronze is similar to that of 22 carat gold and it is frequently called '**imitation gold**'.

Phosphor bronze

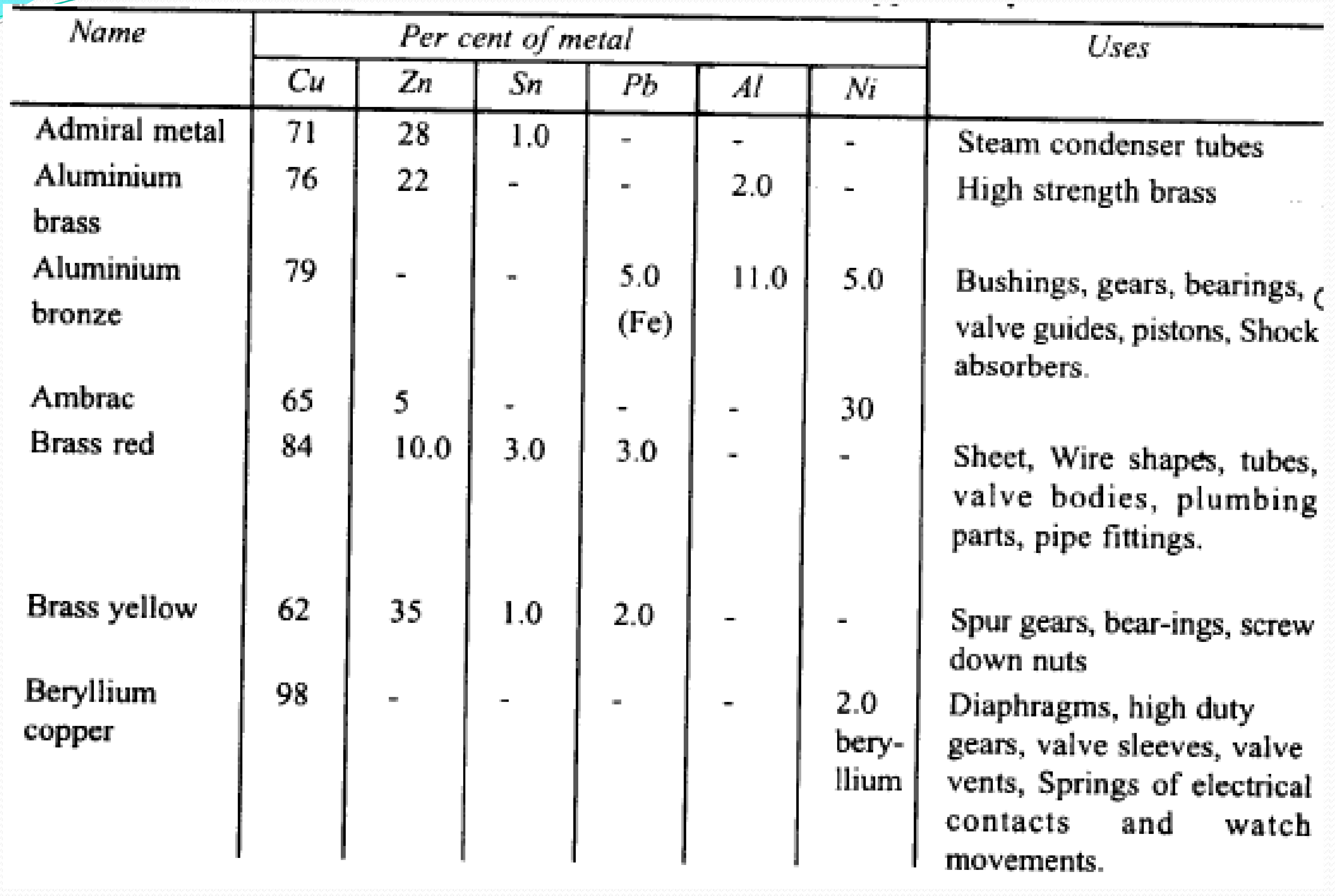
- When bronze contains phosphorus, it is called phosphor bronze.
- Phosphorus increases the strength, ductility and soundness of castings.
- This alloy possesses good wearing qualities and high elasticity.
- A common type of phosphor bronze has the following composition according to Indian standards Copper = 87–90%, Tin = 9–10%, and Phosphorus = 0.1–3%.
- The material is specified for pump parts, gears, springs, power screw nuts and bearings.

Gun Metal

- It is an alloy of copper, tin and zinc.
- It usually contains 88% copper, 10% tin and 2% zinc.
- This metal is also known as **Admiralty gun metal.**
- The zinc is added to clean the metal and to increase its fluidity.
- It is not suitable for being worked in the cold state but may be forged when at about 600°C.
- It is extensively used for casting boiler fittings, bushes, bearings, glands, etc.

Monel metal

- It is an important alloy of nickel and copper.
- It contains 68% nickel, 29% copper and 3% other constituents like iron, manganese, silicon and carbon. It is superior to brass and bronze in corrosion resisting properties.
- It is used for making propellers, pump fittings, condenser tubes, steam turbine blades, sea water exposed parts, tanks and chemical and food handling plants.



Name	Per cent of metal						Uses
	Cu	Zn	Sn	Pb	Al	Ni	
Admiral metal	71	28	1.0	-	-	-	Steam condenser tubes
Aluminium brass	76	22	-	-	2.0	-	High strength brass
Aluminium bronze	79	-	-	5.0 (Fe)	11.0	5.0	Bushings, gears, bearings, (valve guides, pistons, Shock absorbers.
Ambrac	65	5	-	-	-	30	
Brass red	84	10.0	3.0	3.0	-	-	Sheet, Wire shapes, tubes, valve bodies, plumbing parts, pipe fittings.
Brass yellow	62	35	1.0	2.0	-	-	Spur gears, bear-ings, screw down nuts
Beryllium copper	98	-	-	-	-	2.0 beryllium	Diaphragms, high duty gears, valve sleeves, valve vents, Springs of electrical contacts and watch movements.

Gear bronze	86.5	-	-	3.3 (Fe)	10.2	-	Gears of high strength
Gun metal	88	2.0	10.0	-	-	-	Boiler fittings, bushes, bearings, glands
Manganese bronze	90	5.8	-	2.0	2.0 (Fe)		Bushes, plungers, feed pump rods, worm gears
Monel metal	30	-	-	-	-	67	Steam turbine blades, high temperature valves, impeller of centrifugal pump, springs.
K - monel	29.0	-	-	-	2.75	66	-do-
Muntz metal	60.0	40.0	-	-	-	-	Water fittings, condenser tubes, household articles
Phosphor bronze	80-90	-	20-10	1.0 (P)	-	-	Bearings, pump parts, worm gears, springs

Inconel

- It consists of 80% nickel, 14% chromium, and 6% iron.
- This alloy has excellent mechanical properties at ordinary and elevated temperatures.
- It can be cast, rolled and cold drawn.
- It is used for making springs which have to withstand high temperatures and are exposed to corrosive action.
- It is also used for exhaust manifolds of aircraft engines.

Nichrome

- It consists of 65% nickel, 15% chromium and 20% iron.
- It has high heat and oxidation resistance.
- It is used in making electrical resistance wire for electric furnaces and heating elements.

Nimonic

- It consists of 80% nickel and 20% chromium.
- It has high strength and ability to operate under intermittent heating and cooling conditions.
- It is widely used in gas turbine engines.

Babbit metal

- The tin base and lead base babbits are widely used as a bearing material, because they satisfy most requirements for general applications.
- The babbit is generally used as a thin layer, 0.05 mm to 0.15 mm thick, bonded to an insert or steel shell. The composition of the babbit metals is as follows:
- **Tin base babbits :** Tin 90% ; Copper 4.5% ; Antimony 5% ; Lead 0.5%.
- **Lead base babbits :** Lead 84% ; Tin 6% ; Anitmony 9.5% ; Copper 0.5%.

Columbium/Niobium

- Columbium finds much use in large-scale applications, such as steel for automobile bodies and pipelines. The use that probably will consume most of the columbium is microalloying.
- Relatively small amount of columbium lend high strength to steel. The microalloyed, or high-strenght, low-alloy (HSLA) steels, are used for automobile bodies, structures of all kinds, and high-pressure pipe, particulary in the oil and gas industry.
- Columbium with oxygen as dominant substiutitional alloying atoms is used in the nuclear fusion reactor.
- Nuclear material refers to the metals uranium, plutonium, and thorium, in any form, according to the IAEA

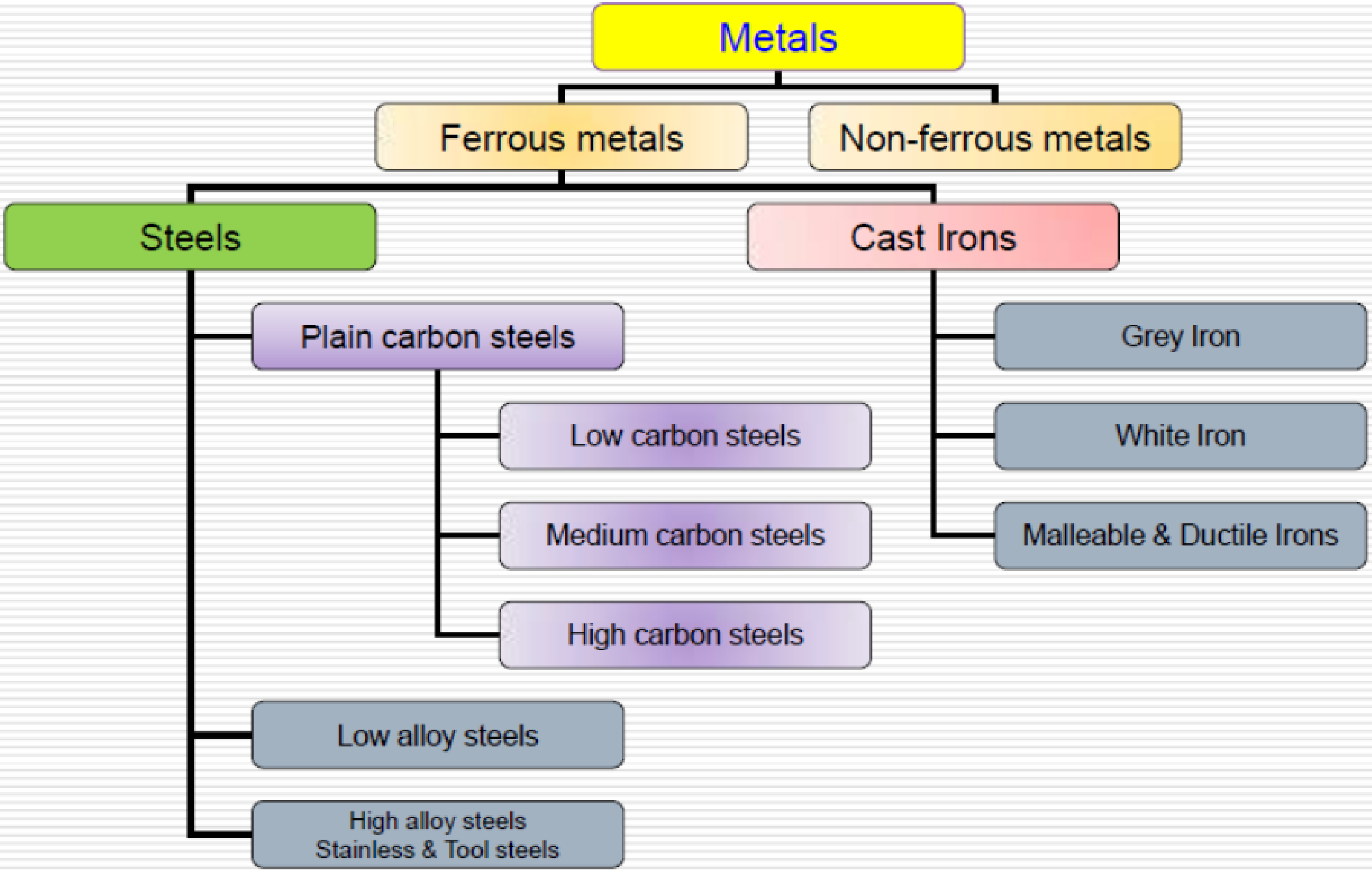
Nimonic 90

- A precipitation hardenable nickel-chromium-cobalt alloy, having high stress-rupture strength and creep resistance at elevated temperatures up to about 950 °C.
- For springs exposed to lower loads, the material can be used up to 700 °C.
- Nimonic 90 offers good resistance to corrosion and is non-magnetic.
- Applications include the aircraft industry, gas turbines, vehicle components and springs in high temperature environments, and thermal.
- Operating temperature: -100 – + 550 °C

Unit -5

Heat Treatment

Fe-C alloy classification



Metals

Ferrous metals

Non-ferrous metals

Steels

Cast Irons

Plain carbon steels

Low carbon steels

Medium carbon steels

High carbon steels

Low alloy steels

High alloy steels
Stainless & Tool steels

Grey Iron

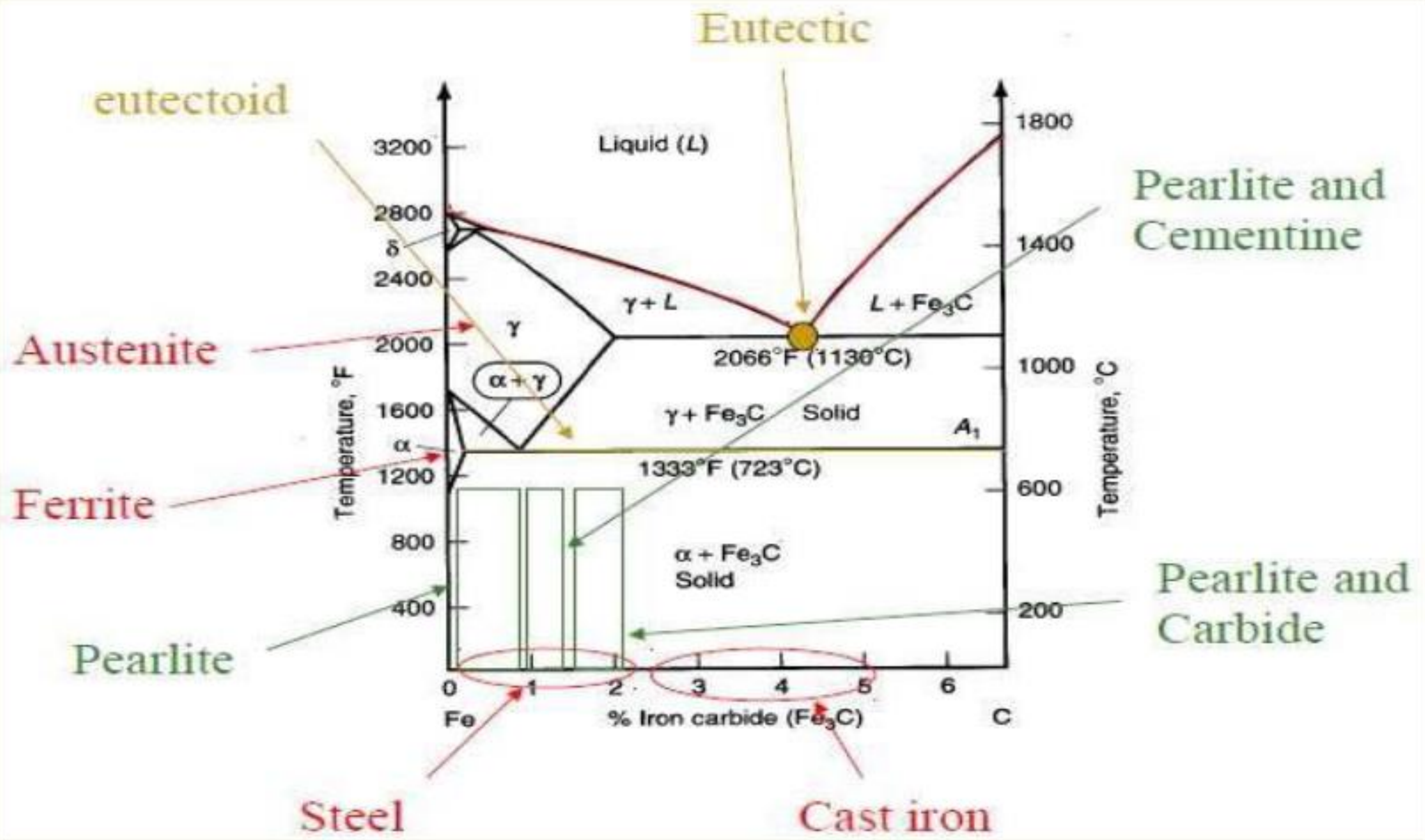
White Iron

Malleable & Ductile Irons

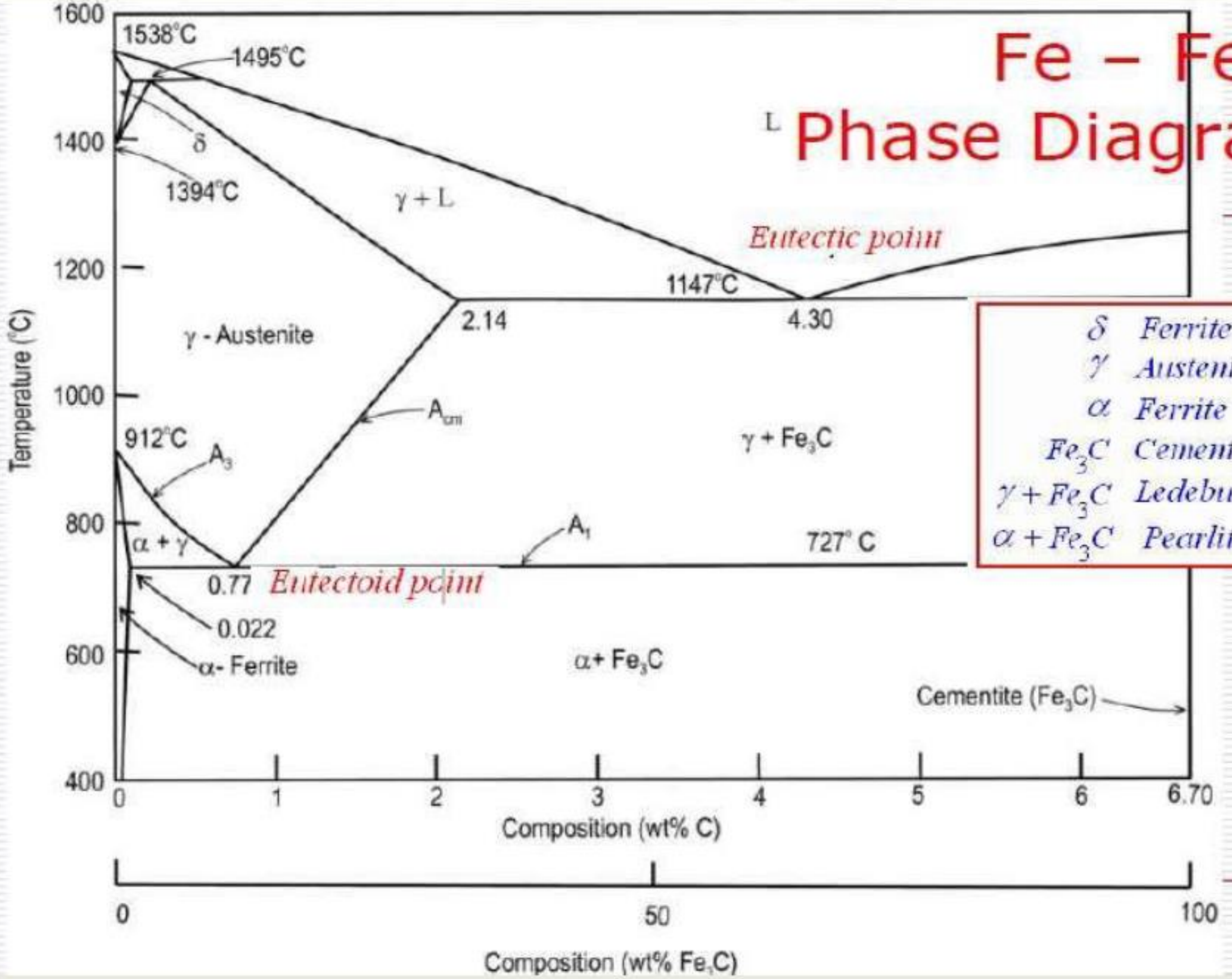
IRON-C phase diagram

It is a 3phase reaction, A soild transform into 2 solid phases at the same time.

3phase liquid
into 2 solid phases at the same time

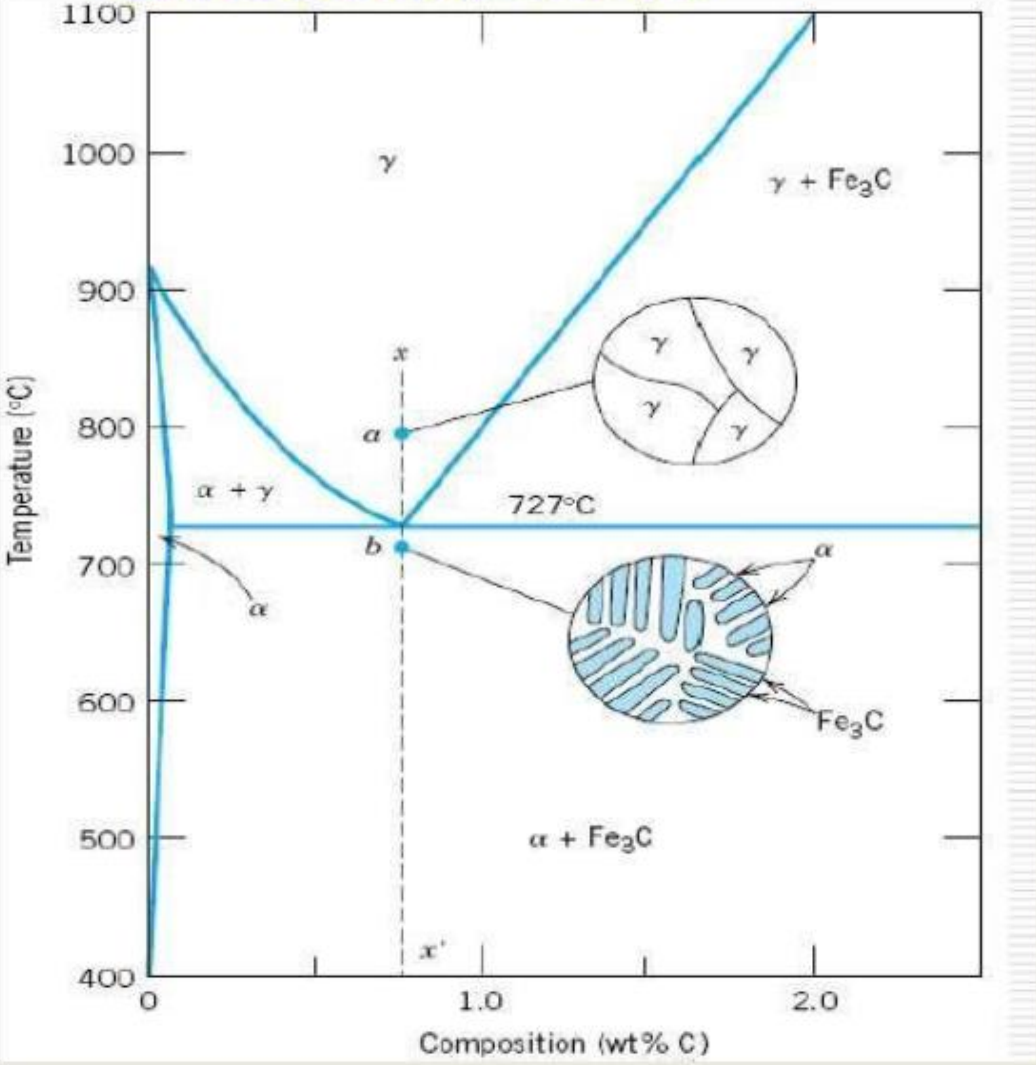


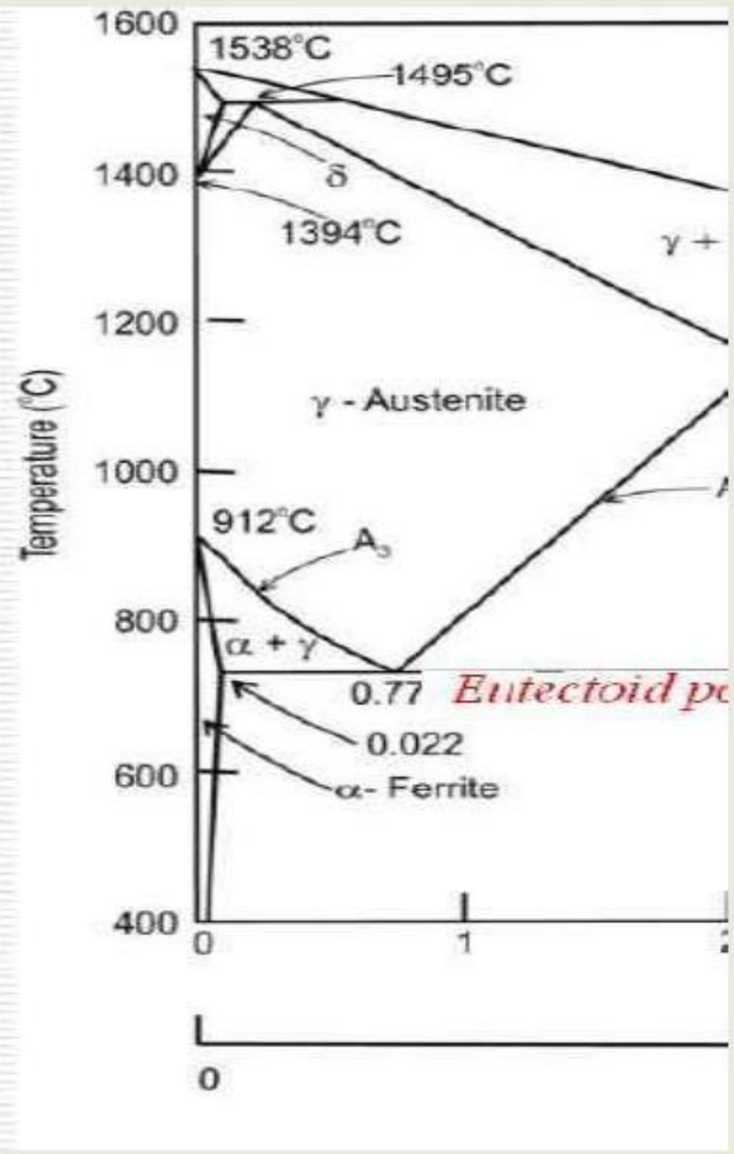
Fe – Fe_3C Phase Diagram



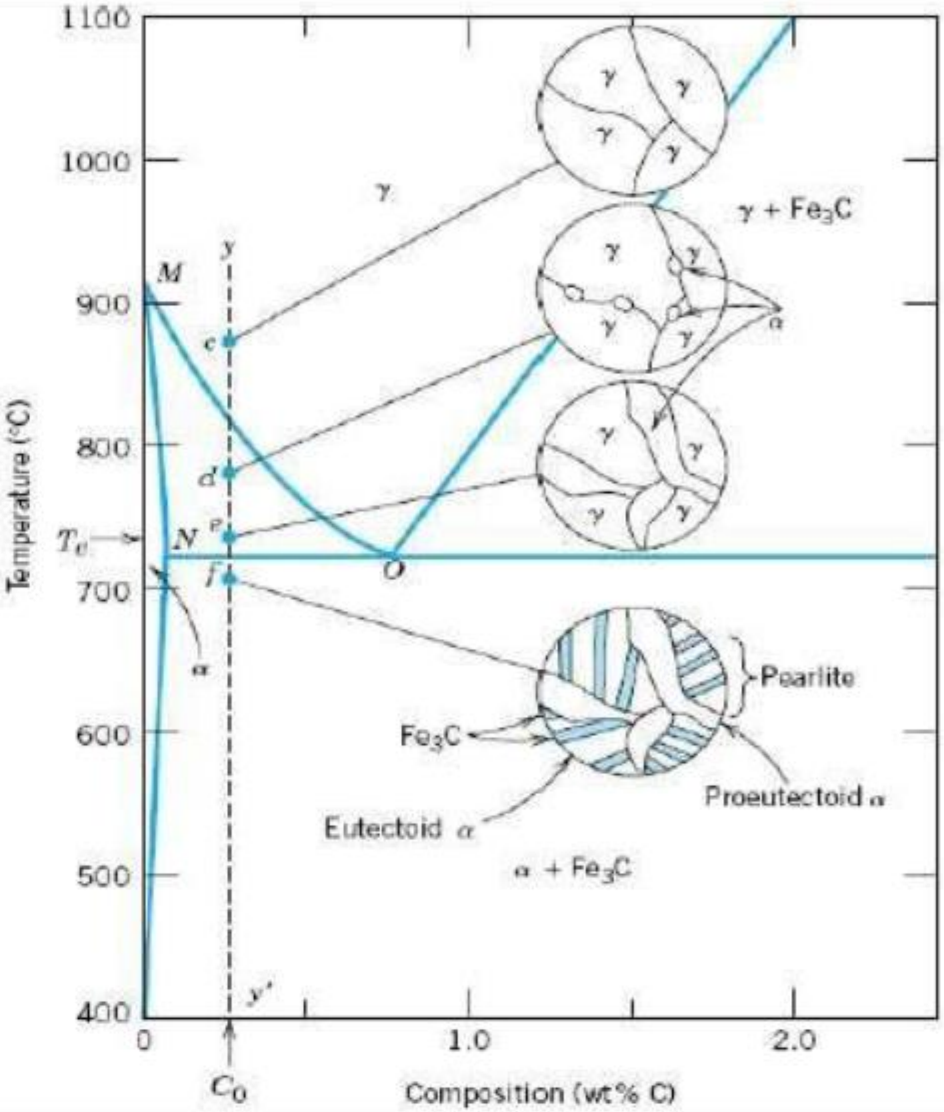
δ	*Ferrite*
γ	*Austenite*
α	*Ferrite*
Fe_3C	*Cementite*
$\gamma + Fe_3C$	*Ledeburite*
$\alpha + Fe_3C$	*Pearlite*

Eutectoid steel

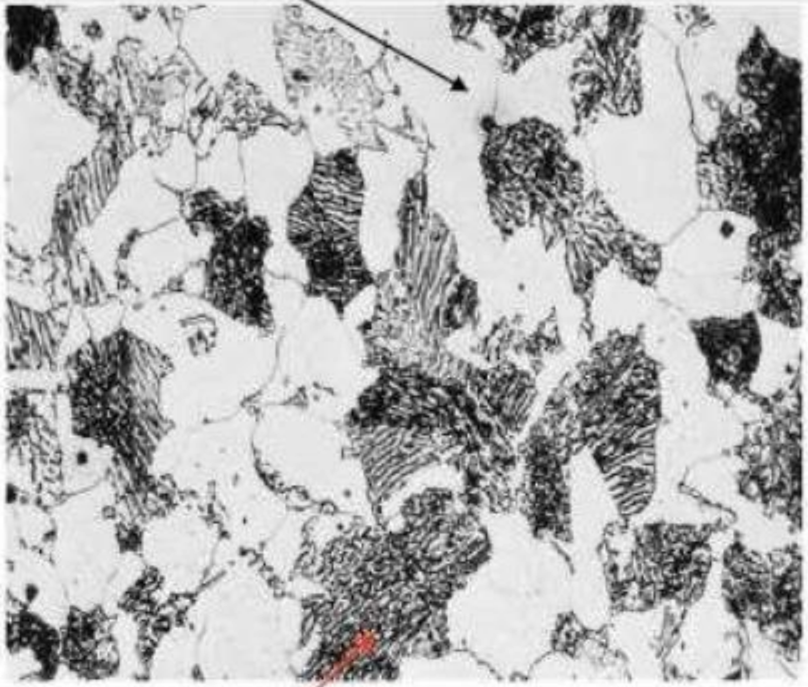




Hypoeutectoid steel



Proeutectoid Ferrite

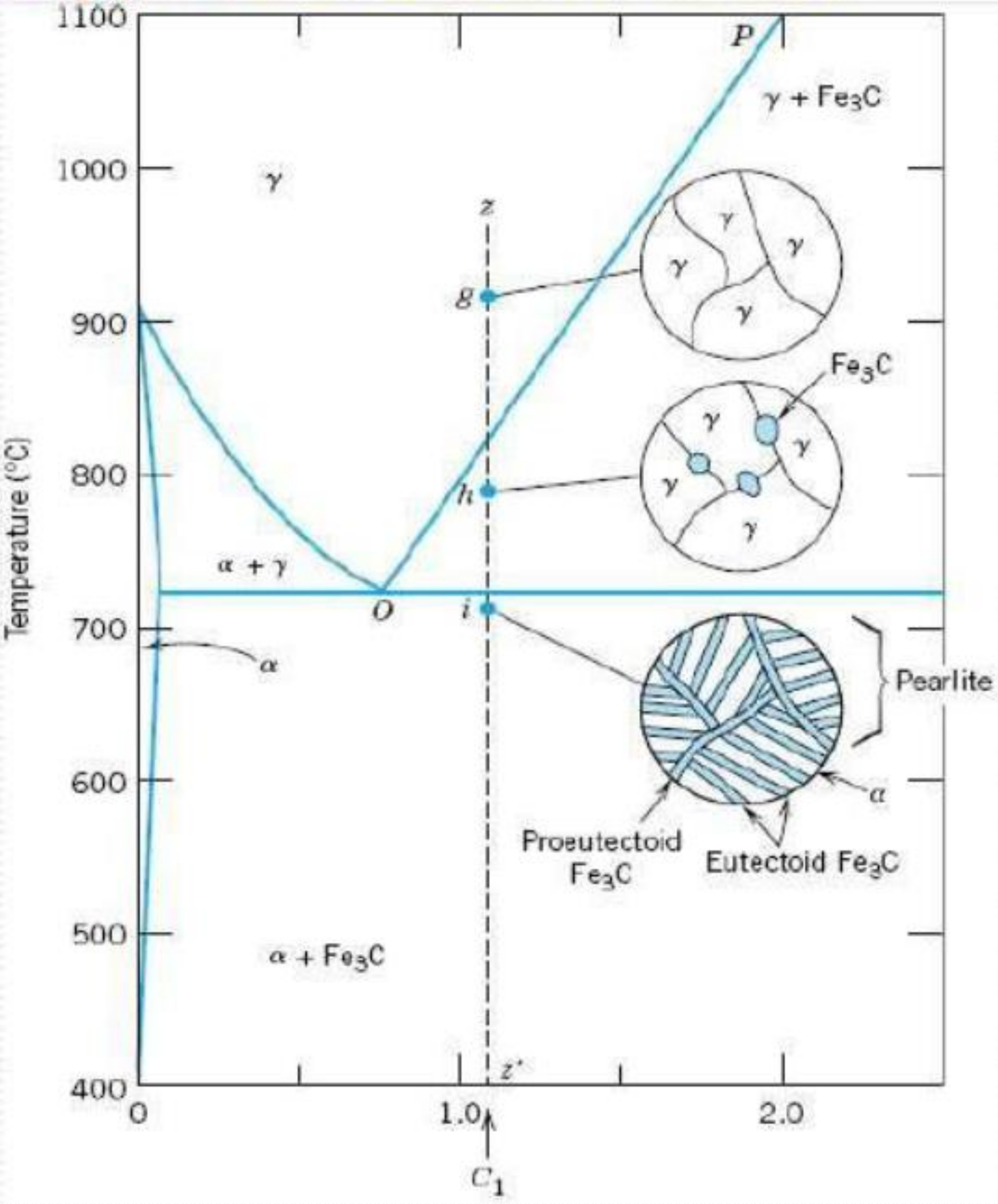


Pearlite

Microstructure of 0.38 wt% C hypoeutectoid steel

- **Hypo-eutectoid steels: Steels having less than** 0.8% carbon are called *hypo-eutectoid steels (hypo means "less than").*
- Consider the cooling of a typical hypo-eutectoid alloy along line *y-y'.*
- At high temperatures the material is entirely austenite.
- Upon cooling it enters a region where the stable phases are ferrite and austenite.
- The low-carbon ferrite nucleates and grows, leaving the remaining austenite richer in carbon.
- At *723°C, the remaining* austenite will have assumed the eutectoid composition *(0.8% carbon), and further* cooling transforms it to pearlite.
- The resulting structure, is a mixture of *primary or proeutectoid ferrite (ferrite that* forms before the eutectoid reaction) and regions of pearlite.

Hypereutectoid steel

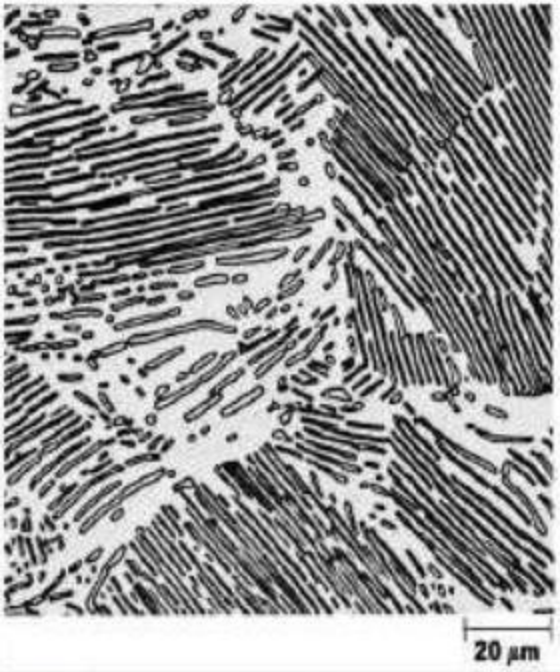
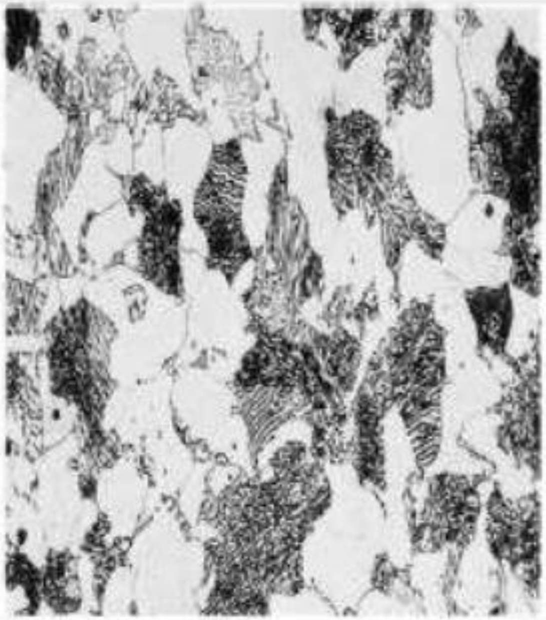


Pearlite

Proeutectoid cementite

Microstructure of 1.4 wt% C hypereutectoid steel

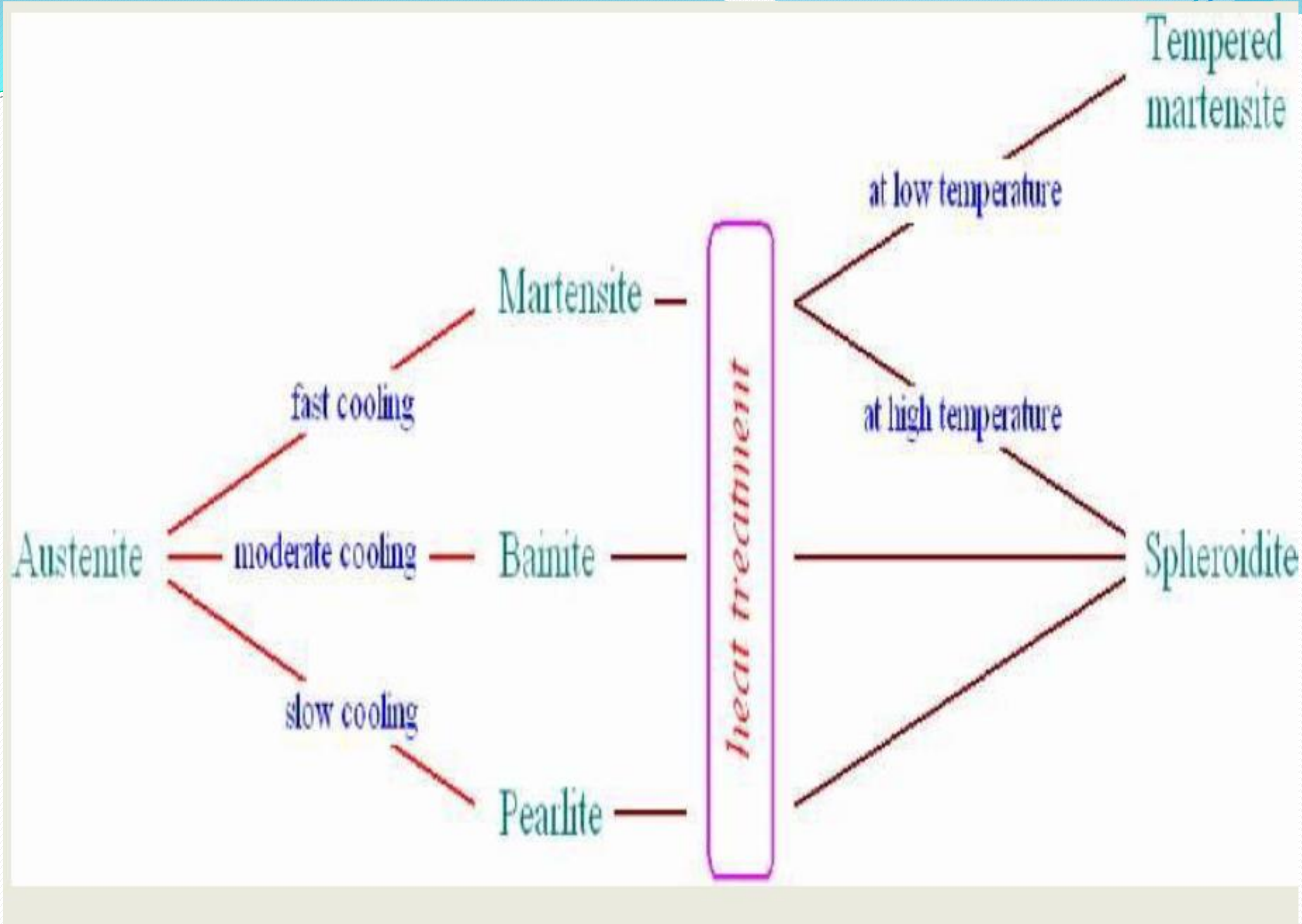
- **Hyper-eutectoid steels *(hyper means*** "greater than") are those that contain more than the eutectoid amount of Carbon.
- When such a steel cools, as along line *z-z'* , the process is similar to the hypo-eutectoid steel, except that the primary or pro-eutectoid phase is now cementite instead of ferrite.
- As the carbon-rich phase nucleates and grows, the remaining austenite decreases in carbon content, again reaching the eutectoid composition at 723°C.
- This austenite transforms to pearlite upon slow cooling through the eutectoid temperature.
- The resulting structure consists of primary cementite and pearlite.
- The continuous network of primary cementite will cause the material to be extremely brittle.

		
Eutectoid steel	**Hypoeutectoid steel**	**Hypereutectoid steel**
$\alpha+Fe_3C$	$\alpha+Fe_3C$	$\alpha+Fe_3C$
Pearlite	Pearlite + proeutectoid ferrite	Pearlite + proeutectoid cementite

DEFINITION OF STRUCTURES

Various phases that appear on the Iron-Carbon equilibrium phase diagram are as under:

- Austenite
- Ferrite
- Pearlite
- Cementite
- Martensite*
- Ledeburite


Austenite
fast cooling
moderate cooling
slow cooling
Martensite
Bainite
Pearlite
heat treatment
at low temperature
at high temperature
Tempered martensite
Spheroidite

Austenite

- **Austenite is an interstitial solid solution of** Carbon dissolved in F.C.C. iron.
- Maximum solubility is 2.0 % C at 1130°C.
- High formability, most of heat treatments begin with this single phase.
- It is normally not stable at room temperature. But, under certain conditions it is possible to obtain austenite at room temperature.

The Austenite to ferrite / cementite transformation in relation to Fe-C diagram

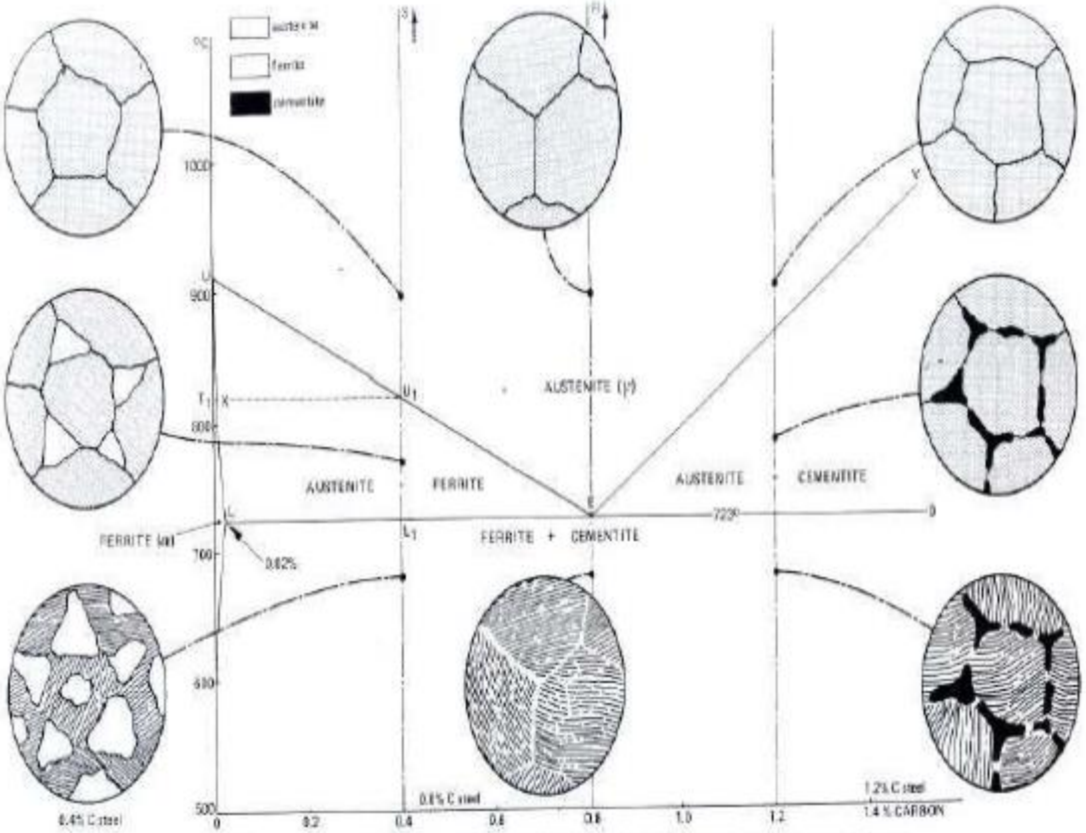


Fig. 9.3—The austenite → ferrite/cementite transformation in relation to the iron-carbon diagram.

Ferrite

- Ferrite is known as α solid solution.
- It is an interstitial solid solution of a small amount of carbon dissolved in α (BCC) iron. stable form of iron below 912 °C.
- The maximum solubility is 0.025 % C at 723°C and it dissolves only 0.008 % C at room temperature.
- It is the softest structure that appears on the diagram.

Pearlite

- Pearlite is the eutectoid mixture containing 0.80 % C and is formed at 723°C on very slow cooling.
- It is a very fine plate like or lamellar mixture of ferrite and cementite.
- The white ferritic background or matrix contains thin plates of cementite (dark).

Cementite or iron carbide

- Cementite or iron carbide, is very hard, brittle intermetallic compound of iron & carbon, as Fe3C, contains 6.67 % C.
- It is the hardest structure that appears on the diagram, exact melting point unknown. Its crystal structure is orthorhombic. It has low tensile strength (approx. 5,000 psi), but high compressive strength.

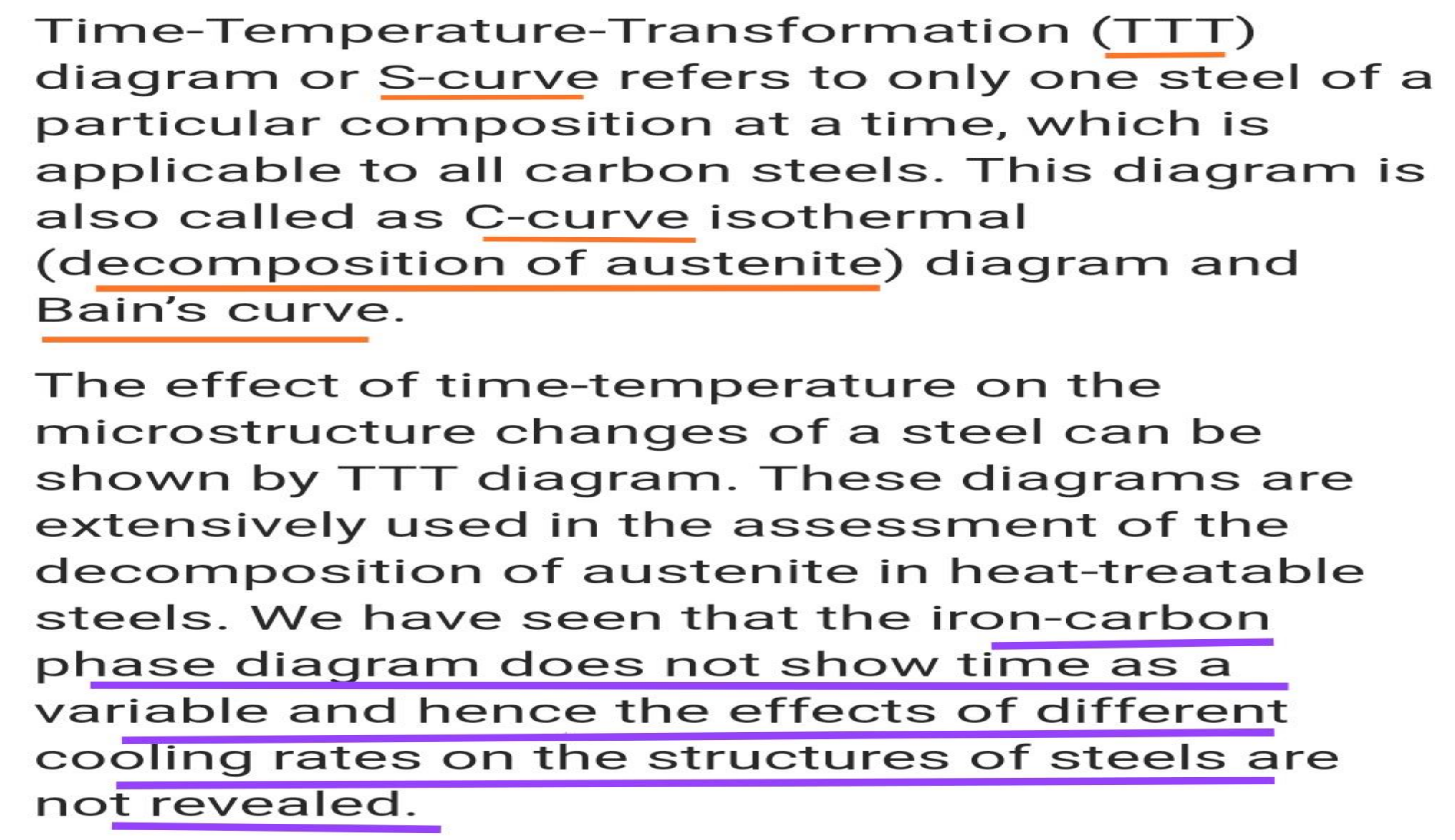
Ledeburite

- Ledeburite is the eutectic mixture of austenite and cementite. It contains 4.3 percent C and is formed at 1130°C.

Martensite

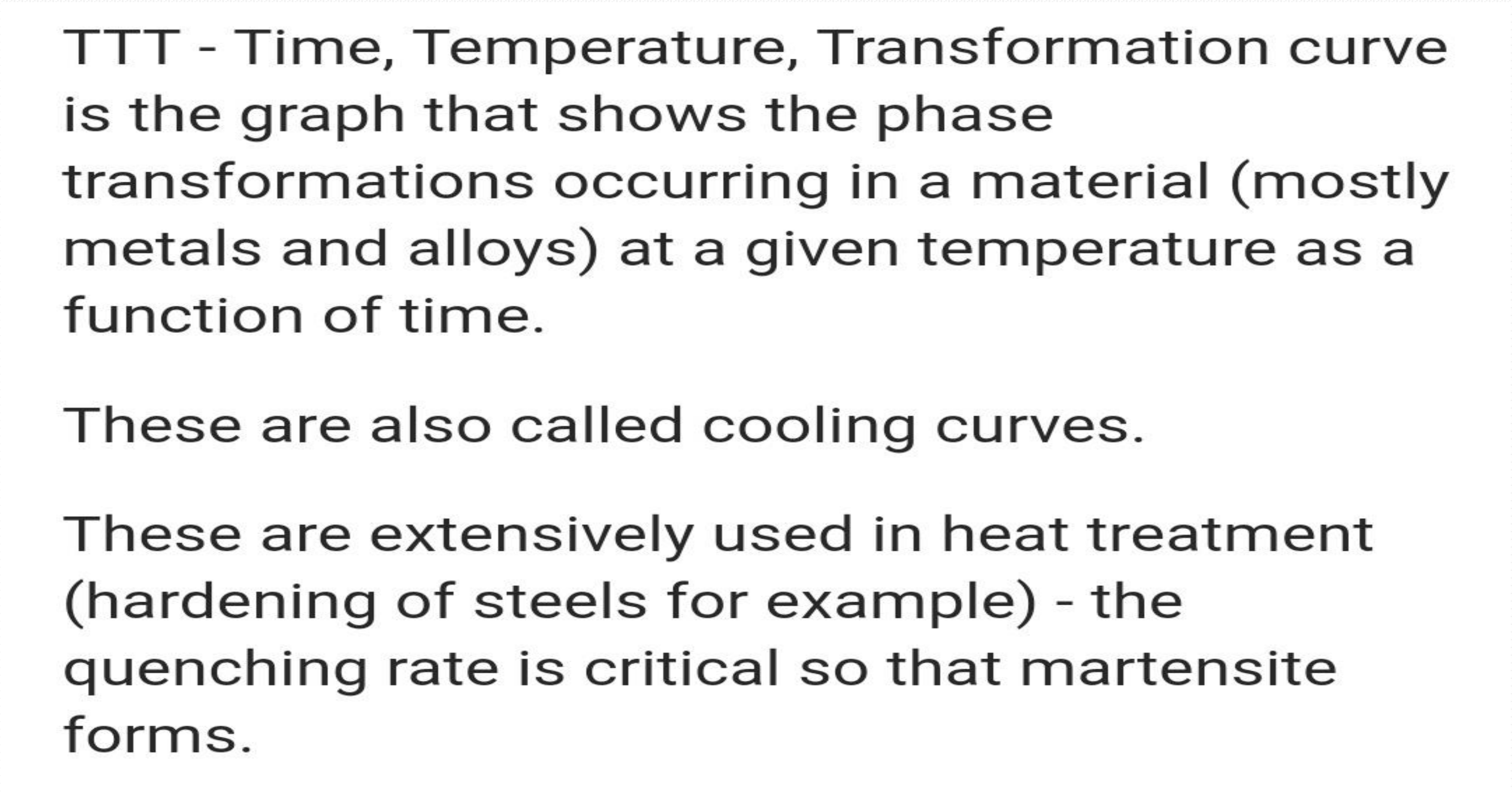
- Martensite - a super-saturated solid solution of carbon in ferrite. It is formed when steel is cooled so rapidly that the change from austenite to pearlite is suppressed.
- The interstitial carbon atoms distort the BCC ferrite into a BC-tetragonal structure (BCT).; responsible for the hardness of quenched steel.

TTT Diagram



Time-Temperature-Transformation (TTT) diagram or S-curve refers to only one steel of a particular composition at a time, which is applicable to all carbon steels. This diagram is also called as C-curve isothermal (decomposition of austenite) diagram and Bain's curve.

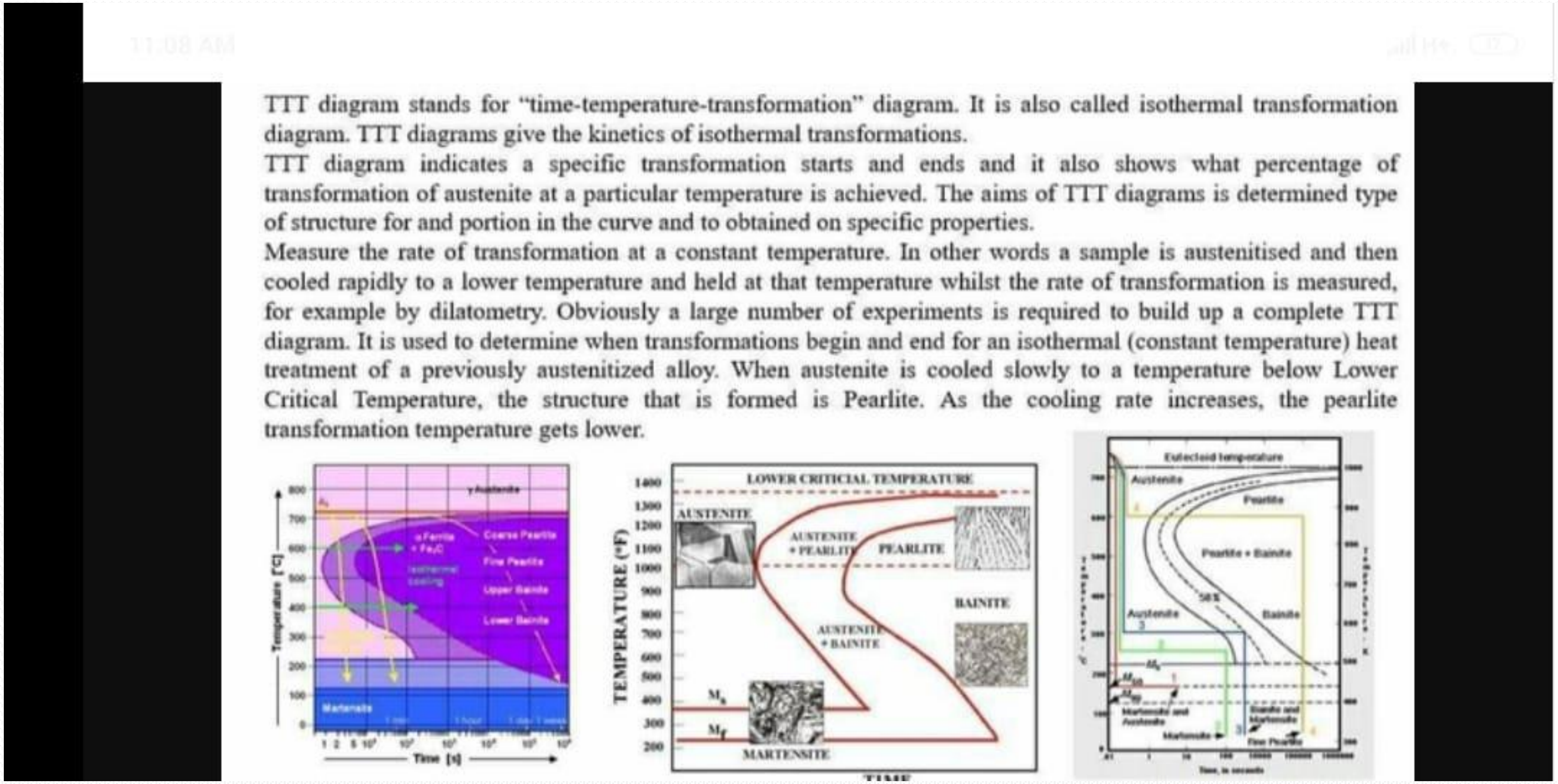
The effect of time-temperature on the microstructure changes of a steel can be shown by TTT diagram. These diagrams are extensively used in the assessment of the decomposition of austenite in heat-treatable steels. We have seen that the iron-carbon phase diagram does not show time as a variable and hence the effects of different cooling rates on the structures of steels are not revealed.



TTT - Time, Temperature, Transformation curve is the graph that shows the phase transformations occurring in a material (mostly metals and alloys) at a given temperature as a function of time.

These are also called cooling curves.

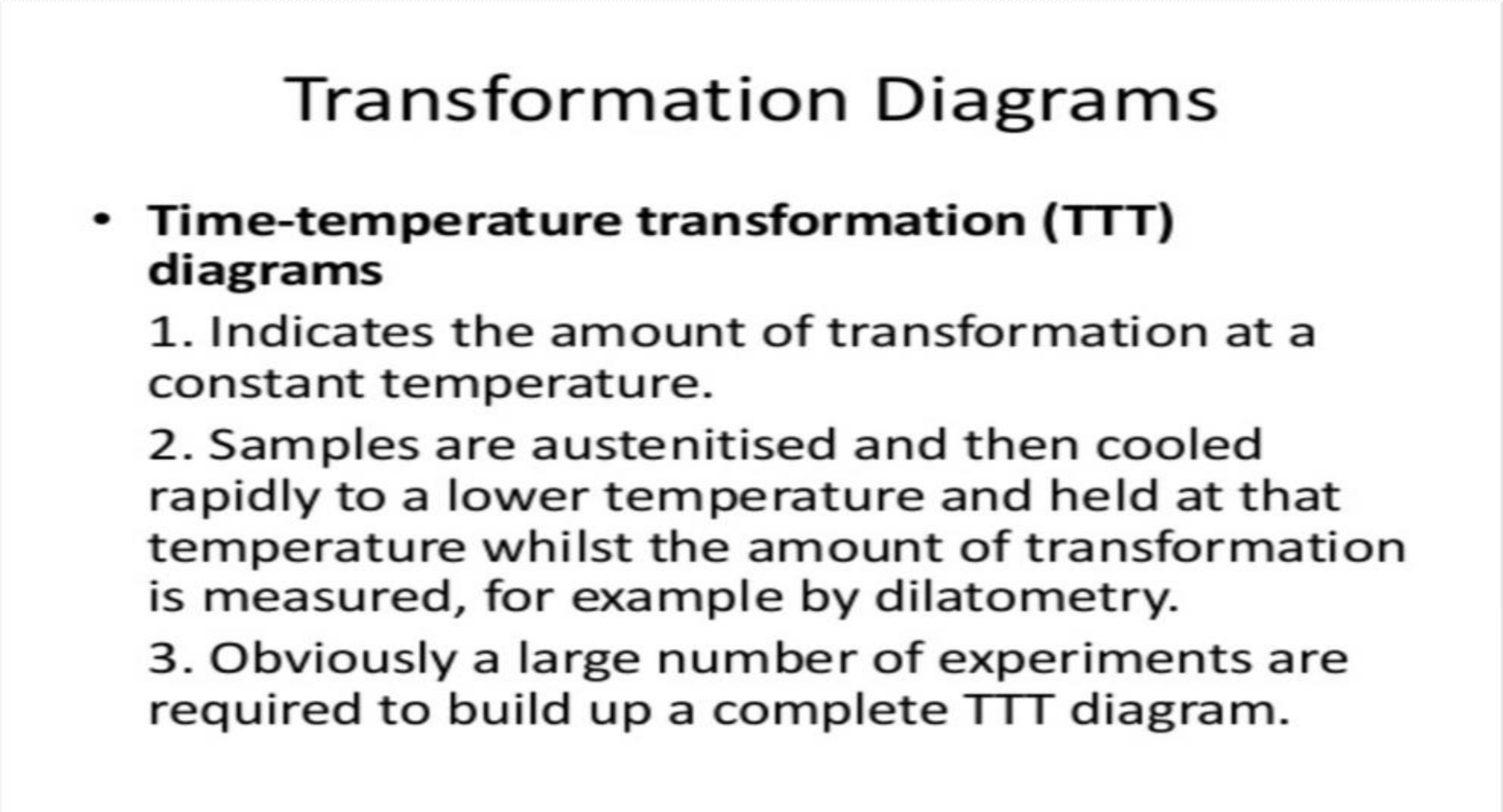
These are extensively used in heat treatment (hardening of steels for example) - the quenching rate is critical so that martensite forms.



TTT diagram stands for "time-temperature-transformation" diagram. It is also called isothermal transformation diagram. TTT diagrams give the kinetics of isothermal transformations.

TTT diagram indicates a specific transformation starts and ends and it also shows what percentage of transformation of austenite at a particular temperature is achieved. The aims of TTT diagrams is determined type of structure for and portion in the curve and to obtained on specific properties.

Measure the rate of transformation at a constant temperature. In other words a sample is austenitised and then cooled rapidly to a lower temperature and held at that temperature whilst the rate of transformation is measured, for example by dilatometry. Obviously a large number of experiments is required to build up a complete TTT diagram. It is used to determine when transformations begin and end for an isothermal (constant temperature) heat treatment of a previously austenitized alloy. When austenite is cooled slowly to a temperature below Lower Critical Temperature, the structure that is formed is Pearlite. As the cooling rate increases, the pearlite transformation temperature gets lower.



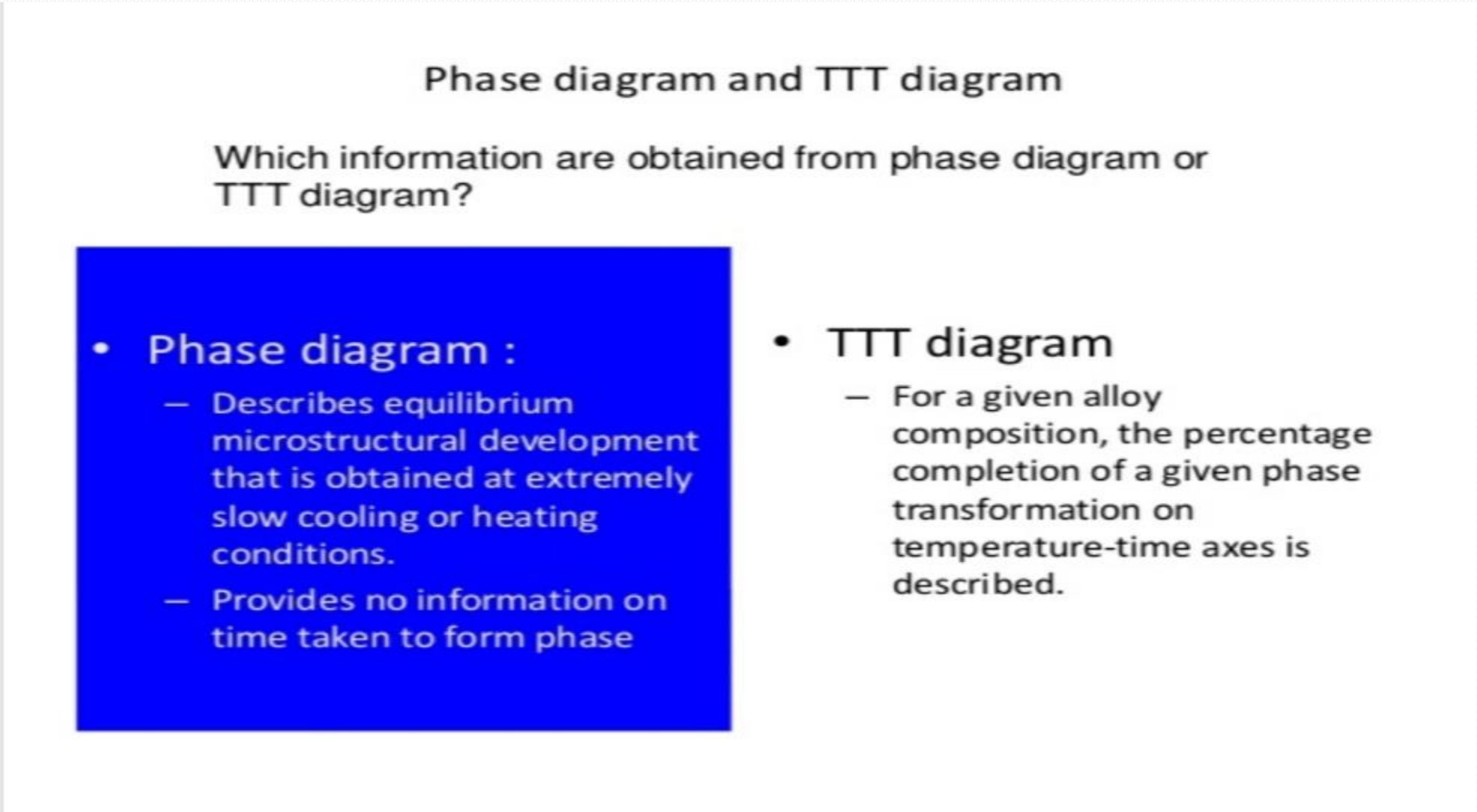
Transformation Diagrams

- **Time-temperature transformation (TTT) diagrams**

  1. Indicates the amount of transformation at a constant temperature.

  2. Samples are austenitised and then cooled rapidly to a lower temperature and held at that temperature whilst the amount of transformation is measured, for example by dilatometry.

  3. Obviously a large number of experiments are required to build up a complete TTT diagram.

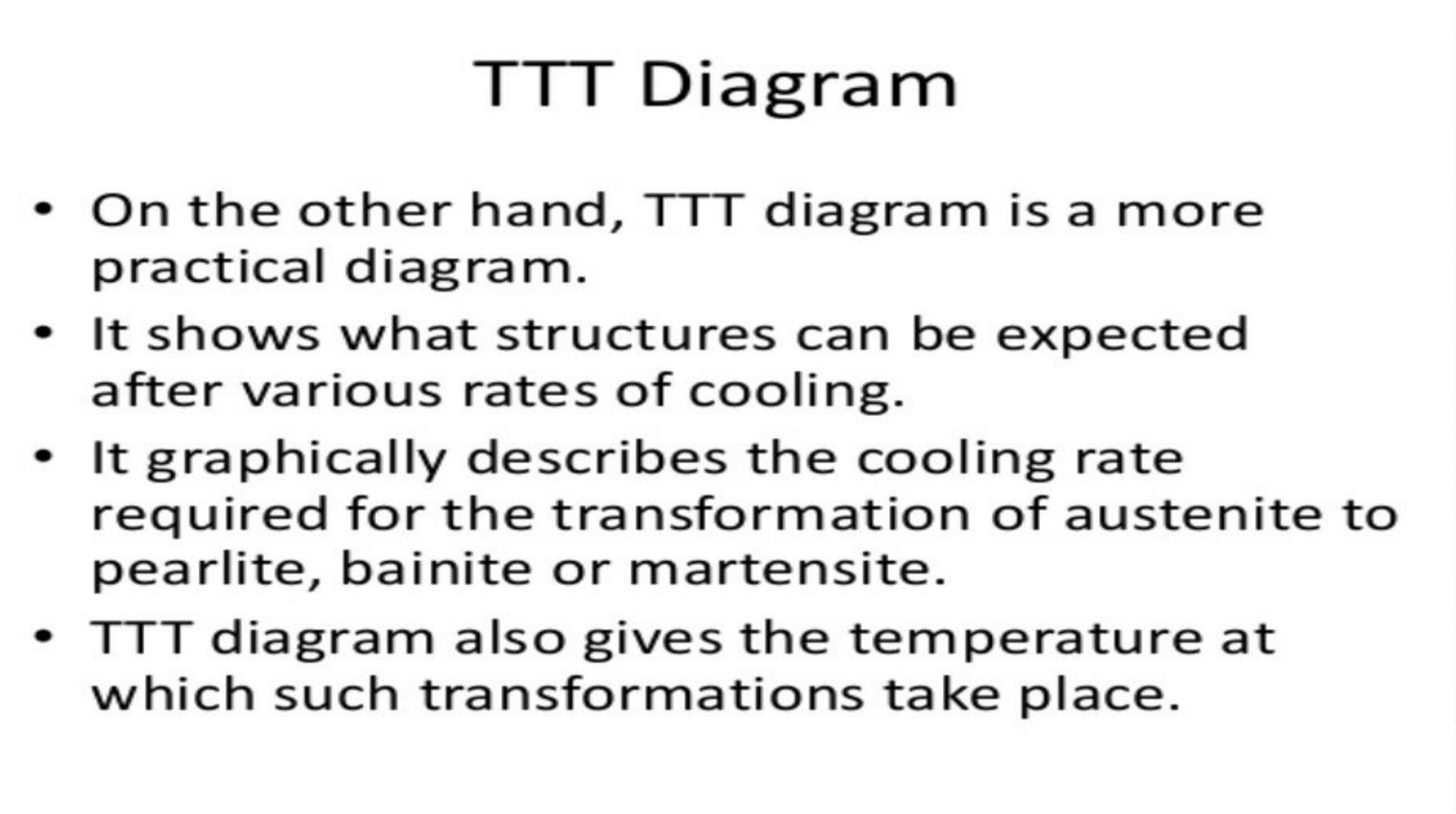


Phase diagram and TTT diagram

Which information are obtained from phase diagram or TTT diagram?

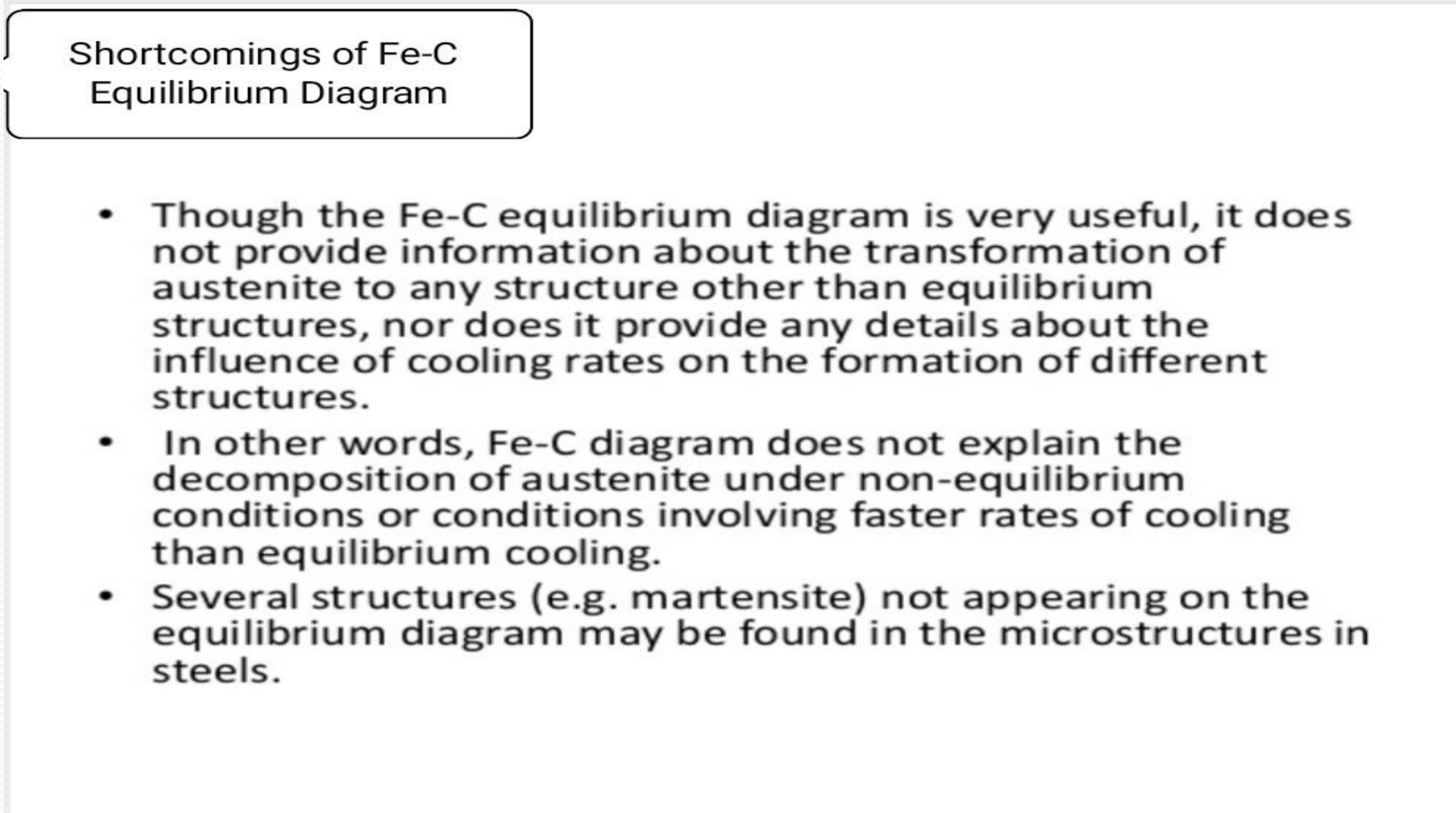
- Phase diagram :
  - Describes equilibrium microstructural development that is obtained at extremely slow cooling or heating conditions.
  - Provides no information on time taken to form phase

- TTT diagram
  - For a given alloy composition, the percentage completion of a given phase transformation on temperature-time axes is described.



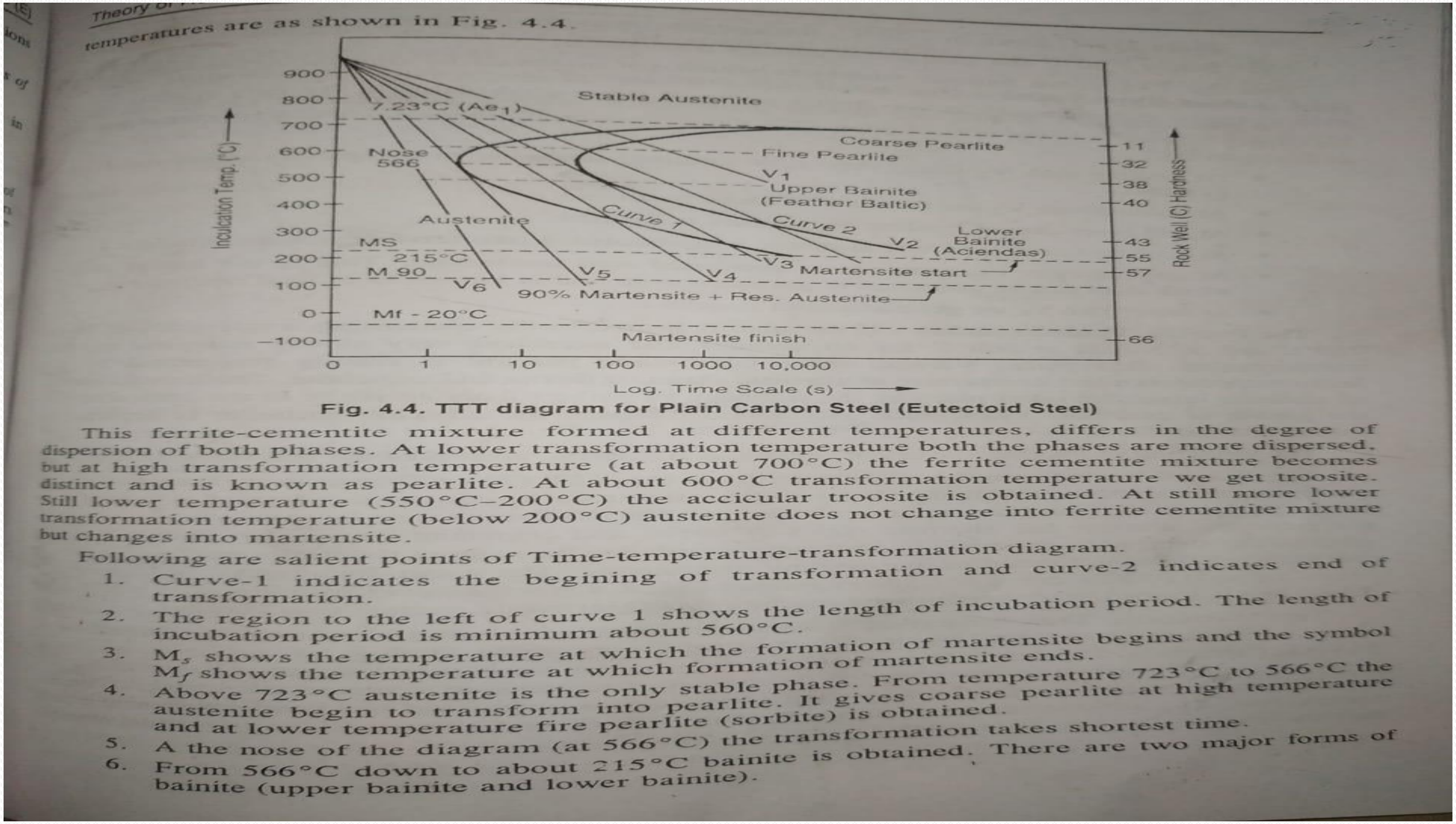
TTT Diagram

- On the other hand, TTT diagram is a more practical diagram.
- It shows what structures can be expected after various rates of cooling.
- It graphically describes the cooling rate required for the transformation of austenite to pearlite, bainite or martensite.
- TTT diagram also gives the temperature at which such transformations take place.



Shortcomings of Fe-C Equilibrium Diagram

- Though the Fe-C equilibrium diagram is very useful, it does not provide information about the transformation of austenite to any structure other than equilibrium structures, nor does it provide any details about the influence of cooling rates on the formation of different structures.
- In other words, Fe-C diagram does not explain the decomposition of austenite under non-equilibrium conditions or conditions involving faster rates of cooling than equilibrium cooling.
- Several structures (e.g. martensite) not appearing on the equilibrium diagram may be found in the microstructures in steels.



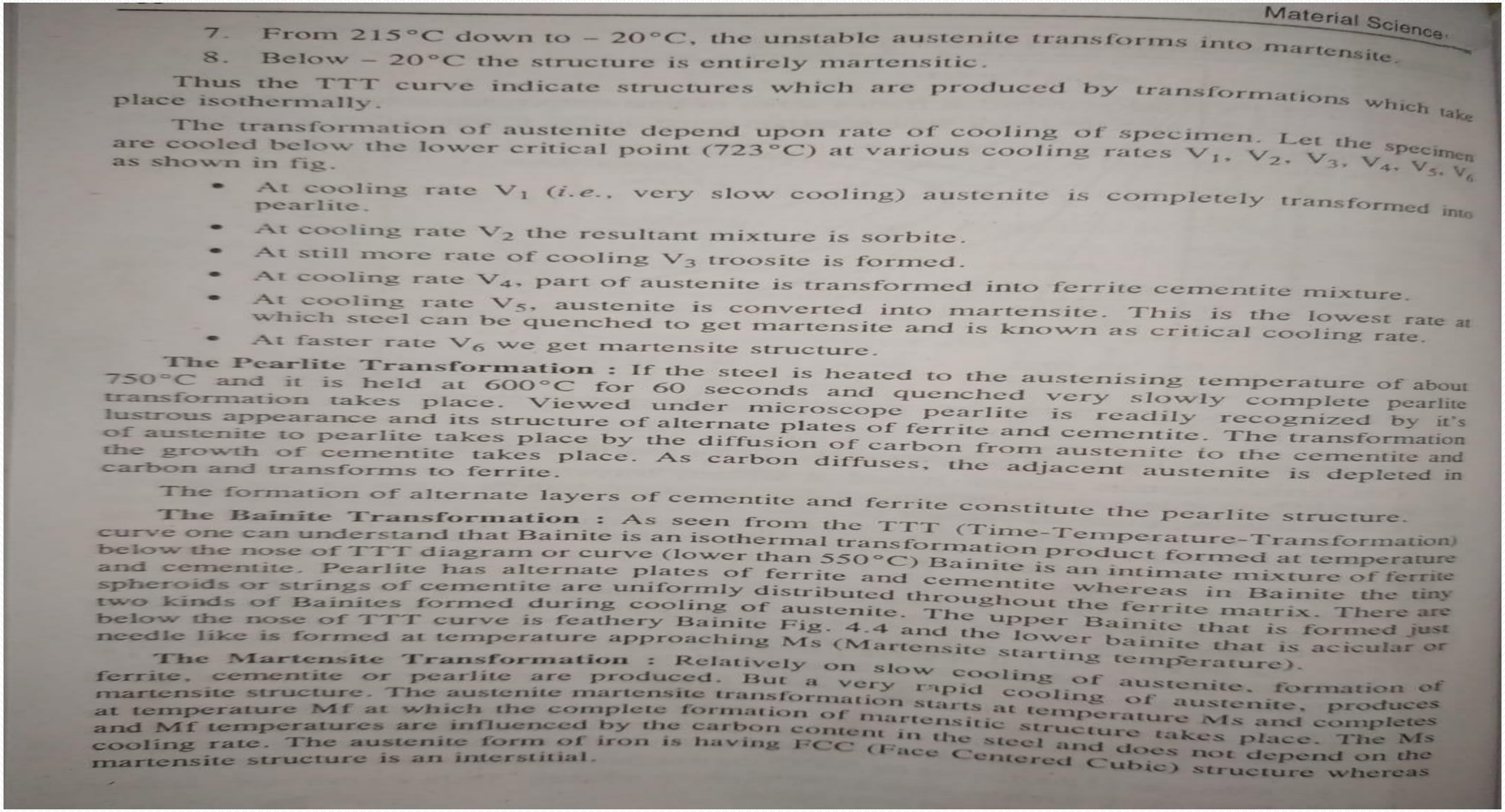
temperatures are as shown in Fig. 4.4.

Fig. 4.4. TTT diagram for Plain Carbon Steel (Eutectoid Steel)

This ferrite-cementite mixture formed at different temperatures, differs in the degree of dispersion of both phases. At lower transformation temperature both the phases are more dispersed, but at high transformation temperature (at about 700°C) the ferrite cementite mixture becomes distinct and is known as pearlite. At about 600°C transformation temperature we get troosite. Still lower temperature (550°C–200°C) the accicular troosite is obtained. At still more lower transformation temperature (below 200°C) austenite does not change into ferrite cementite mixture but changes into martensite.

Following are salient points of Time-temperature-transformation diagram.

1. Curve-1 indicates the begining of transformation and curve-2 indicates end of transformation.
2. The region to the left of curve 1 shows the length of incubation period. The length of incubation period is minimum about 560°C.
3. M_s shows the temperature at which the formation of martensite begins and the symbol M_f shows the temperature at which formation of martensite ends.
4. Above 723°C austenite is the only stable phase. From temperature 723°C to 566°C the austenite begin to transform into pearlite. It gives coarse pearlite at high temperature and at lower temperature fire pearlite (sorbite) is obtained.
5. A the nose of the diagram (at 566°C) the transformation takes shortest time.
6. From 566°C down to about 215°C bainite is obtained. There are two major forms of bainite (upper bainite and lower bainite).



7. From 215°C down to – 20°C, the unstable austenite transforms into martensite.
8. Below – 20°C the structure is entirely martensitic.

Thus the TTT curve indicate structures which are produced by transformations which take place isothermally.

The transformation of austenite depend upon rate of cooling of specimen. Let the specimen are cooled below the lower critical point (723°C) at various cooling rates V_1, V_2, V_3, V_4, V_5, V_6 as shown in fig.

- At cooling rate V_1 (*i.e.*, very slow cooling) austenite is completely transformed into pearlite.
- At cooling rate V_2 the resultant mixture is sorbite.
- At still more rate of cooling V_3 troosite is formed.
- At cooling rate V_4, part of austenite is transformed into ferrite cementite mixture.
- At cooling rate V_5, austenite is converted into martensite. This is the lowest rate at which steel can be quenched to get martensite and is known as critical cooling rate.
- At faster rate V_6 we get martensite structure.

The Pearlite Transformation : If the steel is heated to the austenising temperature of about 750°C and it is held at 600°C for 60 seconds and quenched very slowly complete pearlite transformation takes place. Viewed under microscope pearlite is readily recognized by it's lustrous appearance and its structure of alternate plates of ferrite and cementite. The transformation of austenite to pearlite takes place by the diffusion of carbon from austenite to the cementite and the growth of cementite takes place. As carbon diffuses, the adjacent austenite is depleted in carbon and transforms to ferrite.

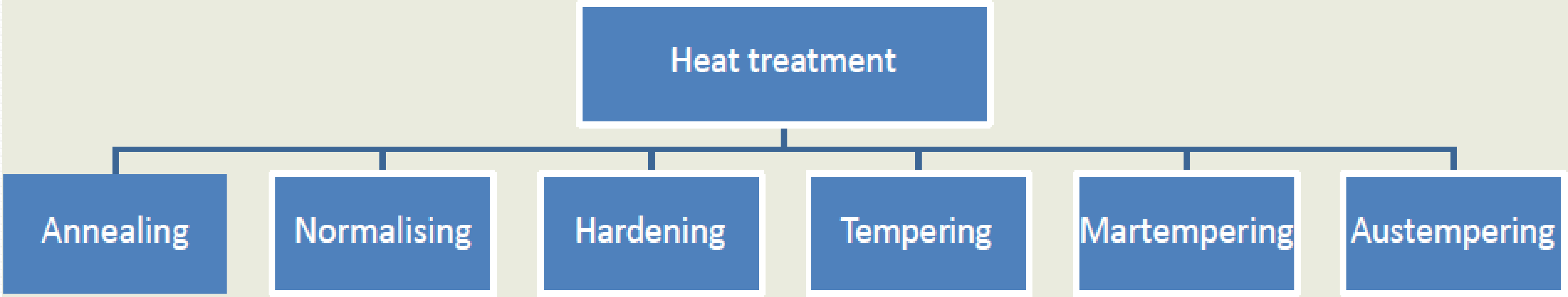
The formation of alternate layers of cementite and ferrite constitute the pearlite structure.

The Bainite Transformation : As seen from the TTT (Time-Temperature-Transformation) curve one can understand that Bainite is an isothermal transformation product formed at temperature below the nose of TTT diagram or curve (lower than 550°C) Bainite is an intimate mixture of ferrite and cementite. Pearlite has alternate plates of ferrite and cementite whereas in Bainite the tiny spheroids or strings of cementite are uniformly distributed throughout the ferrite matrix. There are two kinds of Bainites formed during cooling of austenite. The upper Bainite that is formed just below the nose of TTT curve is feathery Bainite Fig. 4.4 and the lower bainite that is acicular or needle like is formed at temperature approaching Ms (Martensite starting temperature).

The Martensite Transformation : Relatively on slow cooling of austenite, formation of ferrite, cementite or pearlite are produced. But a very rapid cooling of austenite, produces martensite structure. The austenite martensite transformation starts at temperature Ms and completes at temperature Mf at which the complete formation of martensitic structure takes place. The Ms and Mf temperatures are influenced by the carbon content in the steel and does not depend on the cooling rate. The austenite form of iron is having FCC (Face Centered Cubic) structure whereas martensite structure is an interstitial.

HEAT TREATMENT

- An operation or combination of operations which involves heating & cooling of a metal/alloy in solid state to obtain desirable conditions & properties.



- Heat treatment
  - Annealing
  - Normalising
  - Hardening
  - Tempering
  - Martempering
  - Austempering

PURPOSE OF HEAT TREATMENT

- Heat treatment is carried out to

(1) Cause relief of internal stresses developed during cold working, welding casting, forging etc.

(2) Harden & strengthen metals

(3) Improve machinability

(4) Change grain Size

(5) Soften metals for further working as in wire drawing or cold rolling

(6) Improve ductility & toughness

(7) Increase heat, wear & corrosion resistance of materials

(8) Improve electrical & magnetic properties

(9) Homogenize the structure

Heat treatment techniques include

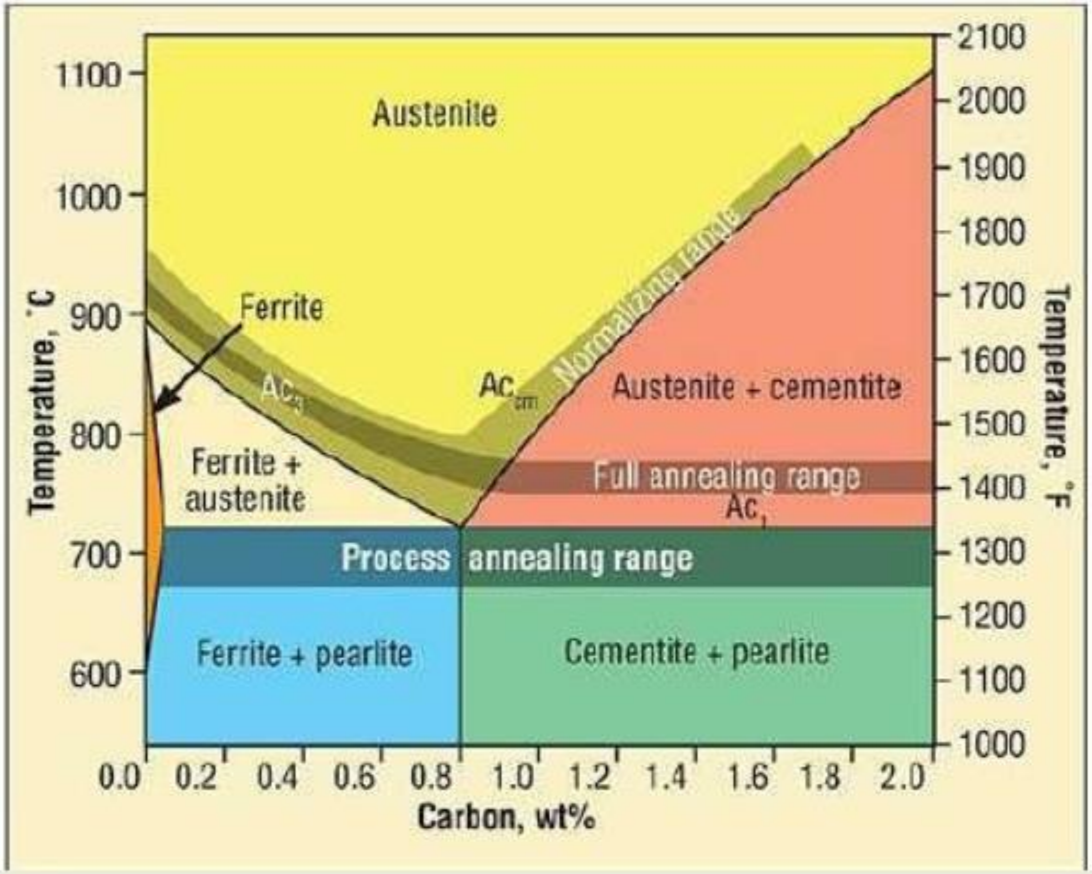
- Annealing,
- Hardening,
- Tempering, and
- Quenching.

Annealing: Process Annealing

- In this treatment, steal (or any material) is heated to a temperature below the lower critical temperature, and is held at this temperature for sufficient time and then cooled.

- Cooling rate is of little importance as the process is being done at sub critical temperatures.

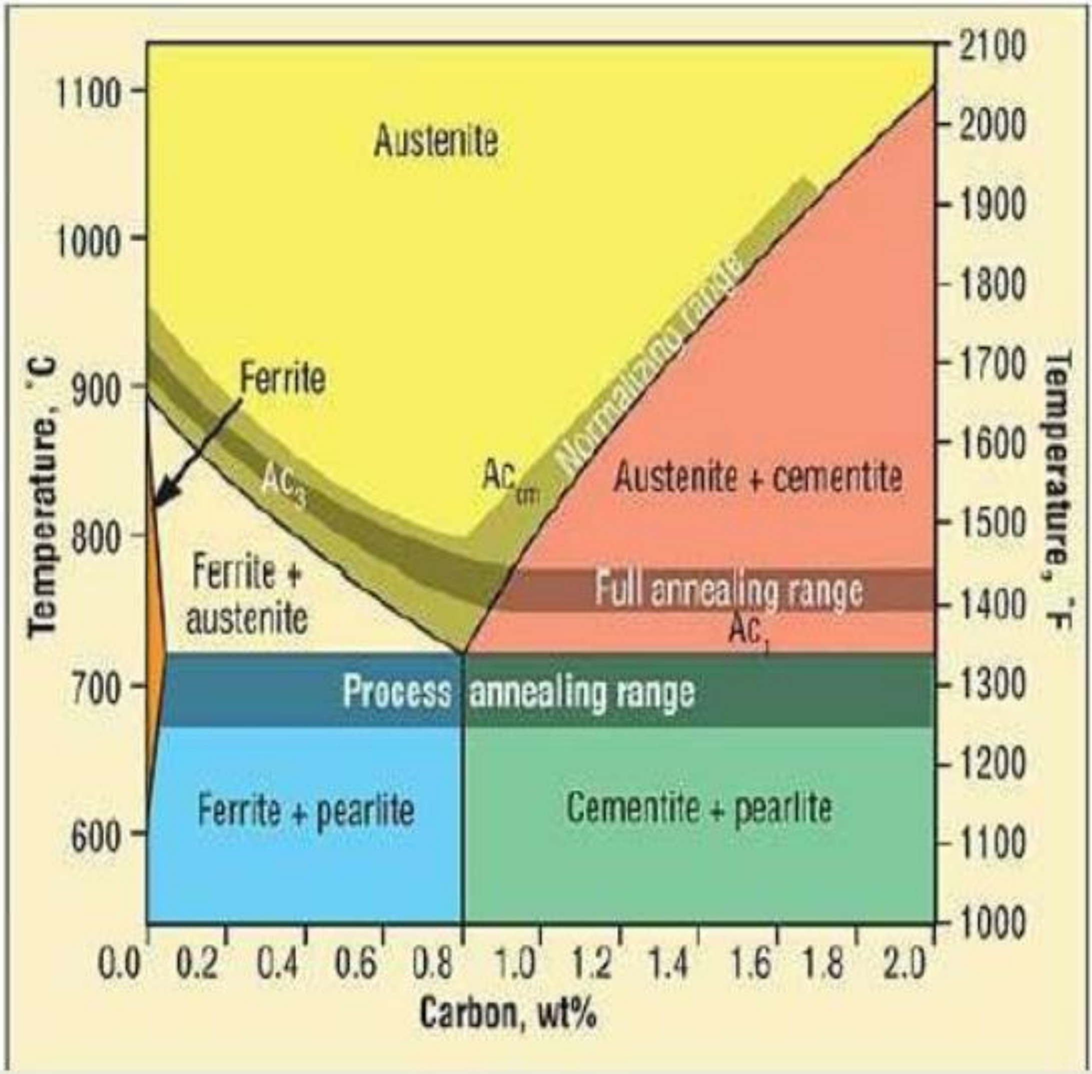
- The purpose of this treatment is to reduce hardness and to increase ductility of cold-worked steel so that further working may be carried easily.



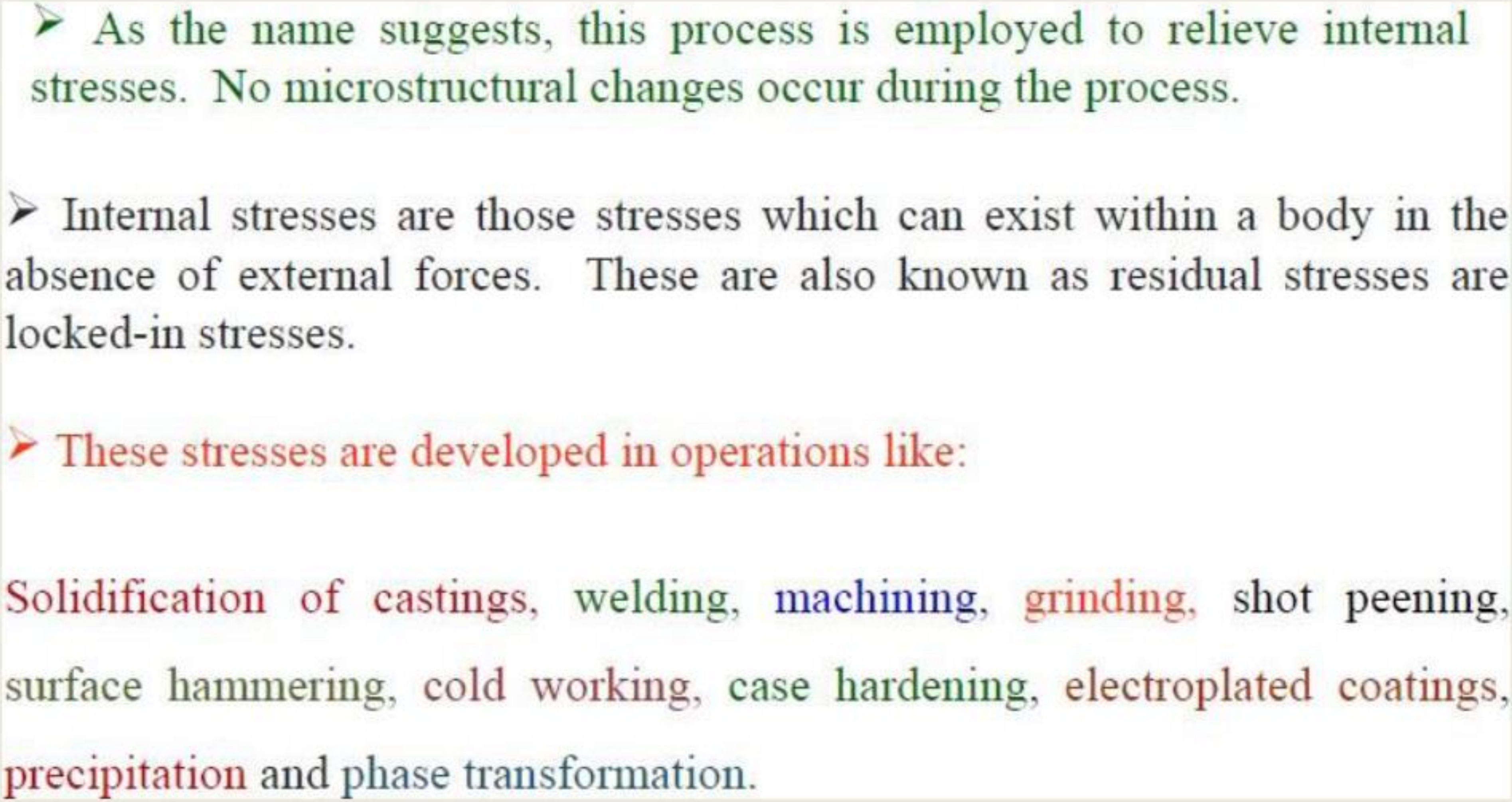
- This process is extensively used in the treatment of sheets and wires.

- Parts which are fabricated by cold forming such as stamping, extrusion, upsetting and drawing are frequently given this treatment as an intermediate step.

- Scaling or oxidation can be prevented or minimized by this process specially if annealed at lower temperatures or in non-oxidizing areas.



Annealing: Stress Relieving

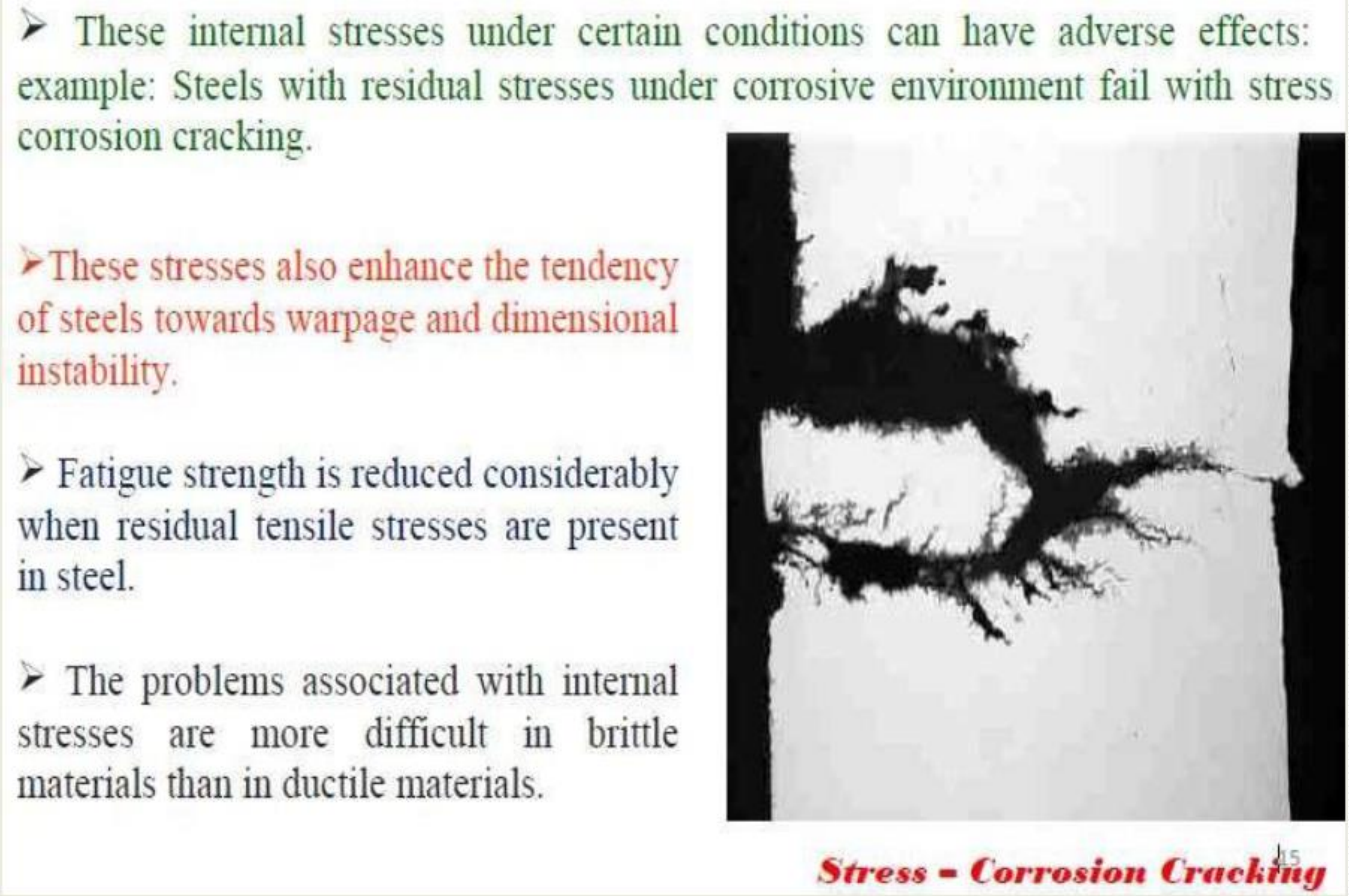


- As the name suggests, this process is employed to relieve internal stresses. No microstructural changes occur during the process.

- Internal stresses are those stresses which can exist within a body in the absence of external forces. These are also known as residual stresses are locked-in stresses.

- These stresses are developed in operations like:

Solidification of castings, welding, machining, grinding, shot peening, surface hammering, cold working, case hardening, electroplated coatings, precipitation and phase transformation.



- These internal stresses under certain conditions can have adverse effects: example: Steels with residual stresses under corrosive environment fail with stress corrosion cracking.

- These stresses also enhance the tendency of steels towards warpage and dimensional instability.

- Fatigue strength is reduced considerably when residual tensile stresses are present in steel.

- The problems associated with internal stresses are more difficult in brittle materials than in ductile materials.

Stress - Corrosion Cracking

- The process of stress relieving consists of heating materials uniformly to a temperature below the lower critical temperature, holding at this temperature for sufficient time, followed by uniform cooling.

- Uniform cooling is of utmost importance as non-uniform cooling will itself result in the development of internal stresses. Thus the very purpose of stress relieving will be lost.
- Plain carbon steels and low alloy steels generally temperature is limited to 600 °C. Higher temperature is used for high alloy steels.
- The extent of the stresses relieved depend upon the temperature employed and holding time.

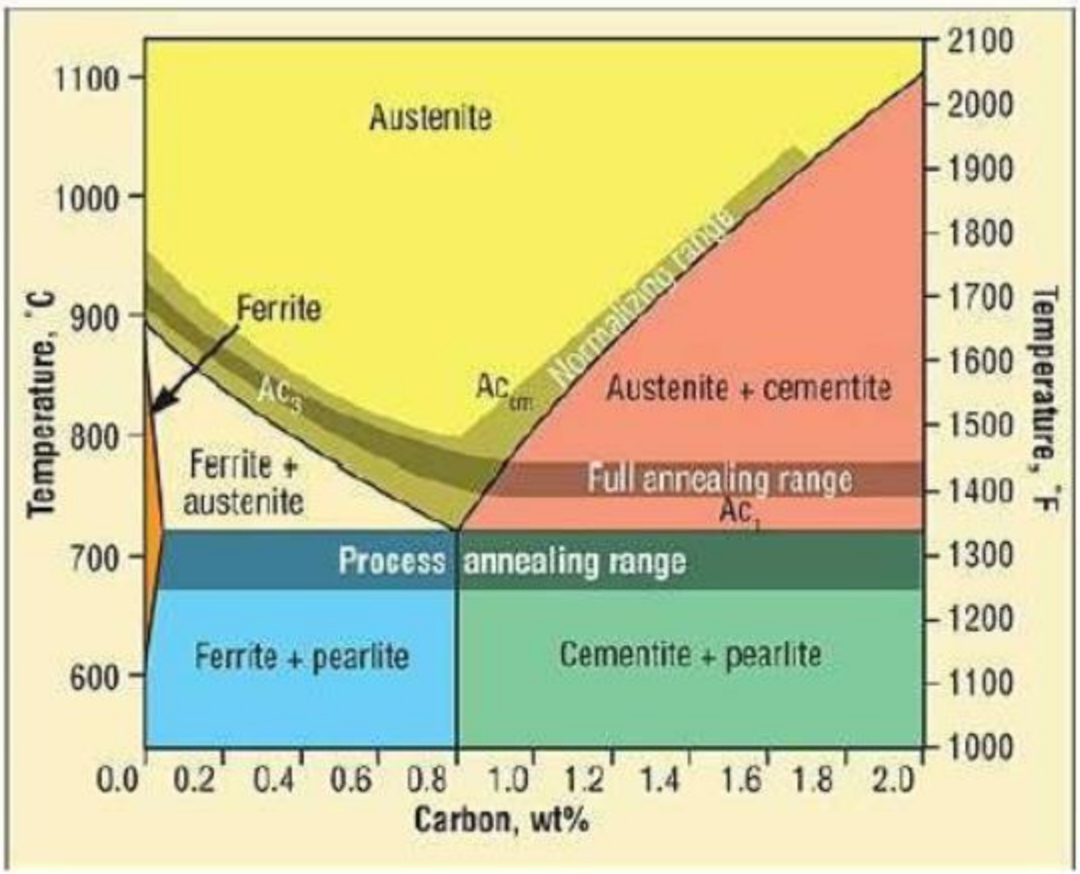
Stress - Corrosion Cracking

Annealing: Normalizing

- Normalizing is similar to full annealing, except steel is generally cooled in still air.

- The normalizing consists of heating steel to about 40-55 ºC above critical temperature (Ac_3 or Ac_{cm}), and holding for proper item and then cooling in still air or slightly agitated air to room temperature.

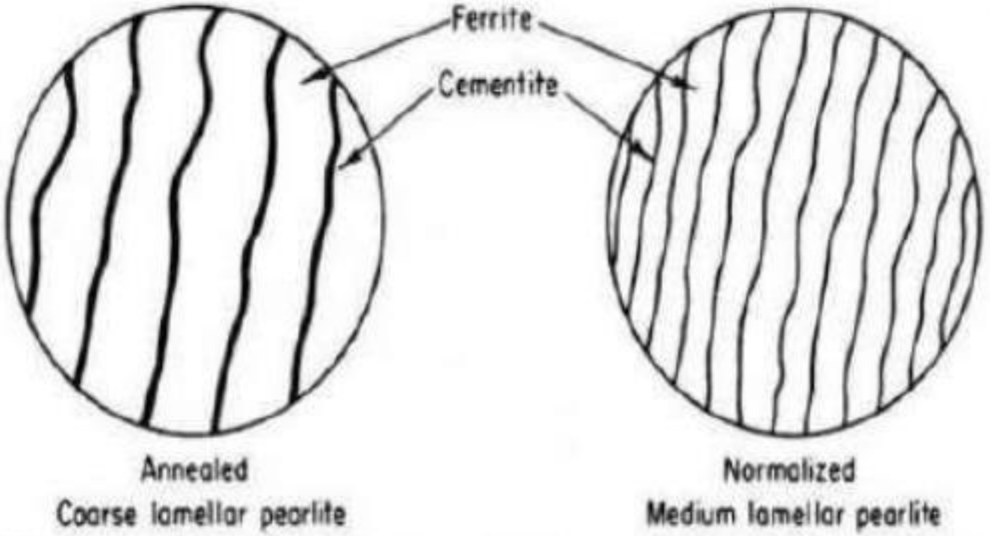
- In some special cases, cooling rates can be controlled by either changing air temperature or air volume.



- After normalizing, the resultant micro-structure should be pearlitic.

- Since the temperature involved in this process is more than that for annealing , the homogeneity of austenite increases and it results in better dispersion of ferrite and Cementite in the final structure.

- Results in better dispersion of ferrite and Cementite in the final structure.



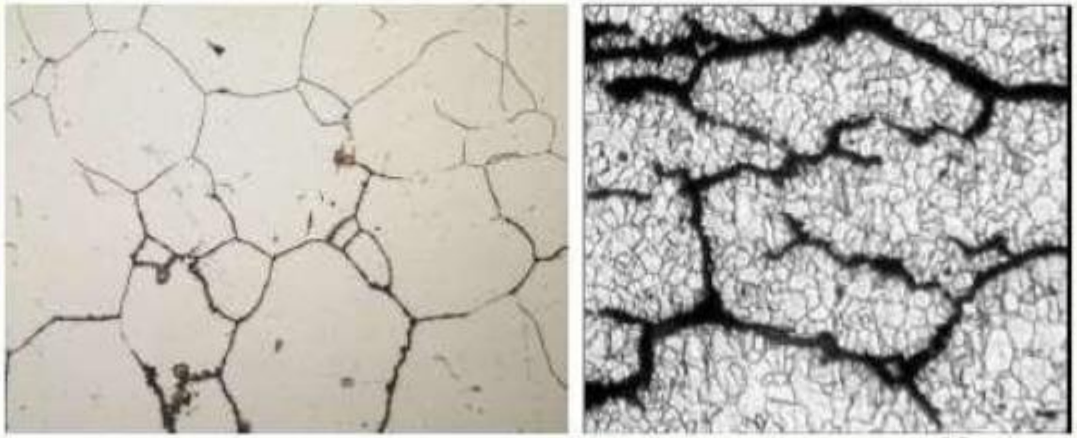
Difference in pearlitic structure due to annealing and normalizing

- The grain size is finer in normalized structure than in annealed structure.

- Normalized steels are generally stronger and harder than fully annealed steels.

- Steels are soft in annealed condition and tend to stick during machining. By normalizing, an optimum combination of strength and softness is achieved, which results in satisfactory level of Machinability in steels.

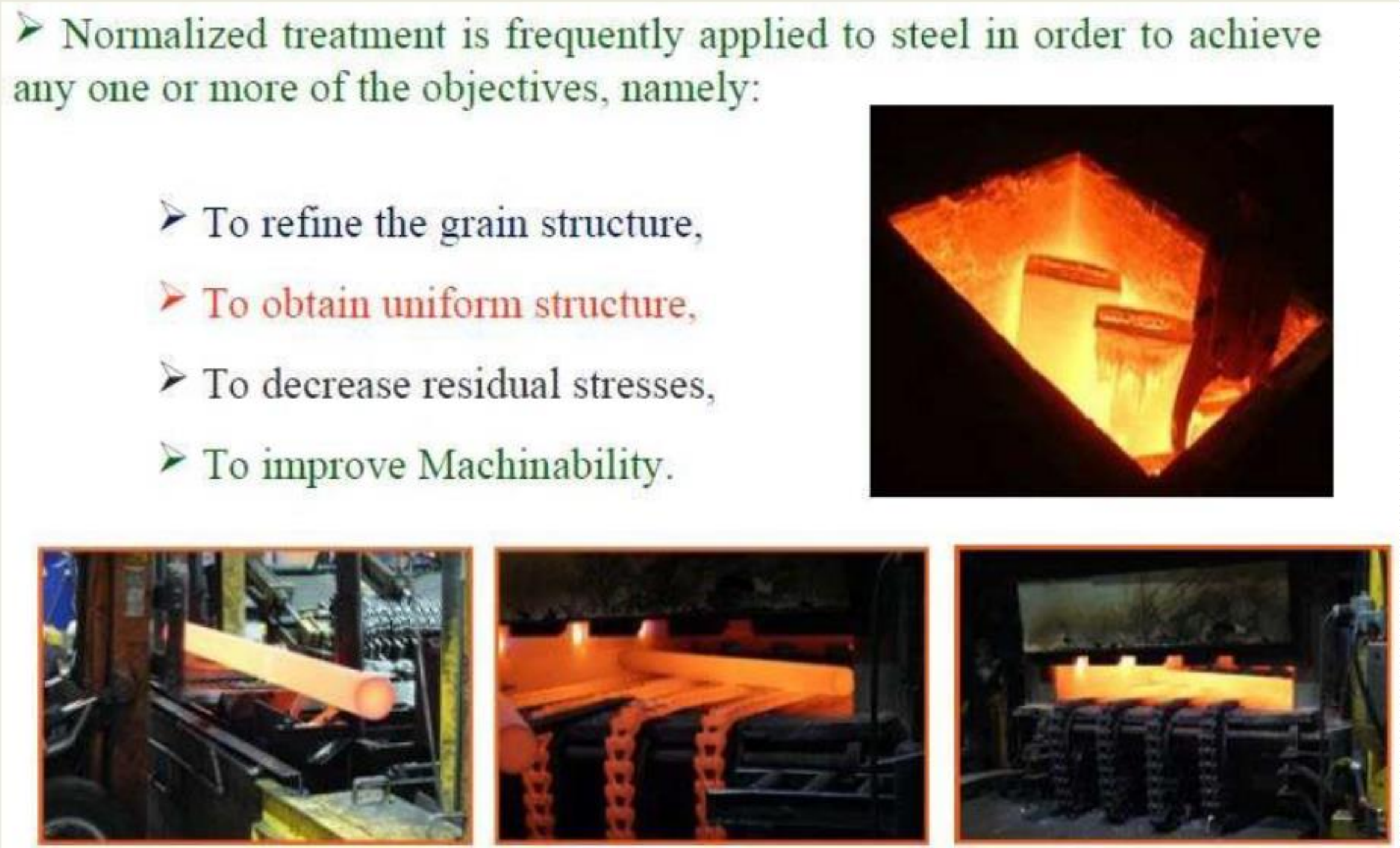
- Normalizing is the effective way to eliminate the carbide network.



- Normalized treatment is frequently applied to steel in order to achieve any one or more of the objectives, namely:

  - To refine the grain structure,
  - To obtain uniform structure,
  - To decrease residual stresses,
  - To improve Machinability.

Hardening



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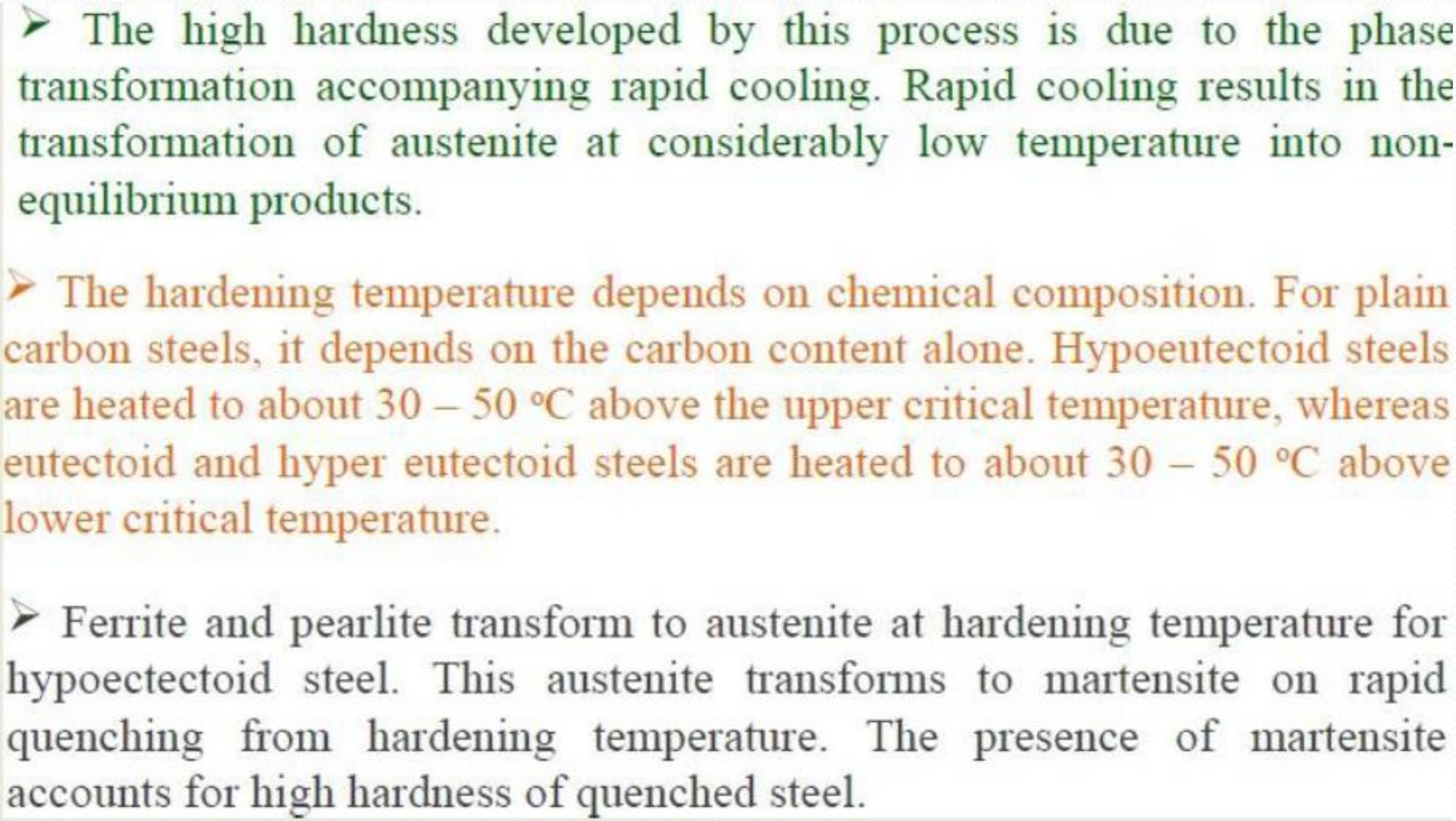
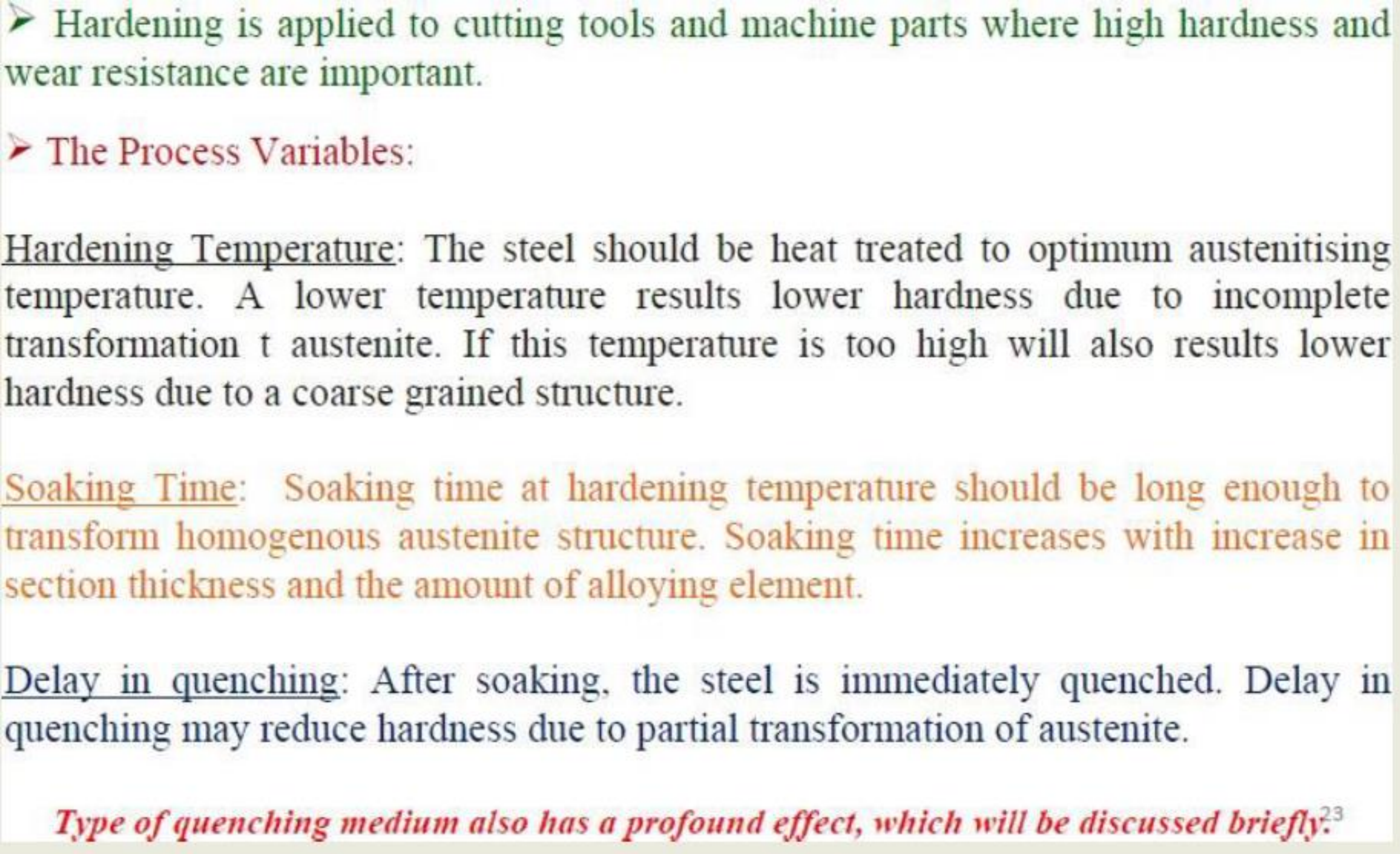


- The high hardness developed by this process is due to the phase transformation accompanying rapid cooling. Rapid cooling results in the transformation of austenite at considerably low temperature into non-equilibrium products.

- The hardening temperature depends on chemical composition. For plain carbon steels, it depends on the carbon content alone. Hypoeutectoid steels are heated to about 30 – 50 °C above the upper critical temperature, whereas eutectoid and hyper eutectoid steels are heated to about 30 – 50 °C above lower critical temperature.

- Ferrite and pearlite transform to austenite at hardening temperature for hypoectectoid steel. This austenite transforms to martensite on rapid quenching from hardening temperature. The presence of martensite accounts for high hardness of quenched steel.



- Hardening is applied to cutting tools and machine parts where high hardness and wear resistance are important.

- The Process Variables:

Hardening Temperature: The steel should be heat treated to optimum austenitising temperature. A lower temperature results lower hardness due to incomplete transformation t austenite. If this temperature is too high will also results lower hardness due to a coarse grained structure.

Soaking Time: Soaking time at hardening temperature should be long enough to transform homogenous austenite structure. Soaking time increases with increase in section thickness and the amount of alloying element.

Delay in quenching: After soaking, the steel is immediately quenched. Delay in quenching may reduce hardness due to partial transformation of austenite.

Type of quenching medium also has a profound effect, which will be discussed briefly.

- The main purpose of hardening tool steel is to develop high hardness. This enables tool steel to cut other metals. High hardness developed by this process also improves wear resistance. Gears, shafts and bearings. Tensile strength and yield strength are improved considerably y hardening structural steels.

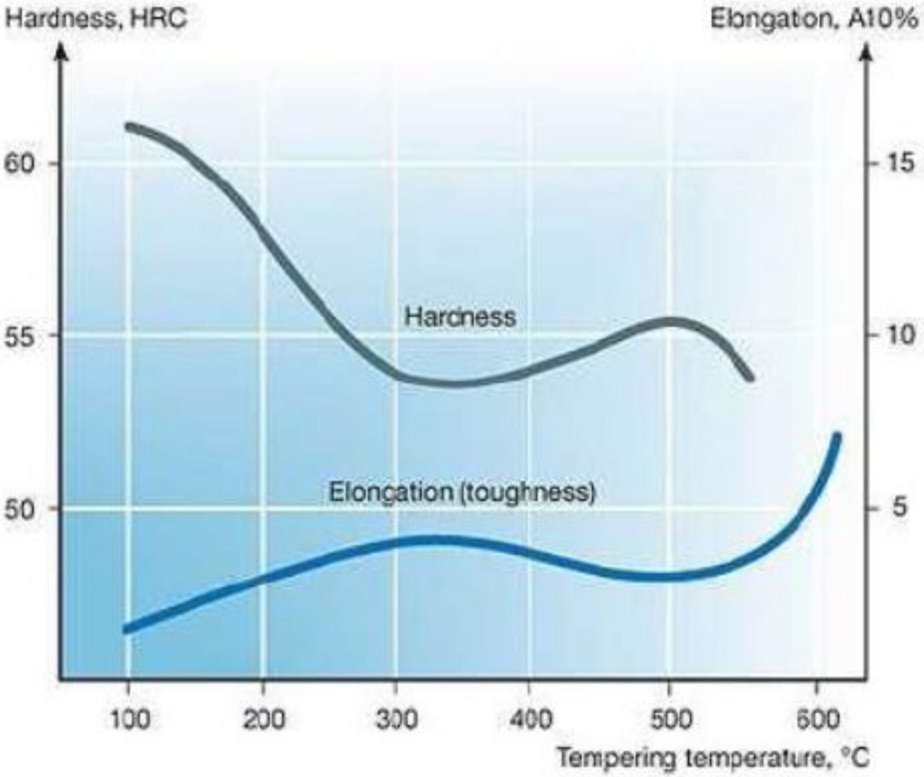
- Because of rapid cooling, high internal stresses are developed in the hardened steel. Hence these steels are generally brittle. Hardening in general is followed by another treatment known as tempering which reduces internal stresses and makes the hardened steel relatively stable.

Tempering

- Hardened steels are so brittle that even a small impact will cause fracture. Toughness of such a steel can be improved by tempering. However there is small reduction in strength and hardness.

- Tempering is a sub-critical heat treatment process used to improve the toughness of hardened steel.

- Tempering consists of reheating of hardened steel to a temperature below Lower critical temperature and is held for a period of time, and then slowly cooled in air to room temperature.

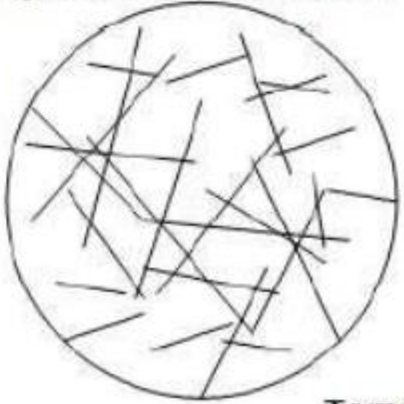


- At tempering temperature, carbon atoms diffuses out and form fine cementite and softer ferrite structure left behind. Thus the structure of tempered steel consists of ferrite and fine cementite.

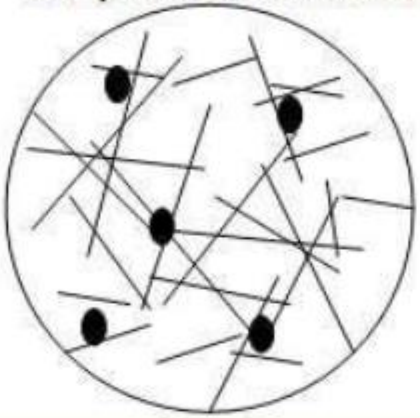
- Thus tempering allows to precipitate carbon as very fine carbide and allow the microstructure to return to BCC

- The temperatures are related to the function of the parts. Cutting tools are tempered between 230 – 300 °C. If greater ductility and toughness are desired as in case of shafts and high strength bolts, the steel is tempered in the range of 300 – 600 °C.

Toughened Microstructure



Tempered Microstructure



- Tempering temperatures are usually identified by the colour. Tempering temperatures for tools and shafts along with temper colors.

- Depending on temperatures, tempering processes can be classified as:

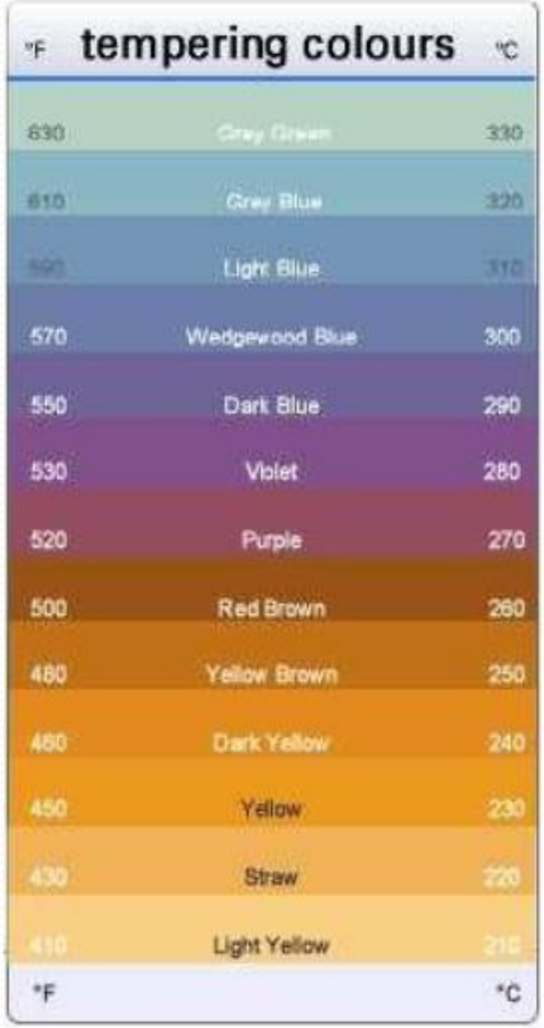
1) Low- temperature tempering (150 – 250 °C),

2) Medium – temperature tempering (350 – 450 °C),

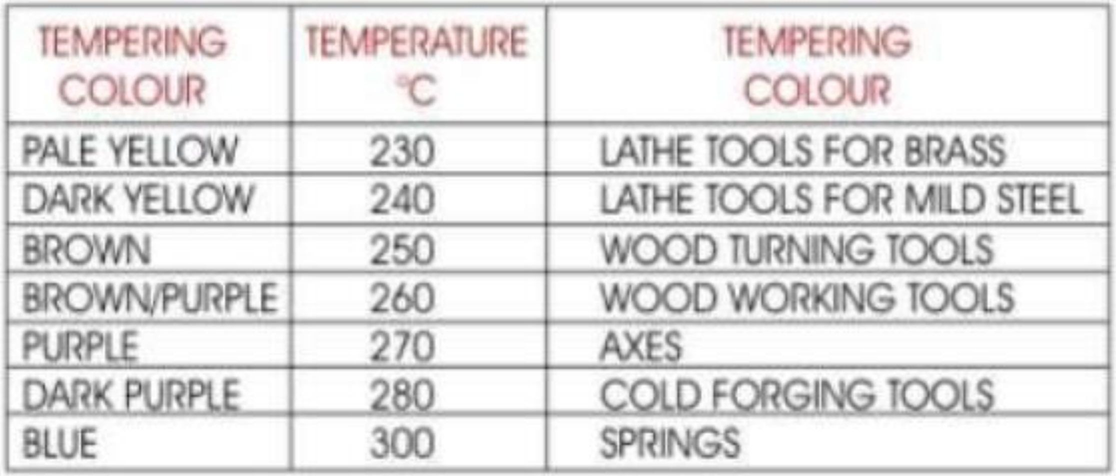
3) High – temperature tempering (500 – 650 °C).

Tempering colors of steel

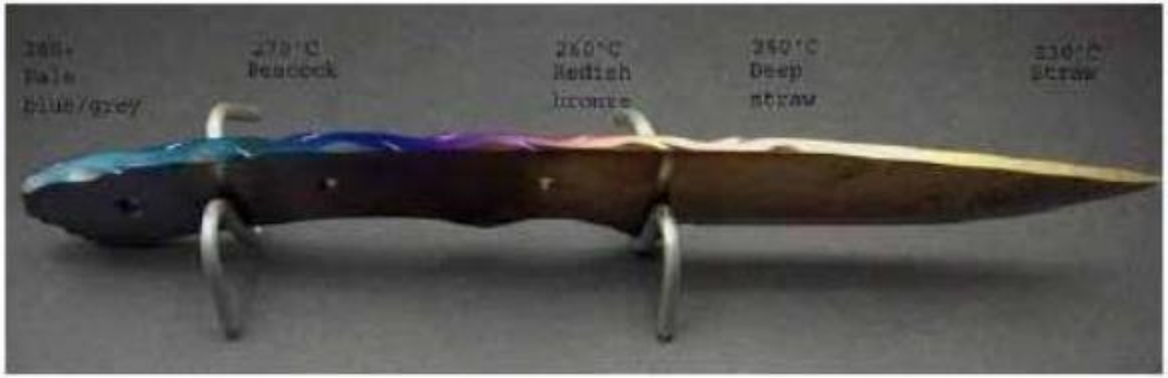
- Tempering temperatures are usually identified by the colour. Tempering temperatures for tools and shafts along with temper colors.



°F	tempering colours	°C
630	Gray Green	330
610	Gray Blue	320
590	Light Blue	310
570	Wedgewood Blue	300
550	Dark Blue	290
530	Violet	280
520	Purple	270
500	Red Brown	260
480	Yellow Brown	250
460	Dark Yellow	240
450	Yellow	230
430	Straw	220
410	Light Yellow	210
°F		°C



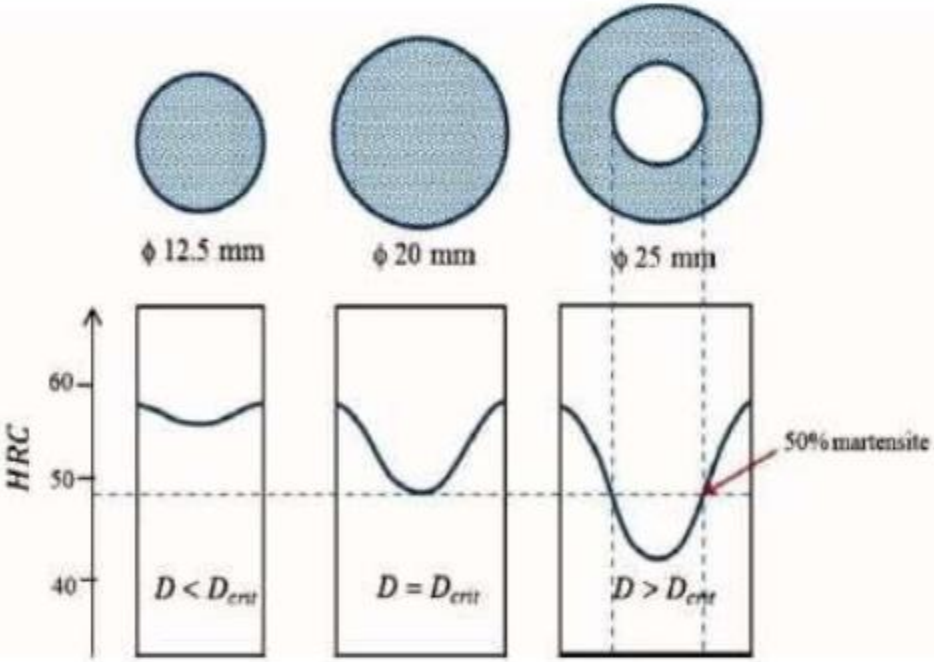
TEMPERING COLOUR	TEMPERATURE °C	TEMPERING COLOUR
PALE YELLOW	230	LATHE TOOLS FOR BRASS
DARK YELLOW	240	LATHE TOOLS FOR MILD STEEL
BROWN	250	WOOD TURNING TOOLS
BROWN/PURPLE	260	WOOD WORKING TOOLS
PURPLE	270	AXES
DARK PURPLE	280	COLD FORGING TOOLS
BLUE	300	SPRINGS



Hardenability

- The responsibility of a steel to a given hardening treatment is indicated by the property known as Hardenability.

- It is an index of the depth to which the martensite can be formed in a given steel as a result of a given hardening treatment.



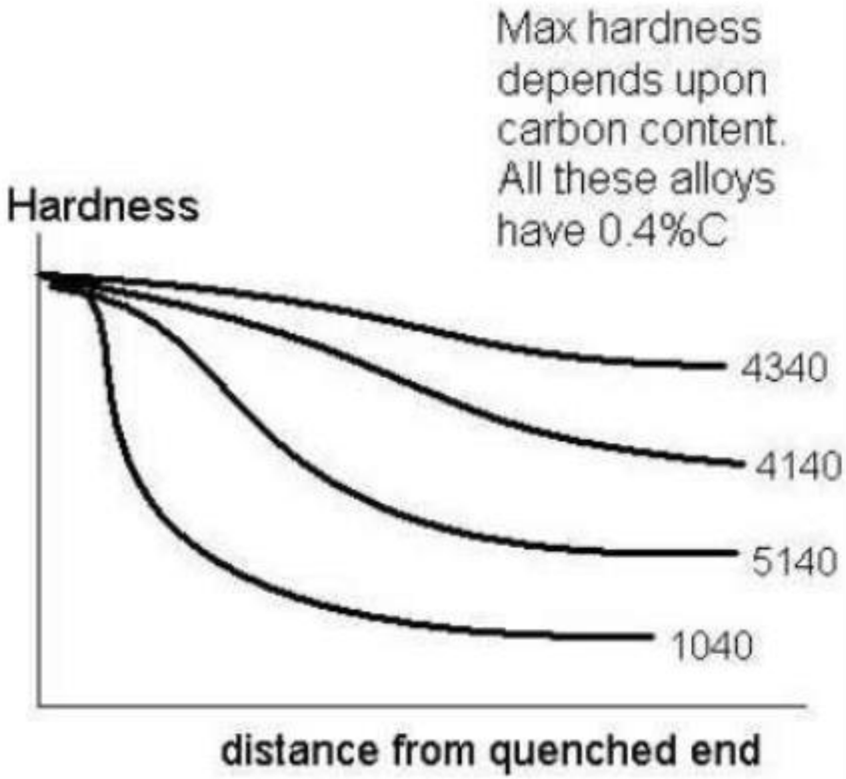
- The term Hardenability is used to measure the depth of hardness achieved i.e. martensite introduced into the steel section by quenching the steel from austenite state.

- Greater the depth of hardness below the surface, higher will be the Hardenability of steel.

- Hardenability of steel depends on composition of steel, method of quenching and section of steel.

- The addition of alloying elements in steel decreases the critical cooling rate. Thus the Hardenability of alloy steels is more than that of the carbon steels.

- While in the oil quenching, the cooling rates are lower than water quenching and thus the hardness values are lower in case of oil quenched steels.


Max hardness depends upon carbon content. All these alloys have 0.4%C

- The larger section shows lower Hardenability because of their increase mass results in a lower overall rate of cooling.

Quenching

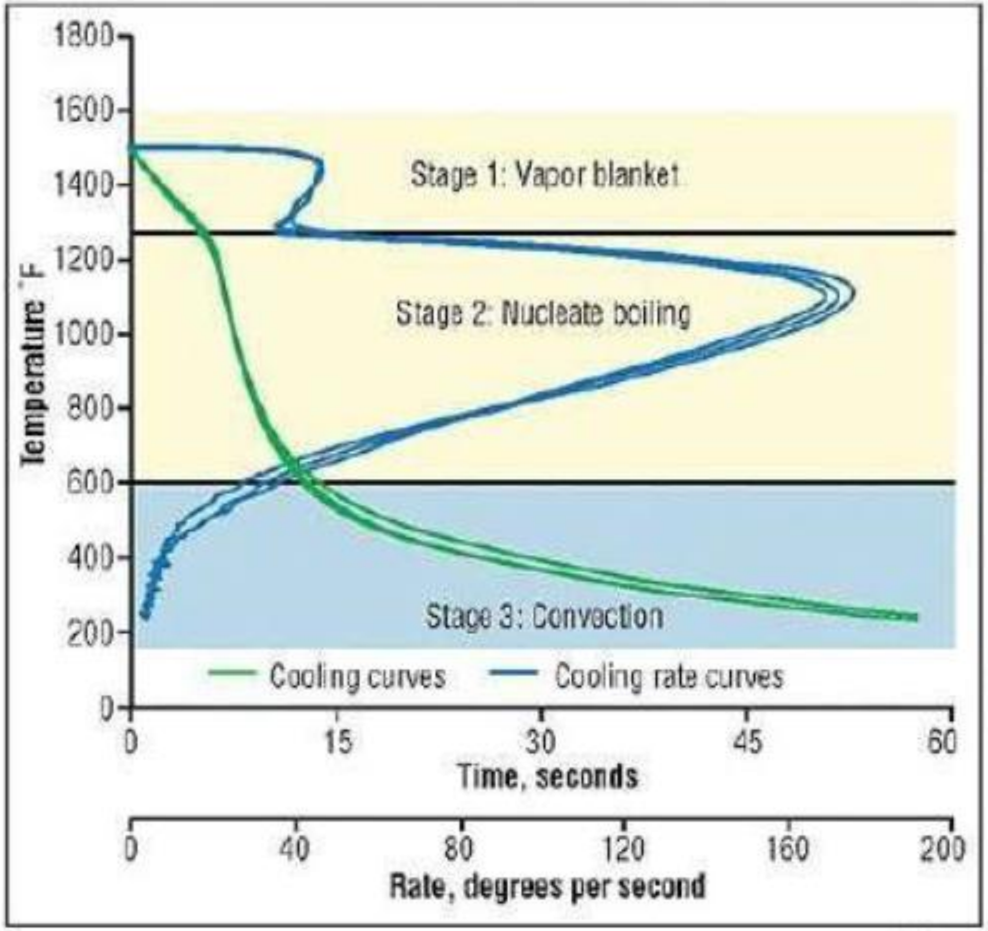
- Quenching is a process of rapid cooling of materials from high temperature to room temperature or even lower. In steels quenching results in transformation of austenite to martensite (a non-equilibrium constituent).

- During cooling, heat must be extracted at a very fast rate from the steel piece. This is possible only when a steel piece is allowed to come in contact with some medium which can absorb heat from the steel piece with in a short period.

- Under ideal conditions, all the heat absorbed by the medium should be rejected to the surroundings immediately.

➢ The removal of heat during quenching is complex in the sense that heat is removed in three stages.

1) Vapor Blanket,
2) Nucleate Boiling,
3) Convection.



Effect of Quenching Medium

- Quenching medium has the profound effect on the final phase of the material. Quenching medium is directly related to the rate of the cooling of the material.

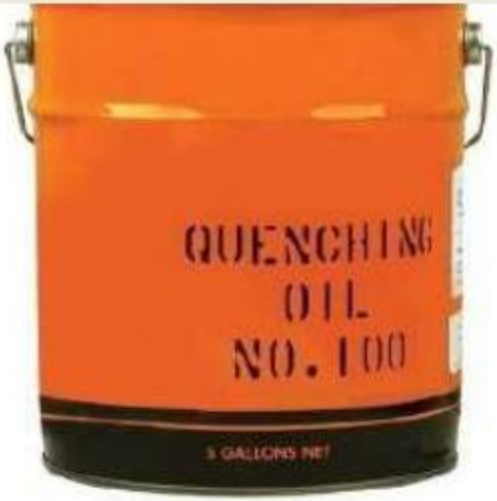
- Some of the widely employed quenching media are water, aqueous solutions, oils (mineral, vegetable and even animal oils), molten salts and air.

Effect of Quenching Medium: water

- Water has maximum cooling rate amongst all common quenchants except few aqueous solutions.
- It is very cheap and easily disposed off compared to other quenchants.
- Hence water is used for carbon steels, alloy steels and non-ferrous alloys.
- The layer if scale formed on the surface during heating is also broken by water quenching, thus eliminating an additional process of surface cooling.

Effect of Quenching Medium: oil

- Most of the Oils used as quenchants are mineral oils. These are in general paraffin based and do not possess any fatty oils.
- Quenching in oil provides slower cooling rates as compared to those achieved by water quenching.
- The slower cooling rate reduces the possibility of hardening defects.
- The temperature difference between core and the case of work piece is less for oil quenching than for water quenching.



Effect of Quenching Medium: Air

- Many alloy steels are capable of getting hardened by cooling either in still air or in a blast of air.

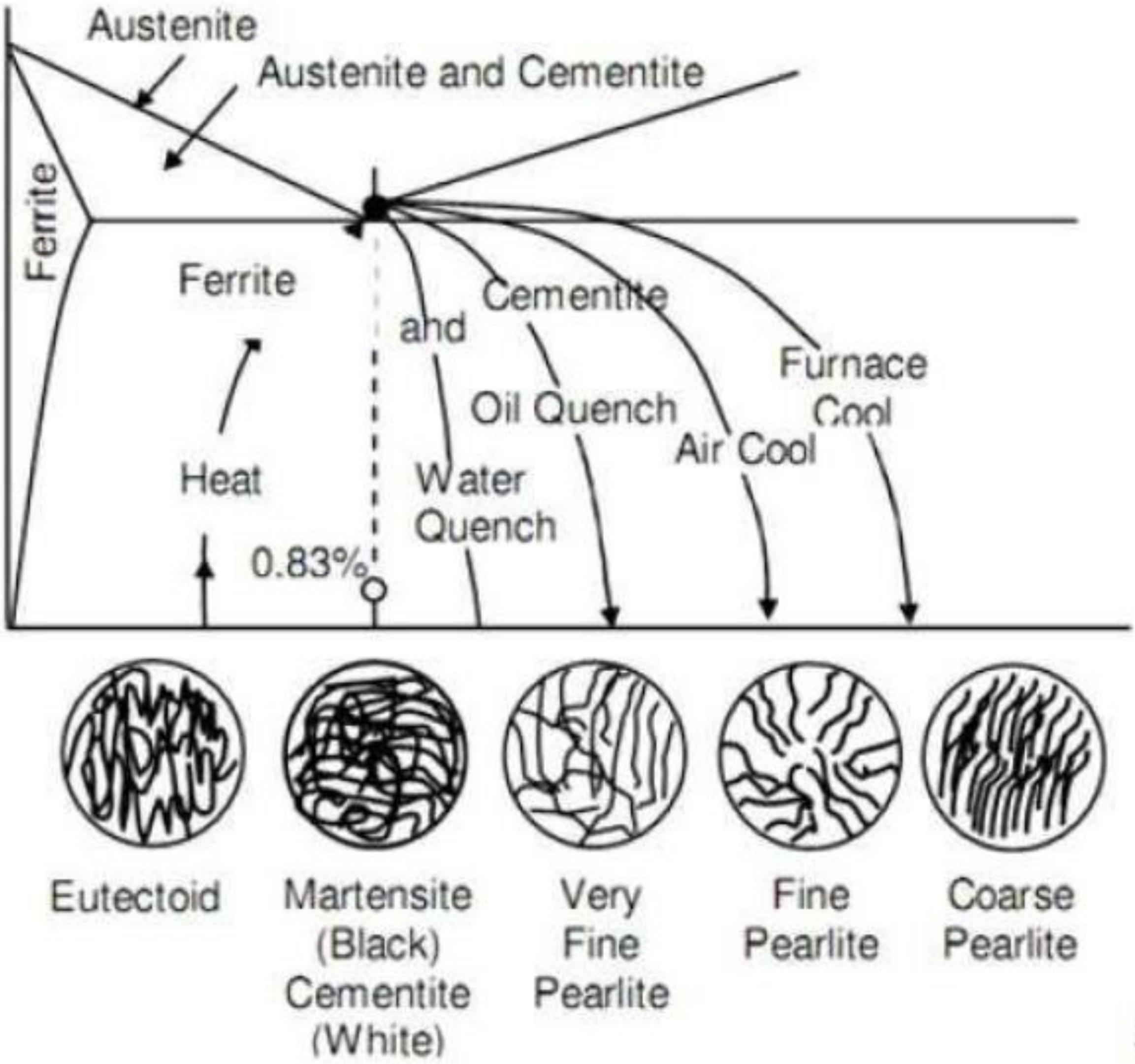
- Such steels are popularly known as air hardening steels.

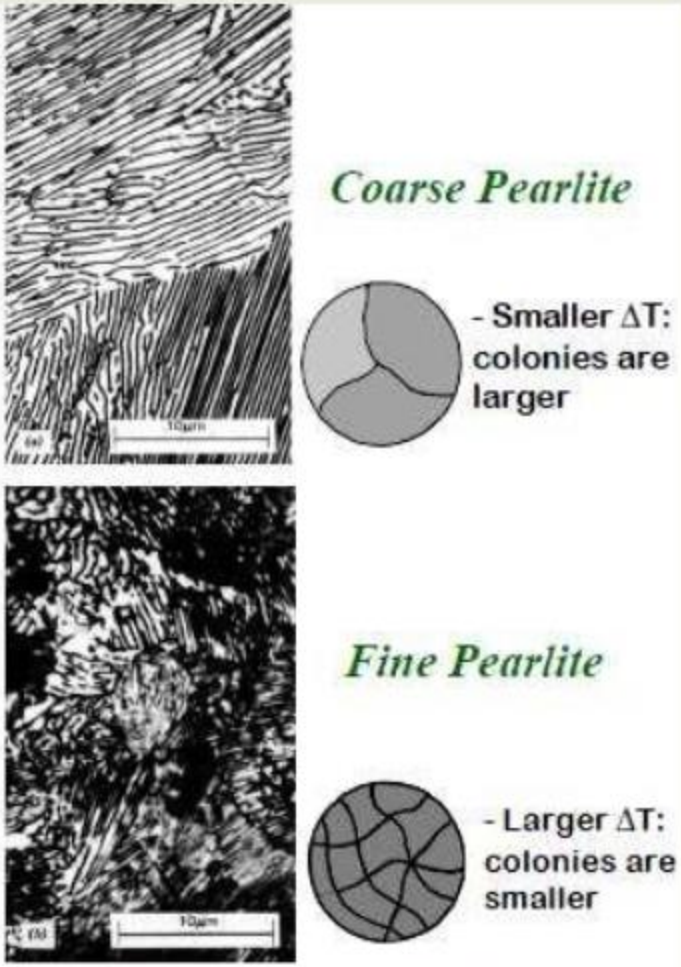
- These steels are almost free from distortion problem. However, the problem of oxidation during cooling (quenching) may be encountered in practice. Many grades of tool steels are subjected to air hardening.

- Cooling rates can be improved by mixing air and water.

- Just the drastic water quench generates a fully martensite structure.
- Although quenched in oil the austensite converts into suitably fine pearlite.
- Accurate pearlite also results if the austenised eutectoid steel is air-cooled.
- Though, if allowed to cool in furnace coarse pearlite is appearance.

Cooling Media	Structure	UTS (N/mm^2)	Y. S. (N/mm^2)	Hardness (Rc)	Elongation % (50 mm g. L)
Water	Martensite	1700	-	65	Low
Oil	Troostite	1100	550	35	5
Air	Fine pearlite	850	270	25	8
Furnace	Coarse pearlite	520	140	15	12





Coarse Pearlite

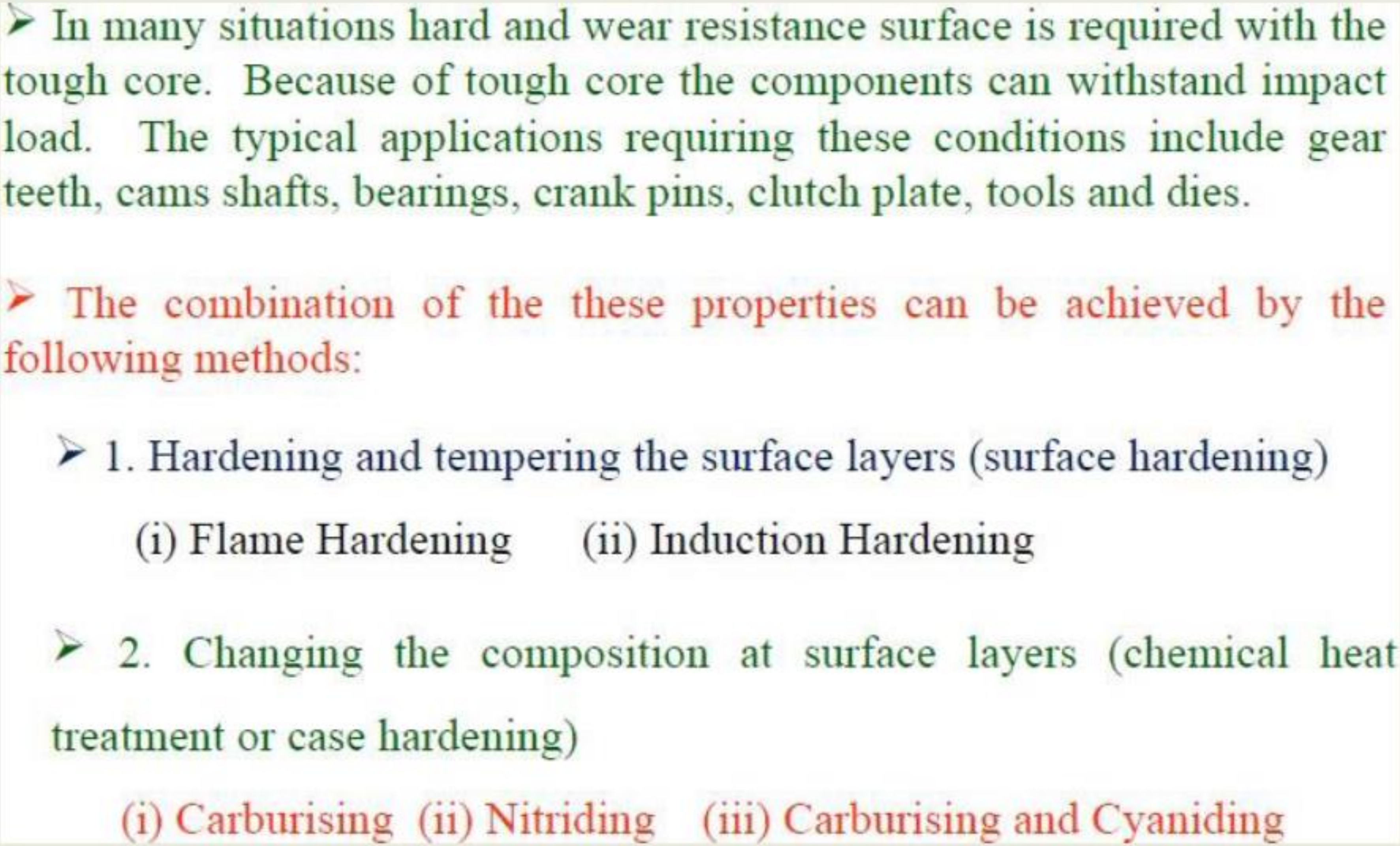
- Smaller ΔT: colonies are larger

Fine Pearlite

- Larger ΔT: colonies are smaller

Figure: Microstructure resulting from Different Cooling Rates Applied to Austenitized Samples of Eutectoid Steel

Surface Hardening



- In many situations hard and wear resistance surface is required with the tough core. Because of tough core the components can withstand impact load. The typical applications requiring these conditions include gear teeth, cams shafts, bearings, crank pins, clutch plate, tools and dies.

- The combination of the these properties can be achieved by the following methods:

  - 1. Hardening and tempering the surface layers (surface hardening)

    (i) Flame Hardening (ii) Induction Hardening

  - 2. Changing the composition at surface layers (chemical heat treatment or case hardening)

    (i) Carburising (ii) Nitriding (iii) Carburising and Cyaniding

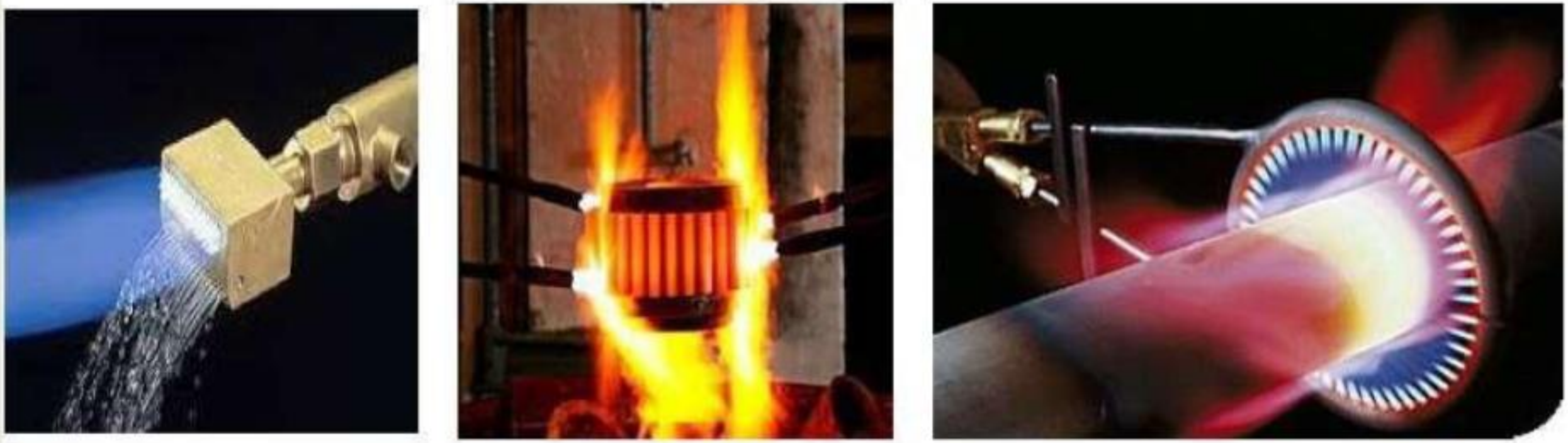
Surface Hardening: Flame Hardening

- The flame hardening involves heating the surface of a steel to a temperature above upper critical point (850 °C) with a oxyacetylene flame and then immediately quenched the surface with cold water.

- Heating transforms the structure of surface layers to austenite, and the quenching changes it to martensite.

- The surface layers are hardened to about 50 – 60 HRC. It is less expensive and can be easily adopted for large and complex shapes.

- Flame hardened parts must be tempered after hardening. The tempering temperature depends on the alloy composition and desired hardness.



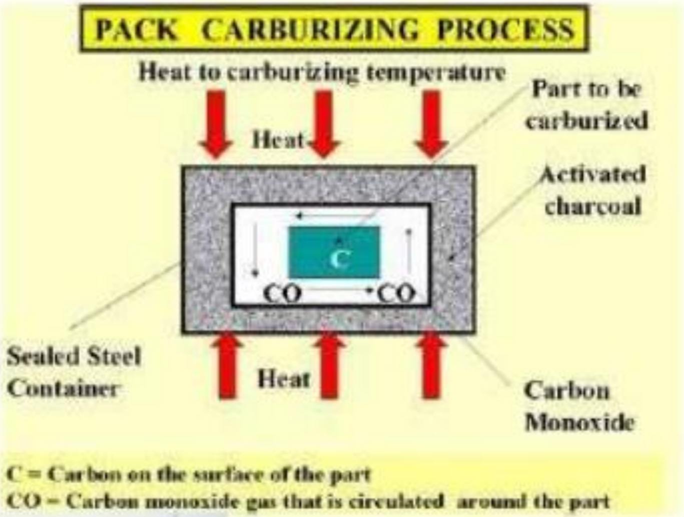
- The flame hardening methods are suitable for the steels with carbon contents ranging from 0.40 to 0.95% and low alloy steels.

Surface Hardening: Carburising

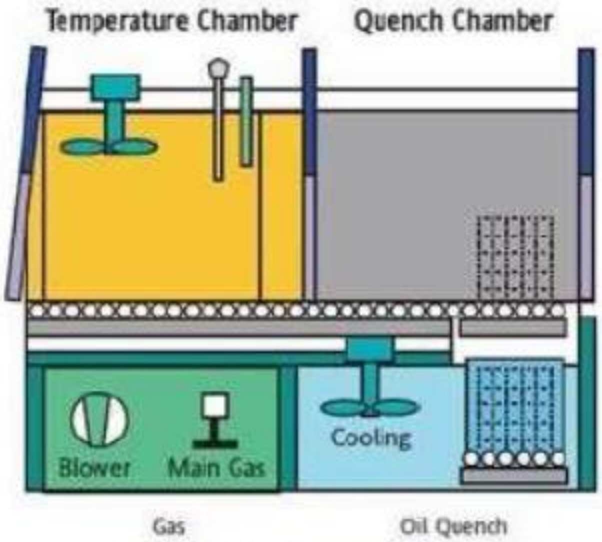
- Carburising is carried out on a steels containing carbon less than 0.2%. It involves increasing the carbon contents on the surface layers upto 0.7 to 0.8%.
- In this process, the steel is heated in contact with carbonaceous material from which it absorbs carbon. This method is mostly used for securing hard and wear resistance surface with tough core carburising is used for gears, cams, bearings and clutch plates.

$$2\,CO \rightarrow C + CO_2$$

- The Following methods are used to diffuse carbon into surface layers:
  1) Pack (solid) Carburising,
  2) Gas Carburising,
  3) Liquid Carburising.



C = Carbon on the surface of the part
CO = Carbon monoxide gas that is circulated around the part



Gas Carburising

Liquid Carburising

Unit-6

Plastics

Plastics or polymer

- **Definition:** A group of engineered materials characterized by large molecules that are built up by the joining of smaller molecules.
- They are natural or synthetics resins.

Properties of plastics

- Light weight
- Good resistance to corrosion
- Easy of fabrication into complex shapes
- Low electrical and thermal conductivity
- Good surface finish
- Good optical properties
- Good resistance to shock and vibration.

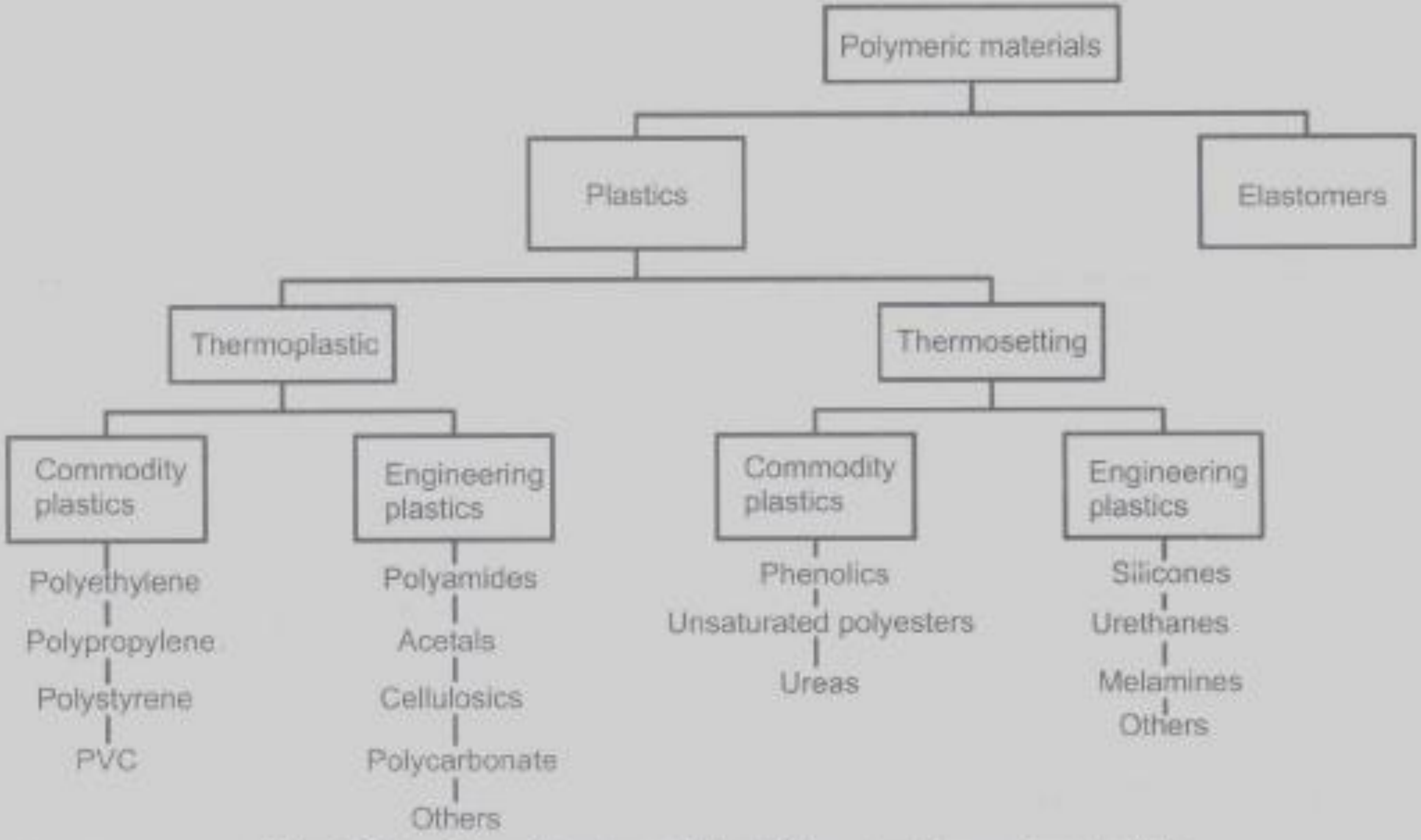


Fig. 12.1 *Classification of the different polymeric materials*

Classification – Polymers

- Classification based on their industrial usage:
  (a) plastics and
  (b) elastomers.
- Classification based on their temperature dependence:
  (a) thermoplasts and
  (b) thermosets

Thermoplasts

- Plastics which softens up on heating and hardens up on cooling where the softening and hardening are totally reversible processes.
- Hence thermoplasts can be recycled.
- They consist of linear molecular chains bonded together by weak secondary bonds or by inter-winding.
- Cross-linking between molecular chains is absent in theromplasts.
- E.g.: Acrylics, PVC, Nylons, Perspex glass, etc.

Thermoplastics

- **Acrylonitrile-butadiene-styrene (ABS):**

  Characteristics: Outstanding strength and toughness, resistance to heat distortion; good electrical properties; flammable and soluble in some organic solvents.

  Application: Refrigerator lining, lawn and garden equipment, toys, highway safety devices.

- **Acrylics (poly-methyl-methacrylate) PMMA**

  Characteristics: Outstanding light transmission and resistance to weathering; only fair mechanical properties.

  Application: Lenses, transparent aircraft enclosures, drafting equipment, outdoor signs.

Contd…

- **Fluorocarbons (PTFE or TFE,Teflon)**

  Characteristics: Chemically inert in almost all environments, excellent electrical properties; low coefficient of friction; may be used to 2600°C; relatively weak and poor cold-flow properties.

  Application: Anticorrosive seals, chemical pipes and valves, bearings, anti adhesive coatings, high temperature electronic parts.

- **Polyamides (nylons)**

  Characteristics: Good mechanical strength, abrasion resistance, and toughness; low coefficient of friction; absorbs water and some other liquids.

  Application: Bearings, gears, cams, bushings, handles, and jacketing for wires and cables.

Contd…

- **Polycarbonates**

  Characteristics: Dimensionally stable: low water absorption; transparent; very good impact resistance and ductility.

  Application: Safety helmets, lenses light globes, base for photographic film

- **Polyethylene**

  Characteristics: Chemically resistant and electrically insulating; tough and relatively low coefficient of friction; low strength and poor resistance to weathering.

  Application: Flexible bottles, toys, tumblers, battery parts, ice trays, film wrapping materials.

Contd…

- **Polypropylene**

  Characteristics: Resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light.

  Application: Sterilizable bottles, packaging film, TV cabinets, luggage

- **Polystyrene**

  Characteristics: Excellent electrical properties and optical clarity; good thermal and dimensional stability; relatively inexpensive

  Application: Wall tile, battery cases, toys, indoor lighting panels, appliance housings.

Contd...

Thermosets

- Plastics which are ‘set’ under the application of heat and/or pressure.
- This process is not reversible, hence thermosets can not be recycled.
- They consist of 3-D network structures based on strong covalent bonds to form rigid solids. linear molecular chains bonded together by weak secondary bonds or by interwinding.
- Characterized by high modulus / rigidity /dimensional stability when compared with thermoplasts.
- E.g.: Epoxies, Amino resins, some polyester resins, etc.

Contd…

- Thermosets are strengthened by reinforcements .
- Different reinforcements are in use according to the necessity. Glass fibers are most commonly used to form structural and molding plastic compounds.
- Two most important types of glass fibers are E (electrical)- and S (high strength)- glasses.
- E-glass (lime-aluminium-borosilicate glass with zero or low sodium and potassium levels) is often used for continuous fibers.
- S-glass (65%SiO_2, 25%Al_2O_3 and 10% MgO) has higher strength-to-weight ratio and is more expansive thus primary applications include military and aerospace applications.
- Carbon fiber reinforced plastics are also often used in aerospace applications. However they are very expansive.

Contd...

- The other classes of reinforcements include **aramid** (aromatic polyamide) fibers.
- They are popularly known as **Kevlar.**

Examples – Thermo setting polymers

- **Epoxies**

  Characteristics: Excellent combination of mechanical properties and corrosion resistance; dimensionally stable; good adhesion; relatively inexpensive; good electrical properties.

  Application: Electrical moldings, sinks, adhesives, protective coatings, used with fiberglass laminates.

- **Phenolics**

  Characteristics: Excellent thermal stability to over 1500 C; may be compounded with a large number of resins, fillers, etc.; inexpensive.

  Application: Motor housing, telephones, auto distributors, electrical fixtures.

Contd…

- **Polyester (PET or PETE)**

  Characteristics: One of the toughest of plastic films; excellent fatigue and tear strength, and resistance to humidity acids, greases, oils and solvents

  Application: Magnetic recording tapes, clothing, automotive tire cords, beverage containers.

Elastomers

- These polymers are known for their high elongations, which are reversible upon release of applied loads.
- They consist of coil-like molecular chains, which straightens up on application of load.
- Characterized by low modulus / rigidity / strength, but high toughness.
- E.g.: natural and synthetic rubber.

Polymer synthesis

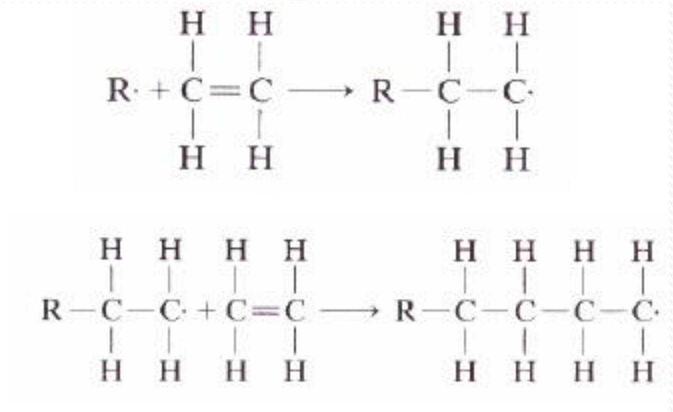
- Processing of polymers primarily limits to synthesis followed by forming.
- Polymers are synthesized by process known as polymerization.
- Polymerization is process in which multi-functional monomers are attached to form linear/3-D macro molecular chains.

Addition Polymerization

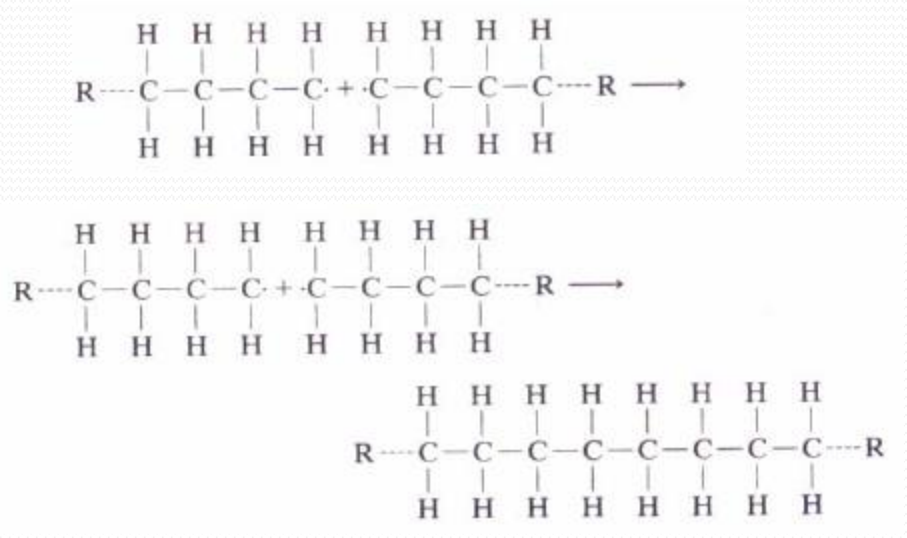
- This polymerization process involves single kind of monomers. Resultant macro-molecule's composition is an exact multiplication of composition of individual monomer.
- Process involves three stages namely initiation, propagation and termination.
- Initiation process will be started by an initiator (e.g. benzoyl peroxide) which forms an reactive site where carbon atom of another monomer is attracted, upon which reaction site transfers to different place leading to molecular chain growth.
- As molecular chain grows longer, reaction rate decreases. However the growth process is terminated either by the combination *or disproportionation* process.

Addition Polymerization

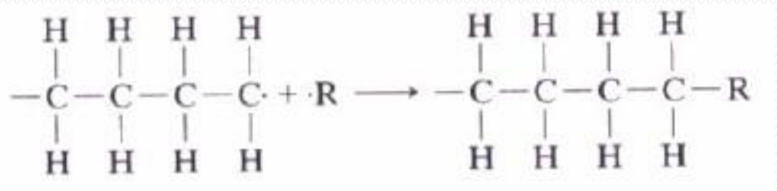
E.g., polyethylene



Combination:



Disproportionation:

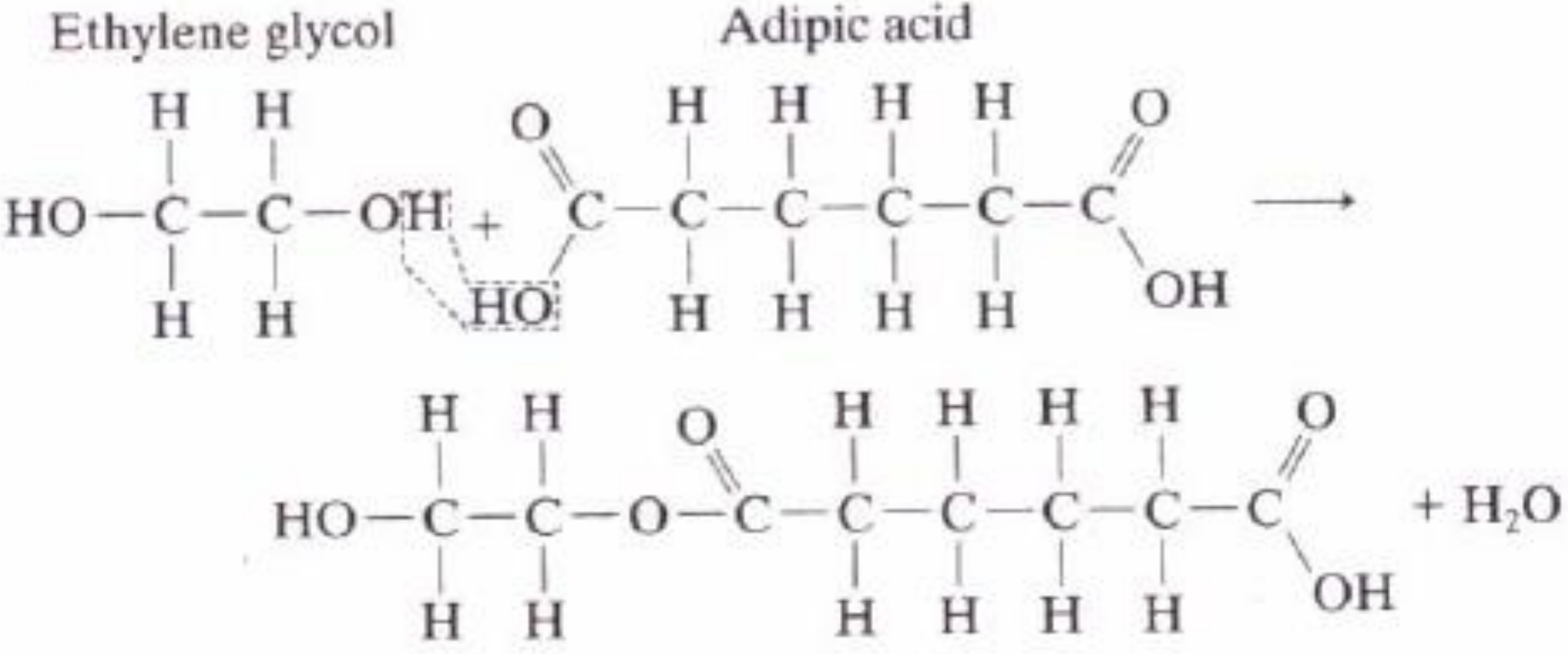


Condensation Polymerization

- It involves more then one monomer species. This process is also known as step growth polymerization.
- In condensation polymerization, smaller macromolecule by-product such as water is eliminated.
- No resultant product has the chemical formula of mere one monomer.
- Repeat unit in condensation process itself is product of polymerization involving basic constituents.
- Reaction times for condensation polymerization is usually longer than those for additional polymerization.

Condensation Polymerization

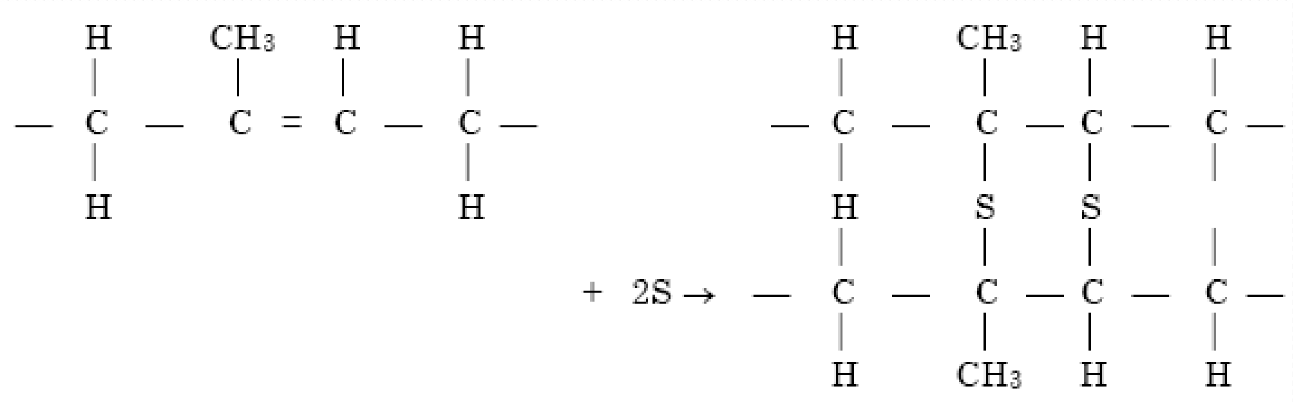
- Formation of a polyester from Ethylene glycol and Adipic acid



- Polyesters, phenol-formaldehyde, nylons, polycarbonates etc are produced by condensation polymerization.
- Condensation polymerization reactions also occur in sol-gel processing of ceramic materials.
- Polymers, unlike organic/inorganic compounds, do not have a fixed molecular weight. It is specified in terms of **degree of polymerization** – number of repeat units in the chain or ratio of average molecular weight of polymer to molecular weight of repeat unit.

Contd…

- **Cross linking:** The cross-linking can occur due to the presence of some elements called vulcanizing agents, e.g. S, Se, Te, and O_2.
- In case of poly isoprene (natural rubber), the sulphur bridges are formed between two macromolecules during vulcanization.
- In this vulcanization process sulphur bridge are formed at the point of opening of double bonds. If the number of cross-links is small; the find product is soft and flexible. The stiffness of the polymeric material increases with the density of cross-lines. When the sulphur content in rubber is as high as 32 weight percent, the hard product is called **ebonite**.



$$\begin{array}{ccccccccc} & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & \\ & | & & | & & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & = & \mathrm{C} & - & \mathrm{C} & - \\ & | & & & & & & | & \\ & \mathrm{H} & & & & & & \mathrm{H} & \end{array} \quad + \; 2\mathrm{S} \rightarrow \quad \begin{array}{ccccccccc} & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & \\ & | & & | & & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - \\ & | & & | & & | & & | & \\ & \mathrm{H} & & \mathrm{S} & & \mathrm{S} & & & \\ & | & & | & & | & & | & \\ - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - \\ & | & & | & & | & & | & \\ & \mathrm{H} & & \mathrm{CH_3} & & \mathrm{H} & & \mathrm{H} & \end{array}$$

Additives to Polymers

- The properties of polymers can be further modified by the addition of agents which are basically of two types.
- Those that enter the molecular structure are usually called "additives", whereas those that form a clearly defined second phase are called "fillers".

Contd...

1. Plasticizers

- Plasticizers are liquids of high boiling point and low molecular weight, which are added to improve the plastic behaviour of the polymer.
- They are essentially oily in nature. Organic solvents, resins and even water are used as plasticizers.

2. Fillers

- A filler is used to economize on the quantity of polymer required and/or to vary the properties to some extent, for example, mechanical strength, electrical resistance etc.
- A filler, whose function is to increase mechanical strength, is termed a "reinforcing filler".
- A filler is commonly fibrous in nature and is chemically inert with respect to the polymer with which it is to be used.
- Common fillers are wood flour, cellulose, cotton flock, and paper (for improving mechanical strength); mica and asbestos (for heat resistance); talc (for acid resistance).Other filler materials are : fabric, chipped-wood moulding compound, wood veneer, textile or glass fibres.
- The commonly used "reinforcing filler agents" with plastics are : fibres/filaments of glass, graphite or boron.

3. Catalysts:

- These are usually added to promote faster and more complete polymerization and as such they are also called 'accelerators' and 'hardeners' e.g., ester is used as a catalyst for Urea Formaldehyde.

4. Initiators:

- As the name indicates, the initiators are used to initiate the reaction, that is, to allow polymerization to begin. They stabilize the ends of the reaction sites of the molecular chains. H_2O_2 is a common initiator.

5. Dyes and Pigments:

- These are added, in many cases, to impart a desired colour to the material.

6. Lubricants:

- Lubricants are added to the polymers for the following purposes : to reduce friction during processing, to prevent parts from sticking to mould walls, to prevent polymer films from sticking to each other and to impart an elegant finish to the final product. Commonly used lubricants include : oils, soaps and waxes.

7. Flame retardants:

- Most plastics will ignite at sufficiently high temperatures. The non-inflammability of the plastics can be enhanced either by producing them from less inflammable raw materials or by adding "flame retardants". The common flame retardants are : compounds of chlorine, bromine and phosphorous.

8. Solvents:

- Solvents are useful for dissolving certain fillers or plasticizers and help in manufacturing by allowing processing in the fluid state, For example, alcohol is added in cellulose nitrate plastics to dissolve Camphor. However, subsequently, the solvents must be removed by evaporation.

9. **Stabilisers and anti-oxidants** are added to retard the degradation of polymers due to heat, light and oxidation.

10. **Elastomers** are added to plastics to enhance their elastic properties.

Note: Above, excepting fillers, all other materials used, fall under the category of "Additives“.

Plastic Process

- The common forms of raw materials for processing plastics into products are :- pellets, granules, powders, sheet, plate, rod and tubing.
- Liquid plastics are used especially in the fabrication of reinforced - plastic parts.
- Thermoplastics can be processed to their final shape by moulding and extrusion processes.
- However, extruding is often used as an intermediate process to be followed by other processes, for example, vacuum forming or machining.

Injection Moulding

- The polymer is melted and than forced into a mould.
- Thermoplastic pellets melted and melt injected under high pressure (70 MPa) into a mold. Molten plastic takes the shape of the mold, cools, solidifies, shrinks and is ejected.
- Molds usually made in two parts (internal and external part).
- Use of injection molding machine mainly used for thermoplastics (gears, cams, pistons, rollers, valves, fan blades, rotors, washing machine agitators, knobs, handles, camera cases, battery cases, sports helmets etc…)

Contd…

– thermoplastic & some thermosets

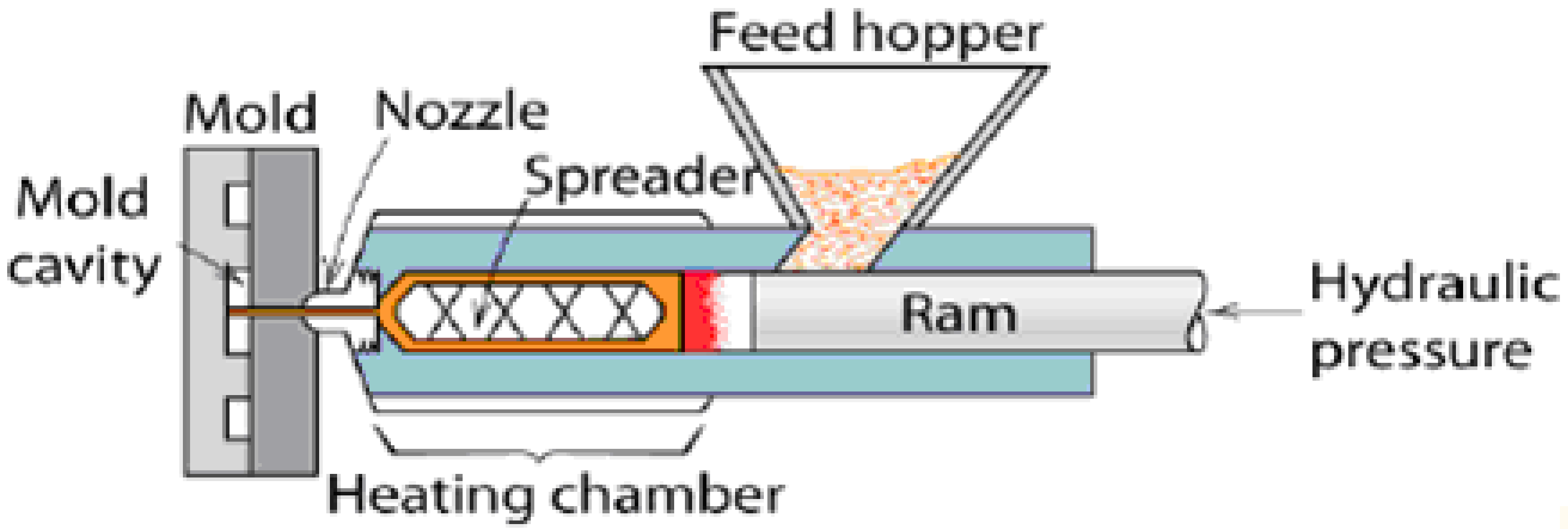


Fig. Injection moulding

Extrusion

- Long plastic products with uniform cross sections are readily produced by the extrusion process.
- Thermoplastic pellets & powders are fed through a hopper into the barrel chamber of a screw extruder. A rotating screw propels the material through a preheating section, where it is heated, homogenized, and compressed, and then forces it through a heated die and onto a conveyor belt.
- As the plastic passes onto the belt, it is cooled by jets of air or sprays of water which harden it sufficiently to preserve its newly imparted shape.
- It continues to cool as it passes along the belt and is then either cut into lengths or coiled.

Contd…

- The process is continuous and provides a cheap and rapid method of moulding.
- Common production shapes include a wide variety of solid forms, as well as tubes, pipes, and even coated wires and cables.

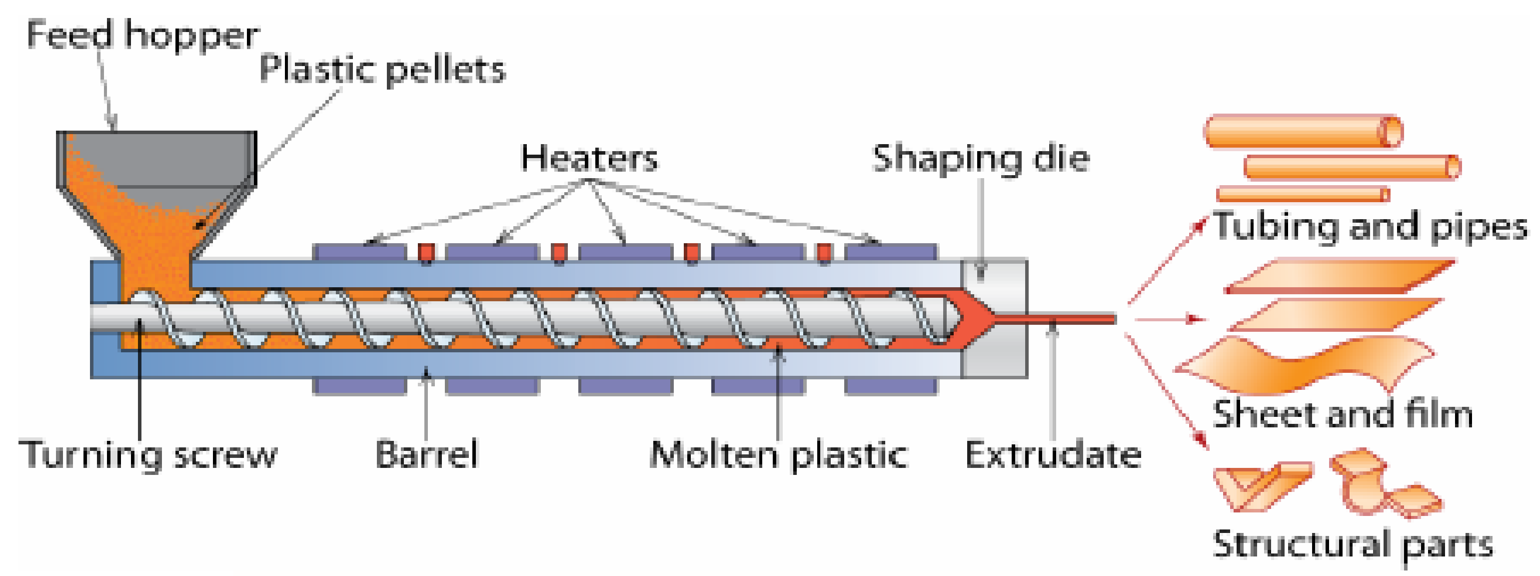


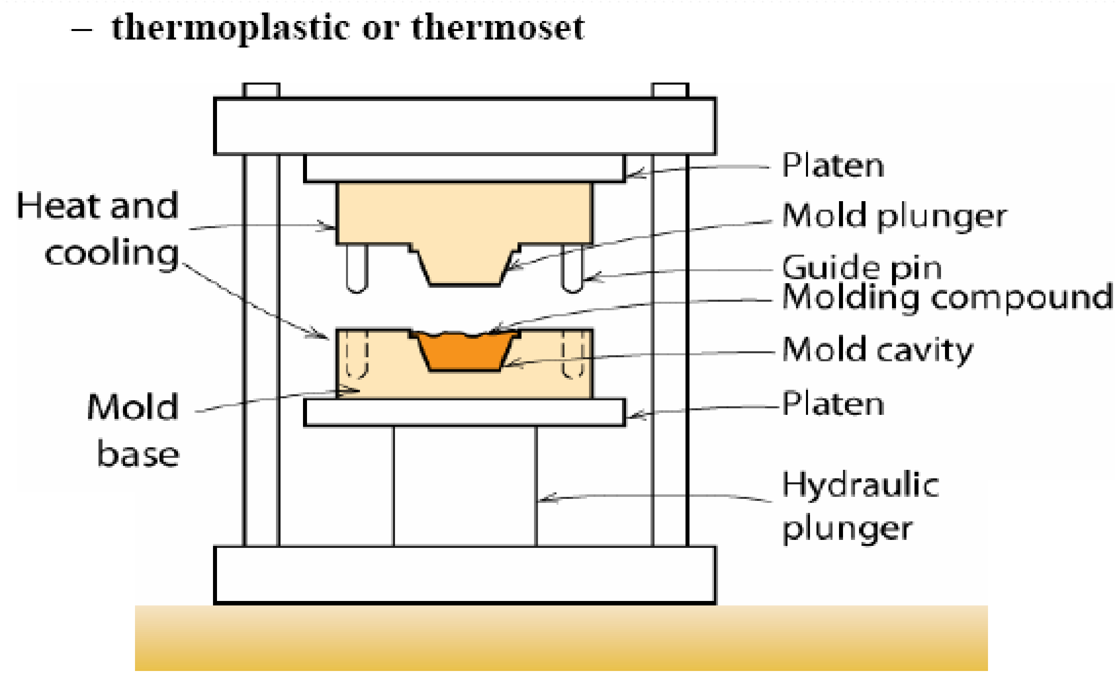
Fig. Extrusion

Compression moulding

- A compression mould is made of two halves with one each being connected to the platens of the press.
- The mould is electrically heated to maintain the required temperature.
- Material is placed in the mould, and it is closed with a hydraulic cylinder, or toggle clamp.
- The pressure maintained on the material is of the order of 14 to 40 MPa of moulding area.
- As the material comes in contact with the heated mould surface, it softens and fills the entire cavity and at the same time initiates the chemical reaction which cures the part.

Contd…

- Cure time is determined by the thickest cross section, mould temperature, material type and grade.
- After curing, the mould opens and the part is ejected.
- The most widely used plastic is phenol- formaldehyde, commonly known as 'Bakelite'.



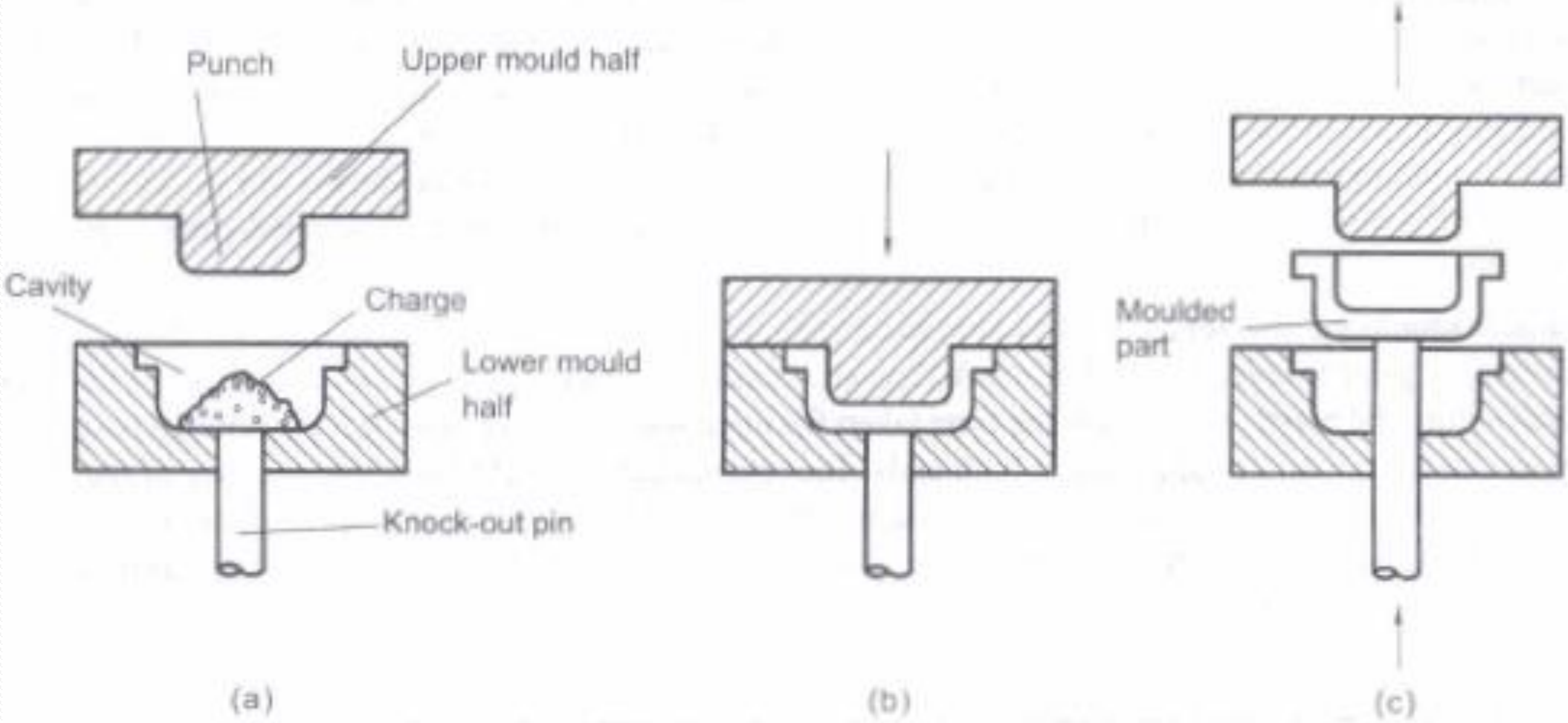


Fig. 12.20 *Steps in compression moulding for thermosetting materials*

Transfer Moulding

- Transfer moulding is very similar to compression moulding and is developed to avoid the disadvantages found in that process.
- In this method, thermosetting charge is heated and compressed in a separate chamber and then injected into the closed mould where it is allowed to cool and solidify.
- Transfer moulding is capable of moulding part shapes that are more intricate than compression moulding but not as intricate as injection moulding.

Contd...

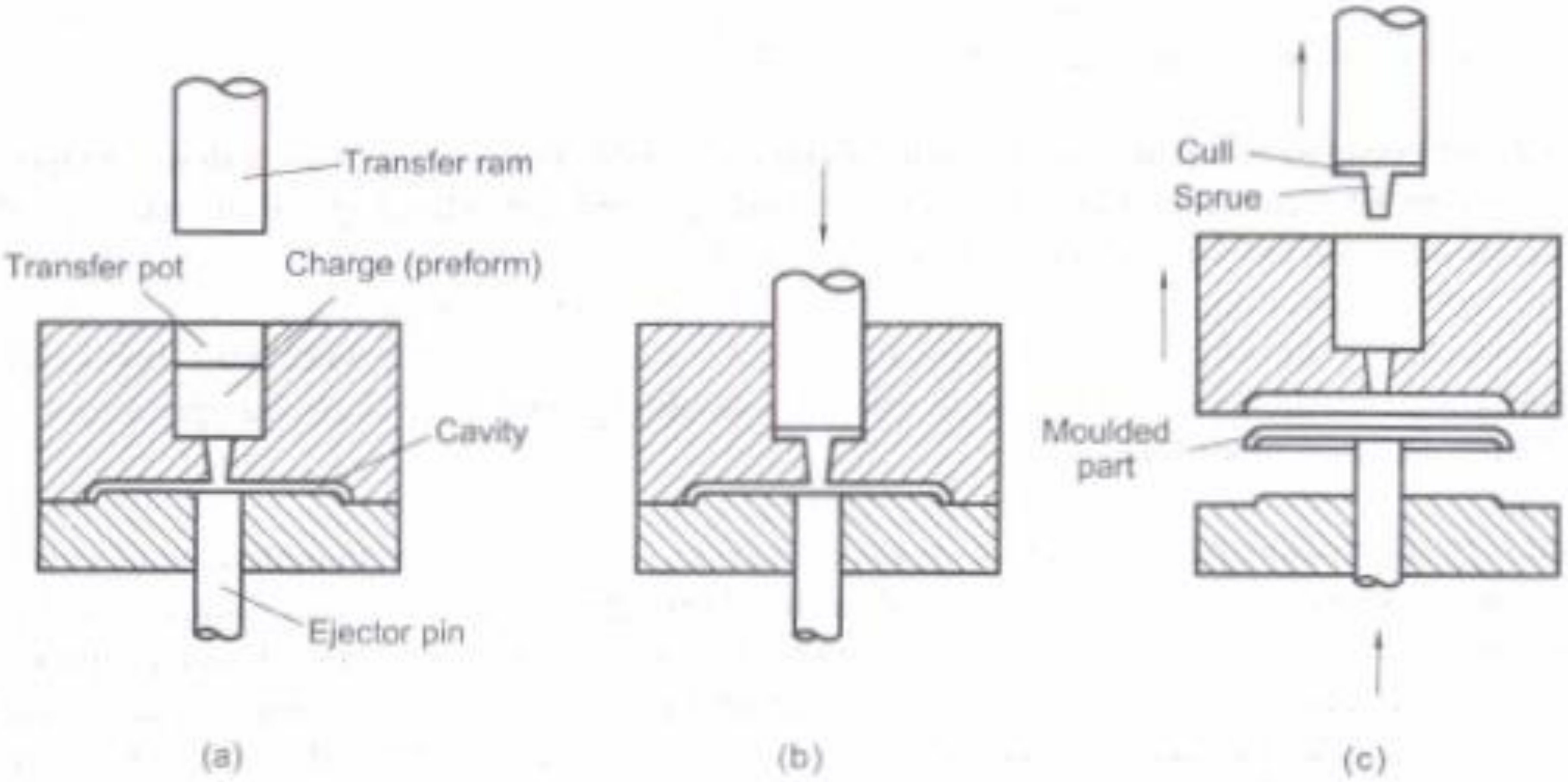


Fig. 12.21 *Steps in transfer moulding for thermosetting materials*

Blow moulding

- Blow moulding is the process of inflating a hot, hollow, thermoplastic preform or parison inside a closed mould so that its shape conforms to that of the mould cavity.
- Typical parts made are bottles, toys, air ducts of automobiles, chemical and gasoline tanks, and a number of housholds goods.

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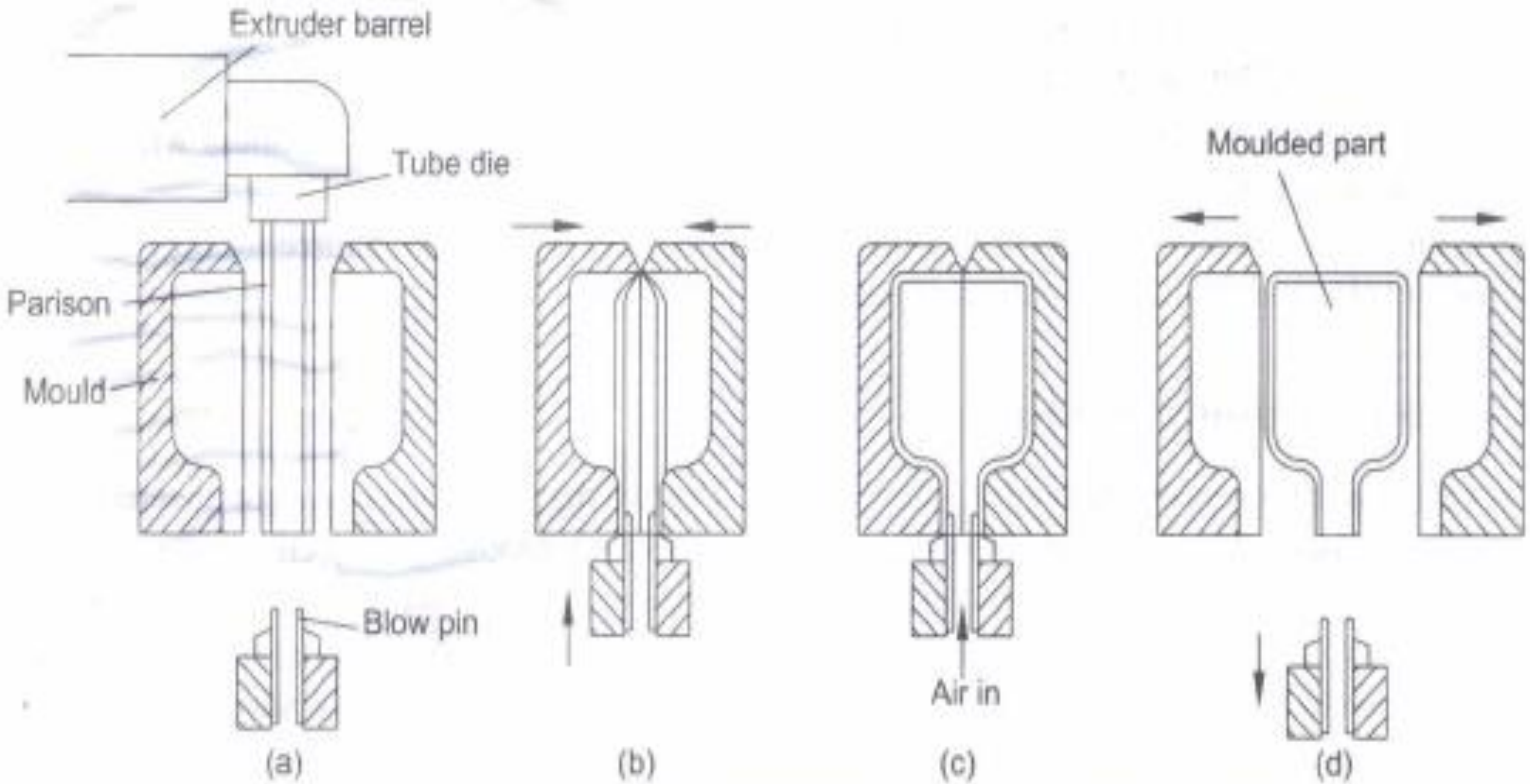


Fig. 12.13 *Operating steps in a blow-moulding operation: (a) Hollow parison is formed with the extruder (b) Mould closes around the parison and blow pin inserted (c) Air is blown into the parison thus expanding it to confirm to the contours of the mould (d) Mould opens and the finished part is removed*

Thermoforming

- In this process, a thermoplastic sheet can be formed into a three- dimensional shape by the application of heat and differential pressures.
- First, the plastic sheet is clamped to a frame and uniformly heated to make it soft and flowable.
- Then a differential pressure (either vacuum or pressure or both) is applied to make the sheet conform to the shape of a mould or die positioned below the frame.
- It is possible to use most of the thermoplastic materials. The starting material is a plastic sheet of uniform thickness.
- It is a relatively simple process and is used for making such parts as covers, displays, blister packaging, trays, drinking cups and food packaging.

Contd...

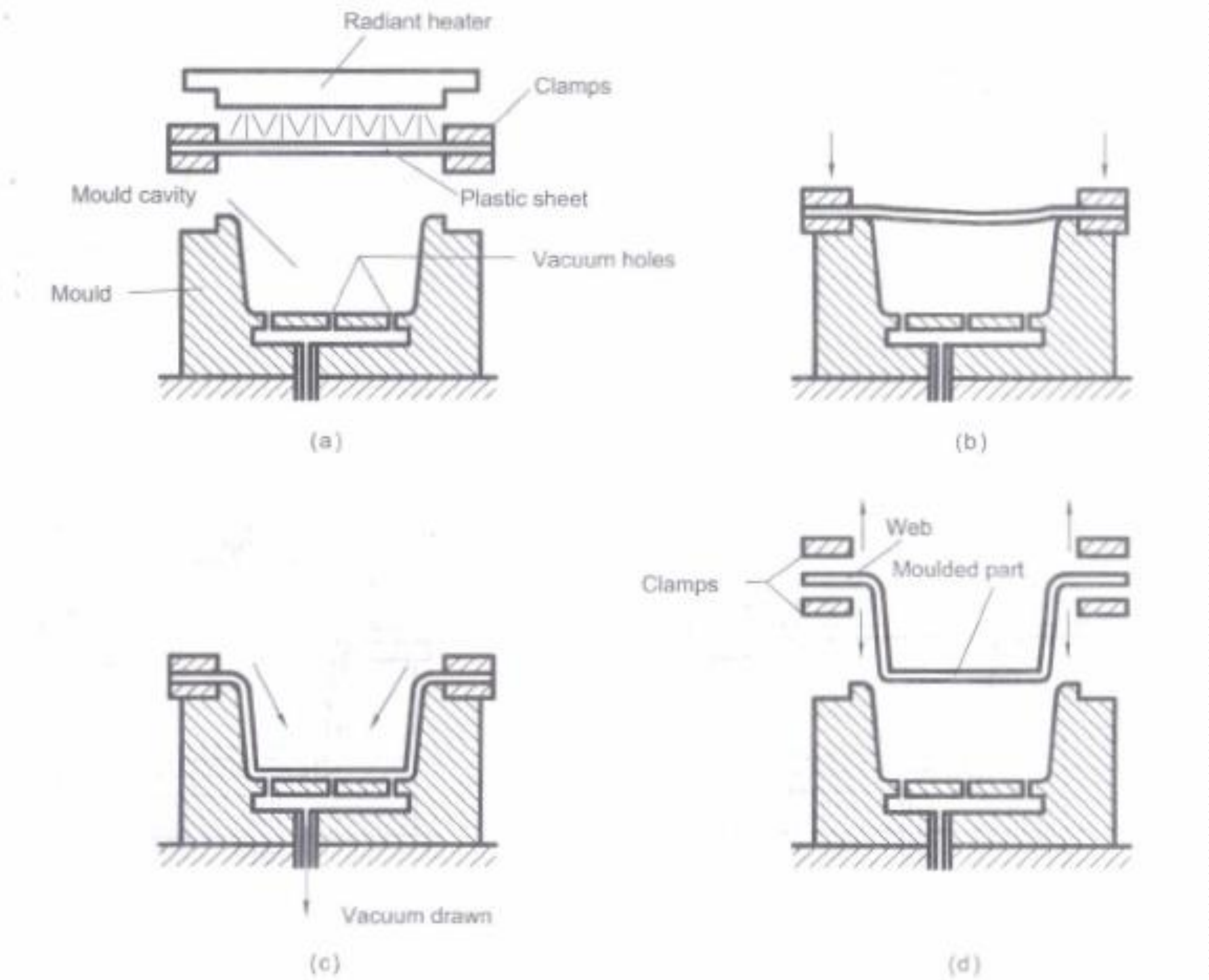


Fig. 12.16 *Steps in vacuum-thermoforming process: (a) Plastic sheet is clamped in a frame and heated. (b) Heated plastic sheet is attached to the mould. (c) Vacuum is applied drawing the plastic sheet to follow the contours of the mould. (d) The moulded part is released*

Contd...

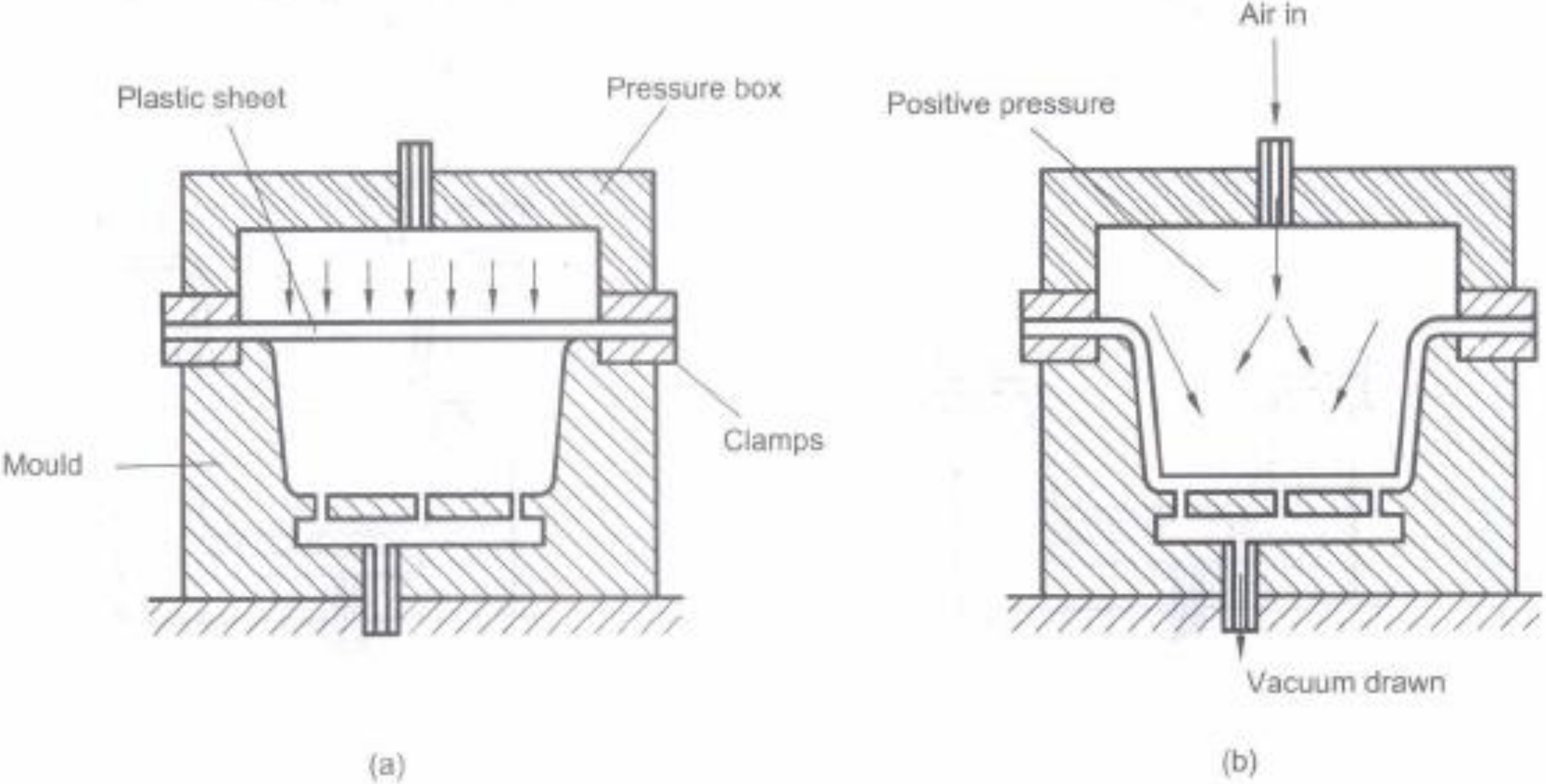


Fig. 12.17 *Steps in pressure thermoforming process: (a) Plastic sheet is clamped in a frame, attached to the mould and heated. (b) Pressure applied on the top forces the plate to follow the contour of the mould. Vacuum is applied from the bottom to assist the forming process.*

Unit-7

Advanced Materials

Elastomer

Elastomers

- Elastomers are a special class, of linear polymers that display an exceptionally large amount of elastic deformation when a force is applied.
- Many can be stretched to several times their original length. Upon release of the force, the deformation can be completely recovered, as the material quickly returns to its original shape. In addition, the cycle can be repeated numerous times with identical results, as with the stretching of a rubber band.
- In the elastomeric polymers, the linear chain-type molecules are **twisted or curled**, much like a coil spring.

Contd…

- When a force is applied, the polymer stretches by uncoiling. When the load is removed, the molecules recoil and the material returns to its original size and shape.
- The relationship between force and stretch does not, however, follow Hooke's Law.
- In reality, the behaviour of elastomers is a bit more complex. While the chains indeed uncoil when placed under load, they also tend to slide over one another to produce a small degree of viscous deformation. When the load is removed, the molecules recoil, but the viscous deformation is not recovered and the elastomer retains some permanent change in shape.
- By cross-linking the coiled molecules, however, it is possible to restrict the viscous deformation while retaining the large elastic response.

Contd...

- The elasticity or rigidity of the product can be determined by controlling the number of cross-links within the material.
- Small amounts of cross-linking leave the elastomer soft and flexible, as in a rubber band.
- Additional cross-linking restricts some of the uncoiling, and the material becomes harder, stiffer, and more brittle, like the rubber used in bowling balls.
- If placed under constant strain, however, even highly cross-linked material will exhibit some viscous flow over time. This phenomenon is known as stress relaxation.
- The rate of this relaxation depends on the material, the force, and the temperature.

Rubber

- Natural rubber, the oldest commercial elastomer, is made from the processed sap of a tropical tree.
- It could be vulcanized (cross-linked) by the addition of about 30% sulphur followed by heating to a suitable temperature. The cross-linking restricts the movement of the molecular chains and imparts strength.
- Properties could be further improved by various additives (e.g., carbon black) which act as stiffeners, tougheners, and antioxidants.
- Accelerators have been found that speed up the vulcanization process. These have enabled a reduction in the amount of sulfur such that most rubber compounds now contain less than 3% sulphur.

Contd...

- Natural rubber compounds **are outstanding for their flexibility, *good electrical insulation*,** low internal friction, and resistance to most inorganic acids, salts, and alkalies.
- However, they have poor resistance to petroleum products, such as oil, gasoline, and naphtha.
- In addition, they lose their strength at elevated temperatures, so it is advisable that they not be used at temperatures above 175°F (80°C).
- They also deteriorate fairly rapidly in direct sunlight unless specially compounded.

Contd…

- Rubber and similar synthetic materials such as Neoprene have a variety of application in machinery.
- Rubber should be protected from high temperature, oil and sunlight.
- It is an excellent material for seats and diaphragms, for water lubricated bearings, for parts subjected to vibrations (such as vibration mountings, flexible couplings and flexible bearing) and for tubes and hose.
- In industry, hard rubber is used for electric insulation, switch handles, bearings, etc.

Contd...

Different types of rubber	Applications
Natural rubber	Tires, gaskets, hose
Polyacrylate	Oil hose, O-rings
EDPM(ethylene propylene)	Electric insulation, footwear, hose, belts
Chlorosulfonated polyethylene	Tank lining, chemical hose, polyethylene shoe, soles and heels
Polychloroprene (neoprene)	Wire insulation, belts, hose, (neoprene) gaskets, seals, linings
Polybutadiene	Tires, soles and heels, gaskets, seals
Polyisoprene	Same as natural rubber
Polysulfide	Seals, gaskets, diaphragms, valve disks
SBR (styrene butadiene)	Moulded mechanical goods, disposable pharmaceutical items, tyres
Silicone	Electric insulation, seals, gaskets, O-rings
Epichlorohydrin	Diaphragms, seals, moulded goods, low-temperature parts
Urethane	Caster wheels, heels, foam padding
Fluoroelastomers	O-rings, seals, gaskets, roll coverings

Ceramic

- Ceramic materials are compounds of metallic and nonmetallic elements (often in the form of oxides, carbides, and nitrides) and exist in a wide variety of compositions and forms.
- The American Ceramic Society has defined ceramic products as those manufactured" by the action of heat on raw materials, most of which are of an earthy nature (as distinct from metallic, organic etc.) while of the constituents of these raw materials, the chemical element silicon, together with its oxide and the compounds thereof (the silicates), occupies a predominant position."

Contd...

- Most have crystalline structures, but unlike metals, the bonding electrons are generally captive in strong ionic or covalent bonds. The absence of free electrons makes the ceramic materials poor electrical conductors and results in many being transparent in thin sections.
- Because of the strength of the primary bonds, most ceramics have high melting temperatures.
- Ceramic articles of industry are : Dinner ware, electrical and chemical porcelain, refractory bricks and tiles, glass, porcelain enamels, abrasives, cutting tools, bricks and tiles, cements and concretes, whitewares, mineral Ores, slags and fluxes and insulators etc.

Contd…

- Ceramics can be natural or manufactured:
- **Natural Ceramics** : The most frequently used, naturally occuring Ceramics we : Silica (SiO), Silicates and Clay minerals.
- **Manufactured Ceramics** : Such ceramics include : SiC, Al_2O_3, Silicon Nitride (Si_3N_4) and many varieties of Oxides, Carbides, Nitrides, Borides and more complex ceramics.

Properties of Ceramics

- The co-valent bonding of ceramic materials, alongwith their high melting point and relative resistance to oxidation, make ceramics good candidates for high temperature applications.
- In addition, they are relatively cheap and abundant and are not dependent on import for supply.
- Many ceramics retain strength to much higher temperatures than metals.
- There being virtual absence of ductility in ceramics, so, in general, they can not be machined or built up from stock.

Contd…

- In general, ceramics are hard, brittle and high melting point materials with :-
  - desirable electrical, magnetic and optical properties, i.e., low electrical and thermal conductivity.
  - good chemical and thermal stability, that is, high hot-strength and high corrosion resistance, and freedom from oxidation.
  - good creep resistance, and
  - High compressive strength and excellent resistance to wear.
  - Their low density is also an attractive feature to minimise centrifugal stresses in parts rotating at high speed.

Processing of Ceramics

The processing of ceramics, except glass, follows the Powder Metallurgy route, that is, consists of the following steps :-

1. Preparation of powders
2. Mixing and Blending of powders
3. Compacting of powders
4. Firing or Sintering.

Machining of Ceramics

- Most ceramics are sintered to their finish dimensions.
- However, sometimes, they are machined to get better dimensional accuracy and surface finish.
- Machining of ceramics can be done with Diamond abrasives, LBM, EBM and CHM.

PRODUCT APPLICATIONS

1. **Clay products** : Clay body ceramics include whitewares and stoneware.

- Whitewares includes such families of products as earthenwares, China and porcelain.
- Whitewares are largely used as tile, sanitary ware, low and high voltage insulators, and high frequency applications.
- Stoneware applications are : Glazed pipes, roofing tiles and tableware.

2. Refractories

- Refractory ceramics are the materials which are capable of withstanding high temperature in various situations. The refractory materials are of three types.
- **Acidic refractories** are based on alumina-silica composition, varying from pure silica to nearly pure alumina, through a wide range of alumina silicates.
- The basic constituent of **basic refractories** is magnesia, MgO. Basic refractories include chrome-magnesite, dolomite, limestone and magnesite.
- **Neutral refractories** include substances which do not combine with either acidic or basic oxides. With increasing alumina content, silica-alumina refractories may gradually change from an acidic to neutral type. A typical neutral character is exhibited by such refractories as Carbon, graphite, carbide, chromite, bauxite and forsterite.

Contd…

- Refractories are used in the construction or lining of furnaces, boilers, flues, regenerators, convertors, crucibles, dryers, pyrometer tubes and in many others, primarly to withstand the high temperature.
- The most widely used **oxide refractory ceramic** is alumina Al_2O_3. It is sintered into cutting tool bits, spark plug insulators, high temperature tubes, melting crucibles, wear components and substrates for electronic circuits and resistors.

Carbide refractory

- Carbides have the highest melting point of all the substances.
- Silicon carbide, SiC, is difficult to sinter, but pressure sintered or reactive sintered solid bodies of SiC are used as high-temperature resistance-heating elements, rocket nozzels and sand blast nozzles.
- Ceramics such as UO2, UC and UC, are used in nuclear applications as fuel elements, fuel containers, moderators, control rods and structural parts.
- Boron carbide, B4C, is extremely hard and is used as a grinding grit.
- Other carbides (Tungsten Carbide, Tantalum Carbide and Titanium carbide) are used in the sintered form as cutting tool materials.

Contd…

- **Nitrides** have only slightly lower melting points than carbides.
- Cubic boron nitride, CBN, is the hardest material after diamond and is used as cutting tool material. Silicon nitride, Si_3N_4, is used for ceramic engine components, turbine disks and rocket nozzles.
- **Sialon** (Si - Al - O - N), that is oxynitrides, have better oxidation resistance and is used for cutting tools and welding pins.
- **Borides** (of Chromium, Zirconium and Titanium) are used as turbine- blades, Rocket nozzles and Combustion chamber liners.
- **Cermet** is a composition of ceramic and metal. This material shows better thermal shock resistance than ceramics, but at the same time retains their high refractoriness.
- It is used as cutting tool material, as crucibles and as jet engine nozzles.

3.Electrical and Magnetic Applications

- Ceramics find wide applications in electrical and electronic industries.
- As insulators, semi-conductors, dielectrics, ferroelectrics, piezoelectric crystals.
- Ceramics such as glass, porcelain, alumina, quartz and mica, are getting heavy demands.
- Ceramics, such as SiC, are used as resistors and heating elements for furnaces.
- Ceramics, having semiconducting properties, are used for thermistors and rectifiers. Barium titantate, for example, is used in capacitors and transducers.

4. Optical Applications

- Ceramics are notably useful as a pigment, because it is exceptionally durable. It is completely oxidised and not subject to chemical attack and variation.
- Yttralox (a new ceramic material) is useful in optical applications, becuase it is as transparent as window glass and can resist very high temperature. Yttralox is completely free from pores.
- Generally, Ceramics are opaque, because of the presence of tiny pores within them that scatter light.

5. Phosphorescence

- Ceramic phosphors emit light of a characteristic wave-length when excited or pumped by some appropriate energy source (an electric discharge or electron beam).
- Light tubes, VDT's and colour T.V. rely on this phenomenon.
- Of increasing interest are Laser materials, The most widely used Laser is ruby (an Al_2O_3 , crystal doped with Cr ions).
- They are being used for machining, welding and cutting etc.

Glass

- Glasses are, by definition, "Ceramics" because the starting materials needed to produce glass are typical of ceramic materials. However, they are produced by the melt processing route, instead of the powder metallurgy route used for other ceramics.
- In ceramic science, the word "glass" signifies any amorphous component of ceramic mixture.
- However, in general terms, glass is a transparent silica product which may be amorphous or crystalline, depending on heat treatment.
- Glasses may be either inorganic or organic.

Contd...

- Vitreous materials or inorganic glasses are the fusion products which during solidification from **a liquid** state failed to crystallise.
- During the cooling process, the glasses exhibit no discontinuous change at any temperature and only a progressive increase in viscosity is noticed. In fact, glass is a hard liquid.
- **Glass Forming Constituents :** Silica, which is obtained from high-purity silica sand is the most widely used glass-forming constituent.
- Other glass forming constituents are the oxides of boron, vanadium, germanium and phosphorous. Some other elements and compounds such as tellurium, selenium and BeF_2 can also form glasses.

Contd…

- Along with oxides, fluxes are also added to the charge for a glass. Fluxes lower the fusion temperature of the glass and render the molten glass workable at reasonable temperature.
- However, fluxes may reduce the resistance of glass to chemical attack, render it water soluble or make it subject to partial or complete **devitrification** (that is, crystallisation) upon-cooling; Such a glass is undesirable since the crystalline are extremely weak and brittle.
- Stabilizers are therefore, added to the glass batch to overcome these problems.

Composites

What are composites?

- Composites are the multiphase materials, which can be defined as any multiphase material that is artificially made and exhibits a significant proportion of the properties of the constituent phases.
- The constituent phases of a composite are usually of macro sized portions, differ in form and chemical composition and essentially insoluble in each other.

Why do we need composites?

- Composites are the class of materials with special properties.
- Properties of the composite can be tailored to meet the required purpose such as superior properties like higher strength to weight ratio, high modulus and high temperature stability along with good damping ability.

TYPES OF COMPOSITE MATERIALS

- Composite materials may roughly be classified as :
  1. Agglomerated materials or Particulate Composites
  2. Reinforced materials
  3. Laminates
  4. Surface-Coated materials.
- The particulate composites and reinforced composites are constituted by just two phases, the matrix phase and the dispersed phase.
- The matrix phase is continuous and surrounds the dispersed phase. The aim is to improve the strength properties of the matrix material.

Contd…

- The matrix material should be : ductile with its modulus of elasticity much lower than that of the dispersed phase. Also, the bonding forces between the two phases must be very strong.
- Depending upon the nature of the reinforcing materials (shape and size), the reinforced composites can be classified as:

  1. Particle reinforced composites or particulate reinforced composites.
  2. Fibre reinforced composites.

- In particle reinforced composites, the dispersed phase is in the form of exi-axed particles, whereas in fibre-reinforced composites, it is in the form of fibres.

Contd...

Agglomerated Materials

- Agglomerated materials or particulate composites consist of discrete particles of one material, surrounded by a matrix of another material. The materials are bonded together into an integrated mass.
- Two classic examples of such a composite material are : Concrete formed by mixing gravel, sand, cement and water and agglomeration of asphalt and stone particles, that is used for paving the highway surfaces. Other examples of particulate composite materials include :-

1. Grinding and cutting wheels, in which abrasive particles (Al_2O_3 , SiC, CBN or diamond) are held together by a vitreous or a resin bond.

Contd…

2. **Cemented carbides**, in which particles of ceramic materials, such as WC, TaC, TiC and of Cobalt and nickle, are bonded together via Powder Metallurgy process, to produce cutting tool materials. Cobalt acts as the binder for ceramic particles. During sintering, the binder melts and forms a continuous matrix between the ceramic particles. This method is called as "**Vitreous sintering**", that is, sintering with the formation of liquid phase.

3. **Cermets** (Ceramics + metals). Metals (W, Mo, Ni, Co act as binders and the product is made by Powder Metallurgy method.

- The sintering temperature is the melting point of the metal.
- In the resulting composite material, the metal contributes high toughness and thermal shock resistance, while the ceramic contributes higher refractoriness and creep resistance, superior chemical stability and abrasion resistance.

Reinforced Materials

- Reinforced materials form the biggest and most important group of composite materials.
- The purpose of reinforcing is always to improve the strength properties.
- Reinforcement may involve the use of a dispersed phase or strong fibre, thread or rod.
- The matrix material provides ductility and toughness and supports and binds the fibres together and transmits the loads to the fibres.
- The fibres carry most of the load.

Contd…

- The toughness of the composite material increases, because extra energy will be needed to break or pull out a fibre.
- Also, when any crack appears on the surface of a fibre, only that fibre will fail and the crack will not propagate catastrophically as in bulk material.
- Wood and bamboo are two naturally occurring fiber composites, consisting of cellulose fibers in a lignin matrix.
- The commonly used matrix materials are : Metals and polymers, such as, Al, Cu, Ni etc. and commercial polymers.

Contd…

- Reinforcing Fibres :A good reinforcing fibre should have : high elastic modulus, high strength, low density, reasonable ductility and should be easily wetted by the matrix.
- Metallic fibres such as patented steel, stainless steel, tungsten and molybdenum wires are used in a metal matrix such as aluminium and titanium.
- Carbon fibres and whiskers are also used to produce ultra-high strength composites.
- Fibres need not be limited to metals. Glass, ceramic and polymer fibres are used to produce variety of composites having wide range of properties.
- The ductile matrix material can be aluminium, magnesium, nickle or titanium and the reinforcing fibres may be of boron, graphite, alumina or SiC.

Whiskers

- Whiskers are single crystals in the form of fine filaments, a few microns in diameter (20-50 nm dia.) and short in length (a few mm).
- These single crystal whiskers are the strongest known fibres.
- Their high strength is due to the high degree of perfection and the absence of dislocation in their structure.
- Their strength is many times greater than that of the normal metals.
- They are introduced into resin or metallic matrix for the purpose of high strength and high stiffness at high temperatures.

Applications of reinforced materials

1. **Glass-fibre reinforced plastics** : Here, we have glass fibres in a matrix of unsaturated polyester.

- Glass fibre-reinforced plastics are used to make : boat hulls, Car bodies, truck, cabins and aircraft fittings.

2. **C-C Composites** : These composites have graphite fibres in a carbon matrix.

- This material is being used to make : Nose cone and leading edge of the missiles and space shuttles, racing car disk brakes, aerospace turbine and jet engine components, rocket nozzles and surgical implants.

Contd...

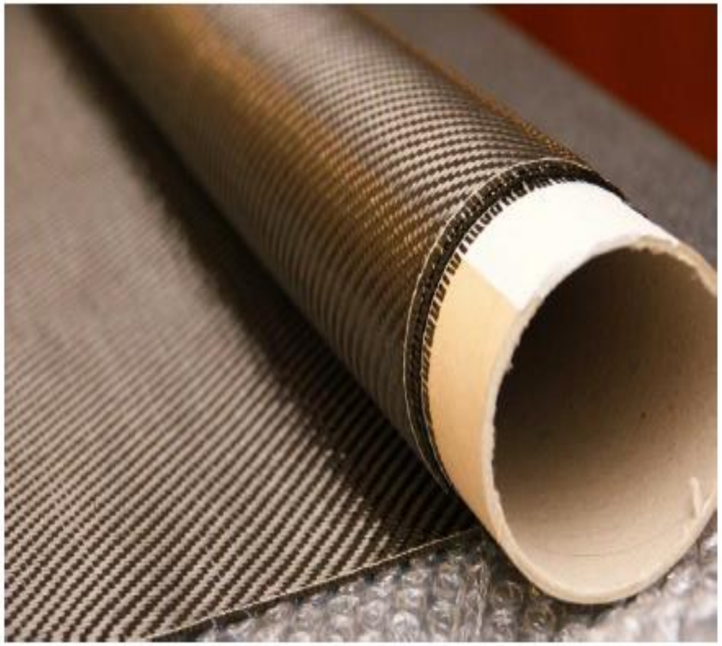
3. **Graphite fibre-reinforced epoxy** : (Organic or Resin matrix composites) : This material is being used to make m y parts of a fighter plane.

4. **Automative uses** : Body panels, drive shafts, springs and bumpers, Cab shells and bodies, oil pans, fan shrouds, instrument panels and engine covers.

5. **Sports equipment** : Golf club shafts, baseball parts, fishing rods, tennis rackets, bicycle frames, skis and pole vaults.

Composite Materials

A composite material is a material made from two or more constituent materials with significantly different physical or chemical properties. When combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure.

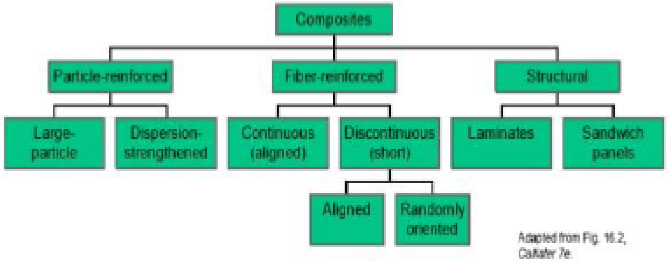


Classification

- Fiber Reinforced In this group of composites, the fiber is the primary load-bearing component.
- Dispersion Strengthened In this group, the matrix is the major loadbearing component.
- Particle Reinforced In this group, the load is shared by the matrix and the particles.

Classification based on reinforcement

Composites



Adapted from Fig. 16.2, Callister 7e.

Properties

A composite material is any material made by combining two or more materials in a structure whereby materials remain separate. This is done to produce materials with desirable properties such as high compressive strength, tensile strength, flexibility and hardness.

Applications

APPLICATION OF COMPOSITE MATERIAL IN AEROSPACE INDUSTRY The Composite materials are used to manufacture Rocket and Missiles motor cases. These composite materials are composites of carbon, aramid and glass.

Ceramics

Ceramic materials are inorganic, non-metallic materials made from compounds of a metal and a non metal. Ceramic materials may be crystalline or partly crystalline. They are formed by the action of heat and subsequent cooling. Clay was one of the earliest materials used to produce ceramics, as pottery, but many different ceramic materials are now used in domestic, industrial and building products. Ceramic materials tend to be strong, stiff, brittle, chemically inert, and non-conductors of heat and electricity, but their properties vary widely.

Classification

- Glasses: containers, windows, mirrors, lenses.
- Clay products: structural products (bricks, tiles, sewer pipes) and whitewares (porcelain, chainware, pottery, etc.).
- Refractories: Thermal insulation.
- Abrasives: Diamond, silicon carbide, tungsten carbide, silica sand, aluminium oxide / corundum are some typical examples of abrasive ceramic ...
- Cements: construction brick.
- Advanced ceramics: heat engines , ceramic armors, electronic packaging, etc.

Properties

- PHYSICAL PROPERTIES: Physical properties are identified by its crystal structure and its chemical composition. Generally, Physical properties are ...
- MECHANICAL PROPERTIES:
- CHEMICAL PROPERTIES:
- THERMAL PROPERTIES:
- ELECTRICAL PROPERTIES:

Applications

- Applications of ceramicsZiad zohdy
- A ceramic material may be defined as any inorganic crystalline material,compounded of a metal and a non-metal .
- Ceramics can be classified as Crystalline ceramics & Non-crystallineceramics .
- Glass-ceramic materials share many properties with both glasses andceramics.
- Glass-ceramics have the fabrication advantage of glass as well as specialproperties of ceramics.

Heat insulating materials

- Thermal insulation is the reduction of heat transfer (i.e., the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials.

Miscellaneous Materials

Miscellaneous Materials CGR offers **cork, graphite, metals** and other miscellaneous materials to deliver a true customization capabilities for our customers.

Properties of Asbestos

- More tensile strength than steel.
- High thermal stability.
- Electrical resistance.
- Non-flammable.
- Has no detectable smell or taste.
- They are all solids that do not move through soil and are insoluble in water.
- Its color will vary according to type, and metallic composition.
- Flexible so that it can be spun and woven like cotton.

Uses of asbestos

Uses of asbestos include a **wide range of products, primarily for heat and sound insulation, roofing and flooring**. Some of the most common asbestos uses were: roofing materials. patching and spackling compound. brake pads and lining. cements. toasters and other heat-related household items. floor tiles.

Properties of glass wool

Gases possess poor thermal conduction properties compared to liquids and solids and thus make good insulation material if they can be trapped in materials so that much of the heat that flows through the material is forced to flow through the gas. In order to further augment the effectiveness of a gas (such as air) it may be disrupted into small cells which cannot effectively transfer heat by natural convection. Natural convection involves a larger bulk flow of gas driven by buoyancy and temperature differences

Uses of glass wool

- Glass wool is a thermal insulation material consisting of intertwined and flexible glass fibers, which causes it to "package" air, resulting in a low density that can be varied through compression and binder content (as noted above, these air cells are the actual insulator). Glass wool can be a loose-fill material, blown into attics, or together with an active binder, sprayed on the underside of structures, sheets, and panels that can be used to insulate flat surfaces such as cavity wall insulation, ceiling tiles, curtain walls, and ducting. It is also used to insulate piping and for soundproofing.

Properties of thermocol

- These are mainly used as cold insulation for piping and cold storage construction. ... properties, it can also provide **acoustic insulation** and is **fire retardant**.

Uses of thermocol

Thermocol are primarily utilized to manufacture **disposable trays, cups, packaging materials, containers**, etc. Thermocol are also used to make loose packaging products known as packing peanuts and insulation boards for floors, walls, and roofs in buildings. With so many uses the production and demand of thermocol is increasing at a faster pace.

Properties of cork

The amazing natural properties of cork. Cork is a pretty extraordinary material and that is why it has so many uses. The key to cork's many properties is its **honeycomb cell structure**. Each cell is a 14-sided polyhedron filled with air with an extremely strong and flexible membrane that is **waterproof and airtight**.

Uses of cork

- Cork makes a very good noise and thermal insulator.
- Cork is used to make pin boards that are commonly found in offices and homes.
- Cork is a very important material for fishing.
- Sometimes cork is added to concrete to improve the qualities of the product.
- The core of cricket balls and baseballs is made from cork.

Properties of mica

- Mica has an estimable electrical, physical, mechanical and thermal pertinacity properties. It has **high transparency, optical clarity, flatness, non-breakability and heat resistancy**.

Uses of mica

- Ground mica is used in gypsum wallboard as a wadding to remove its imperfections…
- It is used in paints to improve their quality and add shine.
- It is added to plastic products to strengthen their mechanical properties.
- It is added to rubber products like tires, as it can serve as an anti-sticking agent.

Tool and die material

- Jump to search Tool and die makers are a class of machinists in the manufacturing industries. Variations on the name including tool maker, toolmaker, die maker, diemaker, mold maker, moldmaker or tool jig and die-maker depend on which area of concentration or industry an individual works in.
- Tool and die makers work primarily in toolroom environments—sometimes literally in one room but more often in an environment with flexible, semipermeable boundaries from production work.

Materials for bearing metals

- Babbitt: SAE 11 Babbitt is used for bearings which are subjected to heavy pressures.
- Copper-Lead Alloys: Copper alloys having a high lead content 20 to 50% are of special interest.
- Plastics: Celoron, Formica and Micarta bearings are made from a special woven duck impregnated...

Spring materials

The spring material can be broadly classified into groups such as high carbon spring steel, alloy spring steel, stainless steel, phosphor bronze and copper base alloys.

Materials for nuclear energy

- "Nuclear materials" most commonly refers to fissile materials that are capable of sustaining a chain reaction in a process that releases energy called nuclear fission. The materials include isotopes of **uranium, thorium, and plutonium**.

Refractory materials

- A refractory material or refractory is a **heat-resistant material:** that is, a mineral that is resistant to decomposition by heat, pressure, or chemical attack, most commonly applied to a mineral that retains strength and form at high temperatures.