Crystallography and Structure

CRYSTALLOGRAPHY

CRYTALLOGRAPHY

It is branch of science in which structure of crystals, external or internal symmetries and properties of crystals are studied.

SPACE LATTICE

The arrangement of atoms in an orderly three dimensional pattern to form a crystal.

Table 3.2 Lattice Parameter Relationships and Figures Showing Unit Cell Geometries for the Seven Crystal Systems

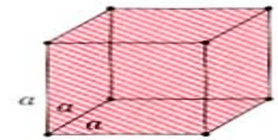
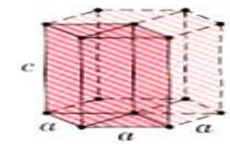
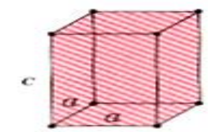
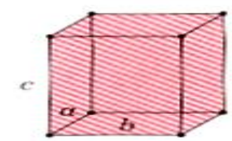
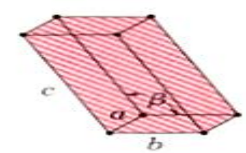
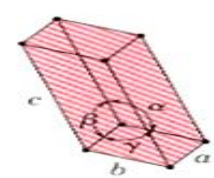
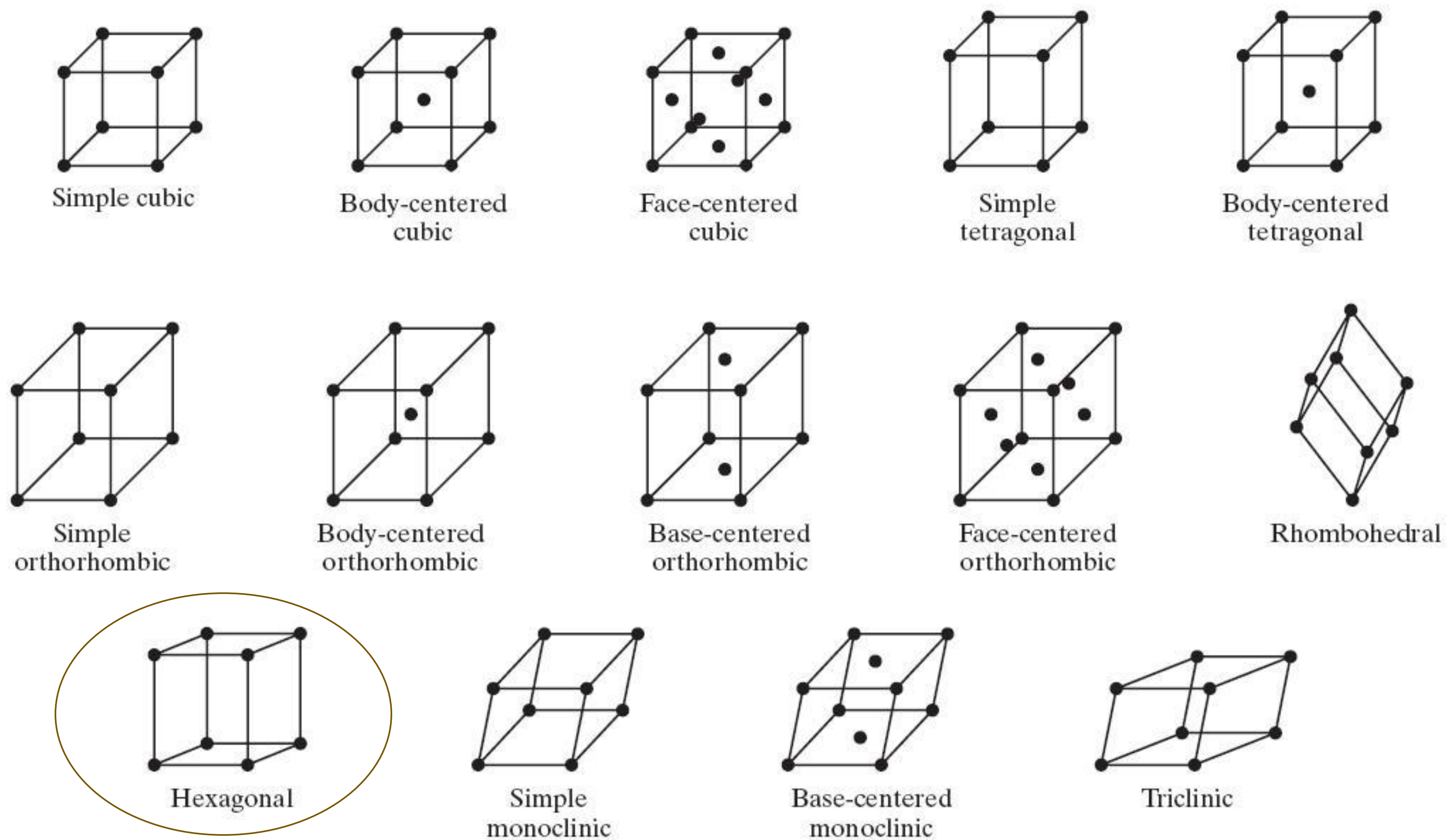
Crystal System	*Axial Relationships*	*Interaxial Angles*	*Unit Cell Geometry*
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90°$	
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90°, \gamma = 120°$	
Tetragonal	$a = b \neq c$	$\alpha = \beta = \gamma = 90°$	
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90°$	
Orthorhombic	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90°$	
Monoclinic	$a \neq b \neq c$	$\alpha = \gamma = 90° \neq \beta$	
Triclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90°$	

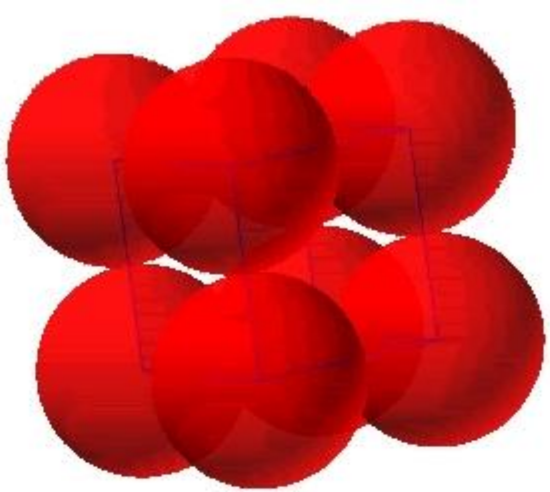
TABLE 3.2

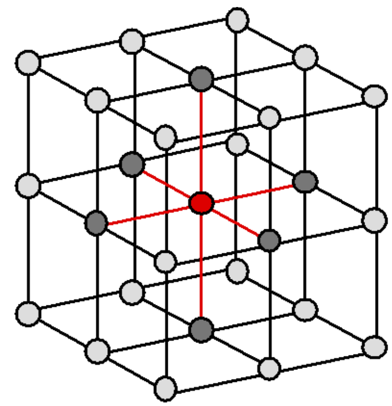
The 14 Crystal (Bravais) Lattices



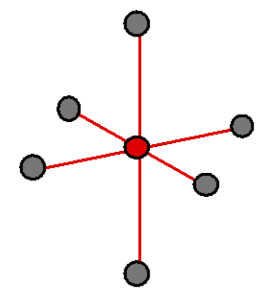
Simple Cubic Structure (SC)

- Rare due to low packing density (only Po – Polonium -- has this structure)
- Close-packed directions are *cube edges.*





- Coordination No. = 6 (# nearest neighbors) for each atom as seen



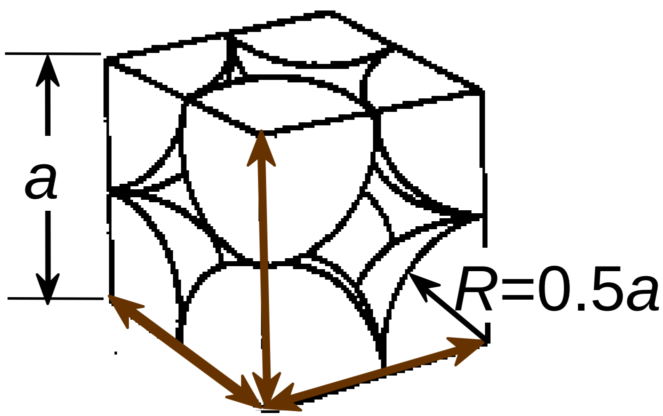
(Courtesy P.M. Anderson)

Atomic Packing Factor (APF)

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

*assume hard spheres

- APF for a simple cubic structure = 0.52



close-packed directions

contains (8 x 1/8) =

1 atom/unit cell

Adapted from Fig. 3.23, *Callister 7e.*

$$\text{APF} = \frac{1 \cdot \frac{4}{3}\pi(0.5a)^3}{a^3}$$

atoms / unit cell → 1

volume / atom → $\frac{4}{3}\pi(0.5a)^3$

volume / unit cell → a^3

Here: a = R_{at}*2

Where R_{at} is the 'handbook' atomic radius

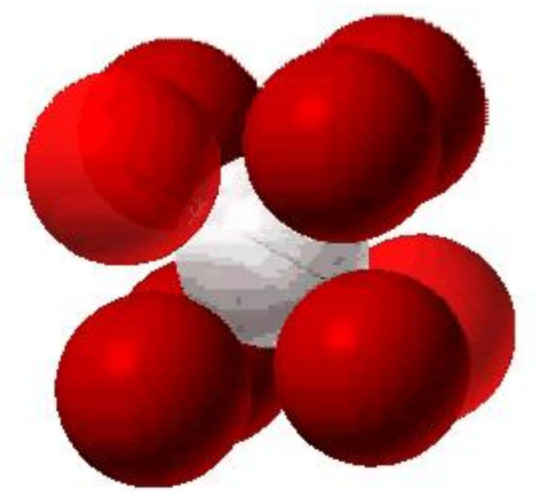
Body Centered Cubic Structure (BCC)

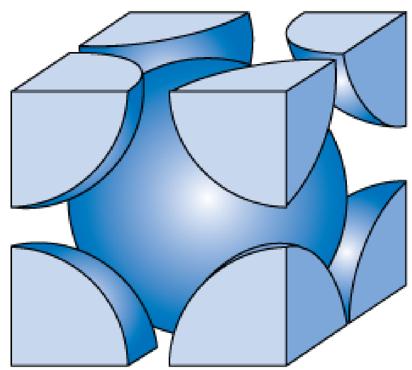
- Atoms touch each other along *cube diagonals*.

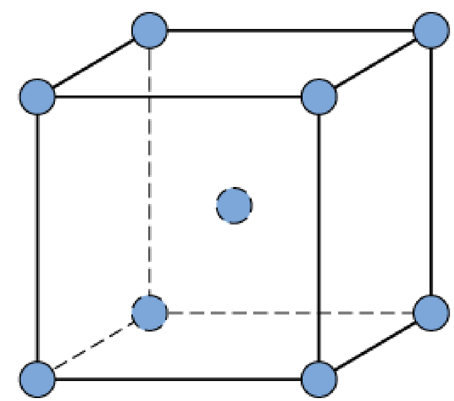
  --Note: All atoms are identical; the center atom is shaded differently only for ease of viewing.

ex: Cr, W, Fe (α), Tantalum, Molybdenum

- Coordination # = 8





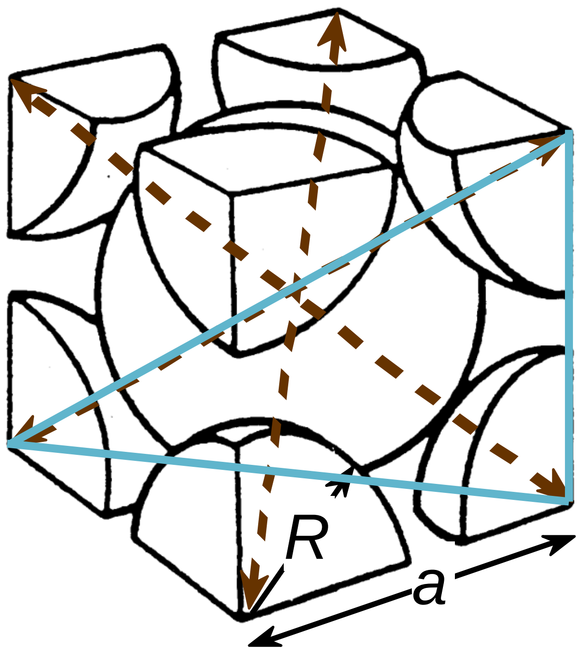


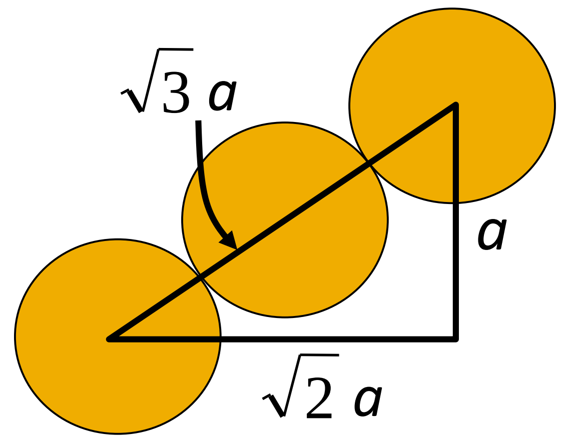
Adapted from Fig. 3.2, *Callister 7e.*

2 atoms/unit cell: (1 center) + (8 corners x 1/8)

(Courtesy P.M. Anderson)

Atomic Packing Factor: BCC





Close-packed directions:
length = $4R = \sqrt{3}\,a$

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

atoms / unit cell → 2

volume / atom → $\frac{4}{3}\pi(\sqrt{3}a/4)^3$

volume / unit cell → a^3

Adapted from
Fig. 3.2(a), *Callister 7e.*

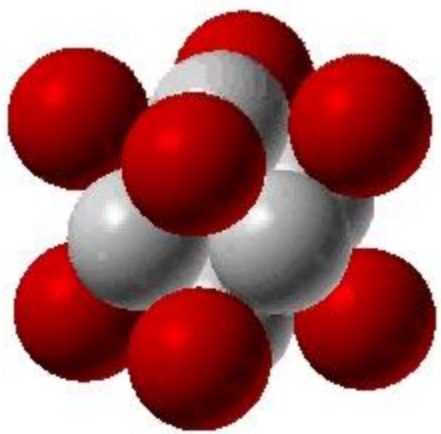
- APF for a body-centered cubic structure = 0.68

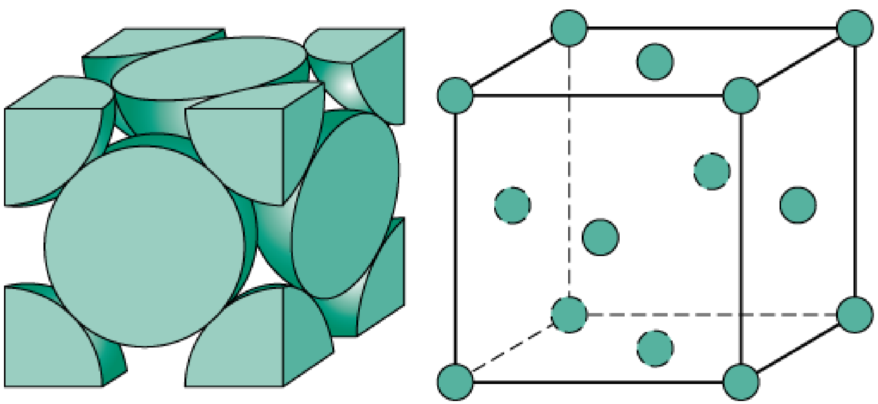
Face Centered Cubic Structure (FCC)

- Atoms touch each other along *face diagonals*.
  --Note: All atoms are identical; the face-centered atoms are shaded differently only for ease of viewing.

ex: Al, Cu, Au, Pb, Ni, Pt, Ag

- Coordination # = 12





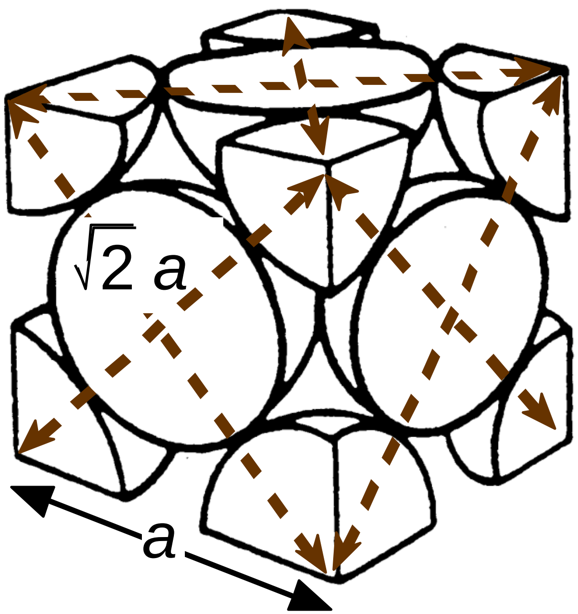
Adapted from Fig. 3.1, *Callister 7e.*

4 atoms/unit cell: (6 face x ½) + (8 corners x 1/8)

(Courtesy P.M. Anderson)

Atomic Packing Factor: FCC

- APF for a face-centered cubic structure = 0.74



Adapted from Fig. 3.1(a), *Callister 7e.*

The maximum achievable APF!

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

($a = 2\sqrt{2}*R$)

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

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

atoms / unit cell → 4

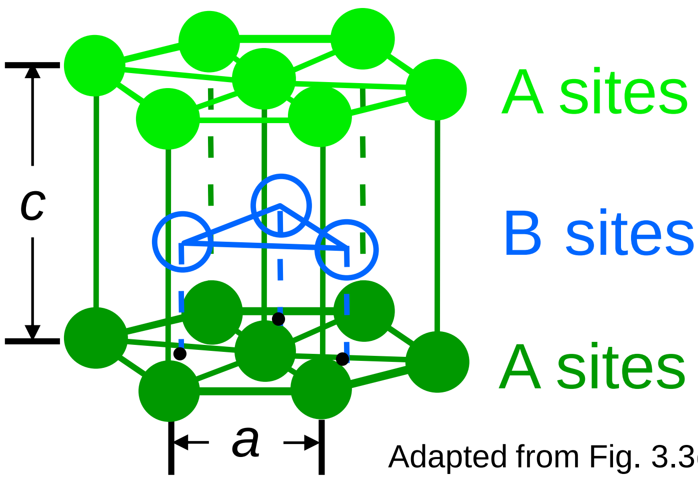
volume / atom → $\frac{4}{3}\pi(\sqrt{2}a/4)^3$

volume / unit cell → a^3

Hexagonal Close-Packed Structure (HCP)

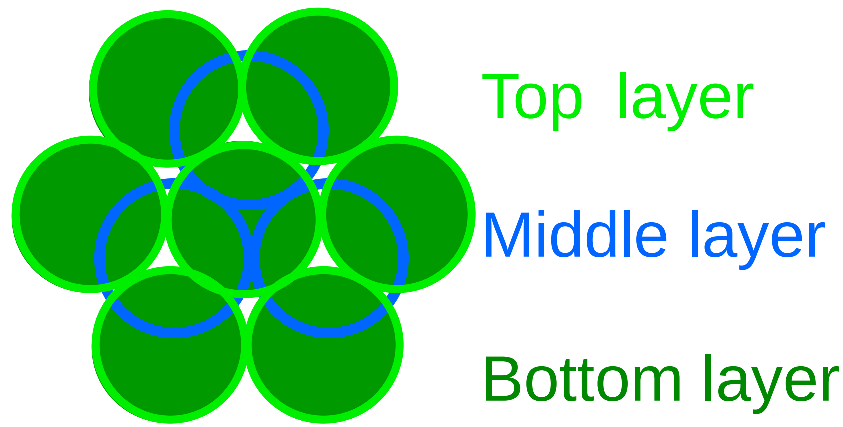
ex: Cd, Mg, Ti, Zn

- ABAB... Stacking Sequence
- 3D Projection



Adapted from Fig. 3.3(a), *Callister 7e.*

- 2D Projection



- Coordination # = 12

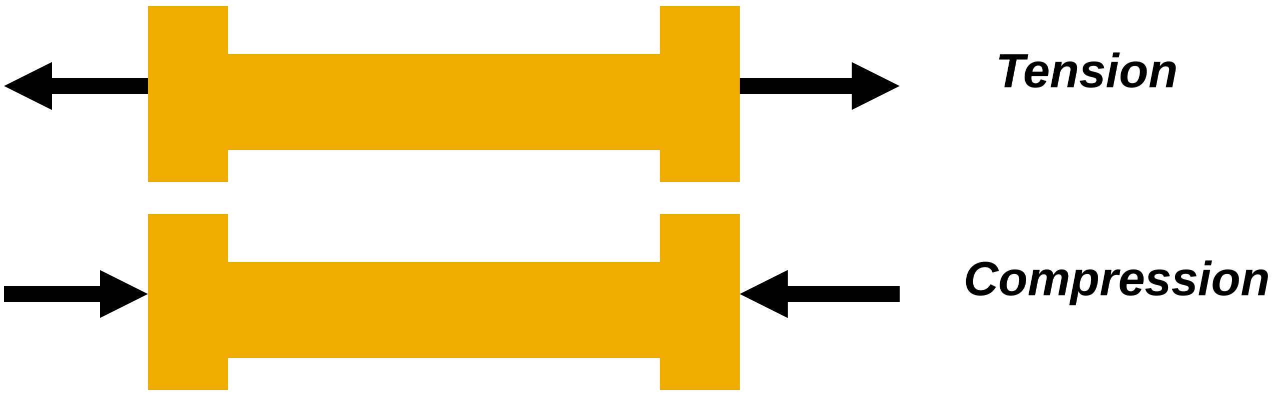
6 atoms/unit cell

- APF = 0.74

- *c/a* = 1.633 *(ideal)*

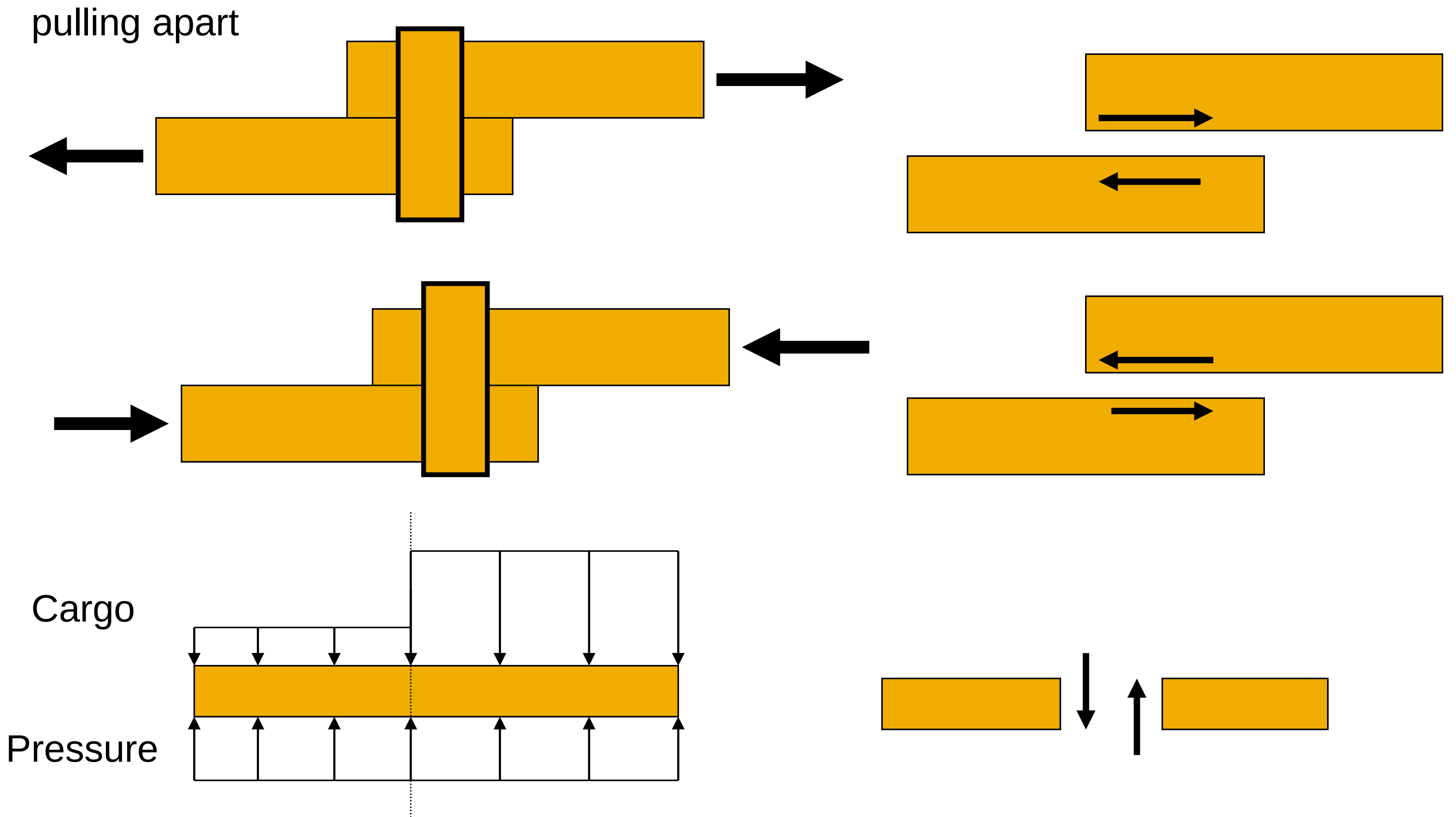
Classifying Loads on Materials

- **Normal Load (Axial load): Load is perpendicular to the supporting material.**
  - **Tension Load: As the ends of material are pulled apart to make the material longer, the load is called a tension load.**
  - **Compression Load: As the ends of material are pushed in to make the material smaller, the load is called a compression load.**



Classifying Loads on Materials

- **Shear Load : Tangential load**



Stress and Strain

In order to compare materials, we must have measures.

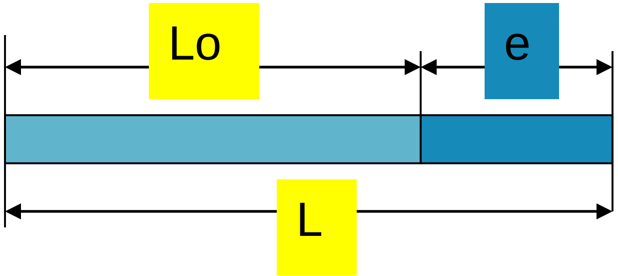
- **Stress : load per unit Area**

$$\sigma = \frac{F}{A}$$

F : load applied in pounds
A : cross sectional area in in²
σ : stress in psi

Stress and Strain

- **Strain:**
  - Ratio of elongation of a material to the original length
  - unit deformation



$$\boldsymbol{\varepsilon = \frac{e}{L_o}}$$

e : elongation (ft)

Lo : unloaded(original) length of a material (ft)

$\boldsymbol{\varepsilon}$: strain (ft/ft) or (in/in)

Elongation:

$$\boldsymbol{e = L - L_o}$$

L : loaded length of a material (ft)

Stress-Strain Diagram

Elastic Region (Point 1 –2) **The material will return to its original shape after the material is unloaded(like a rubber band). The stress is linearly proportional to the strain in this region.**

$$\sigma = E\varepsilon$$

or

$$E = \frac{\sigma}{\varepsilon}$$

σ : Stress (psi)
E : Elastic modulus (Young's Modulus) (psi)
ε : Strain (in/in)

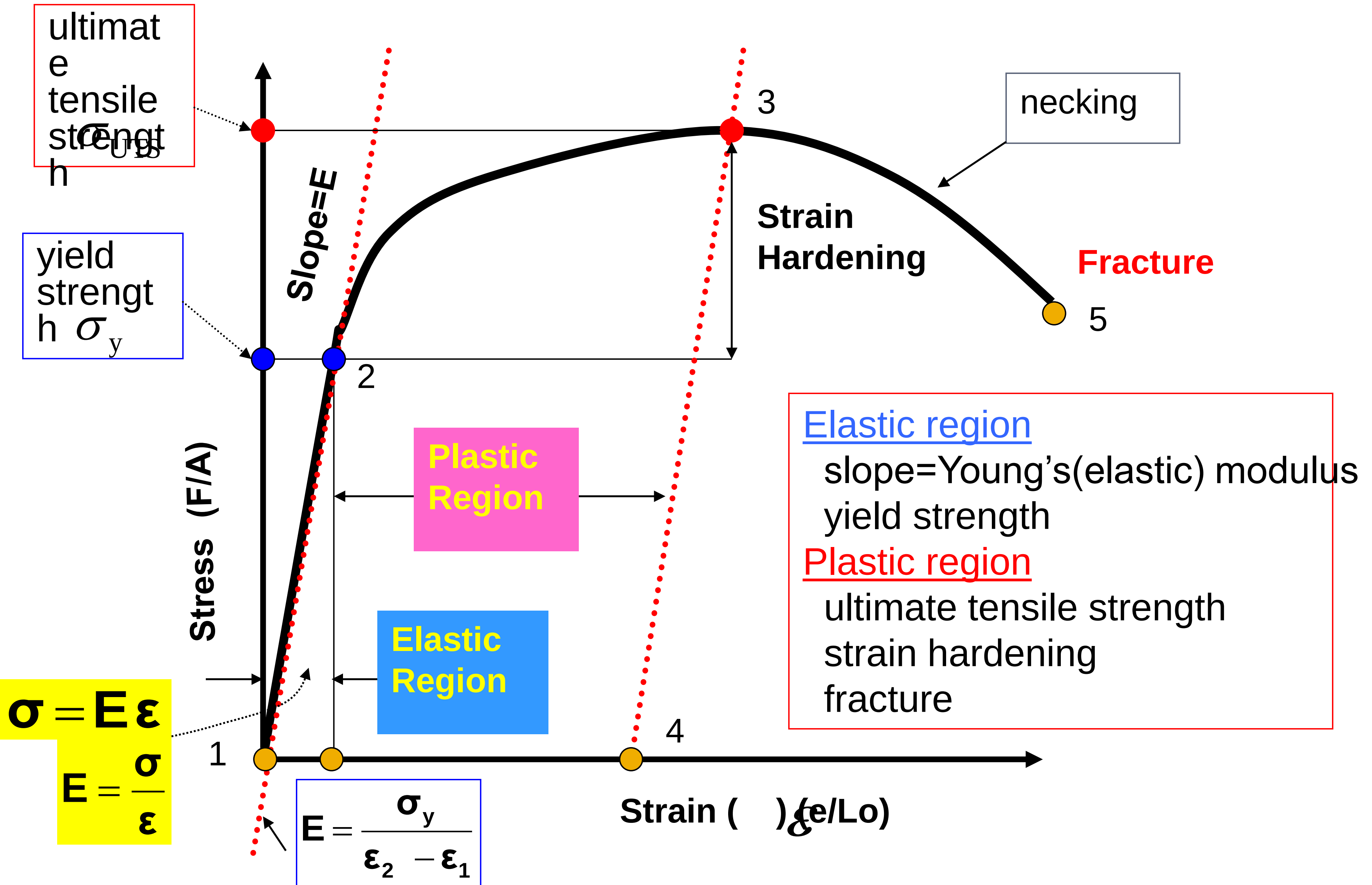
Point 2 : Yield Strength : a point at which permanent deformation occurs. (If it is passed, the material will no longer return to its original length.)

Stress-Strain Diagram

Plastic Region (Point 2 –3)

- **If the material is loaded beyond the yield strength, the material will not return to its original shape after unloading.**
- **It will have some permanent deformation.**
- **If the material is unloaded at Point 3, the curve will proceed from Point 3 to Point 4. The slope will be the as the slope between Point 1 and 2.**
- **The distance between Point 1 and 4 indicates the amount of permanent deformation.**

Stress-Strain Diagram



Plastic deformation

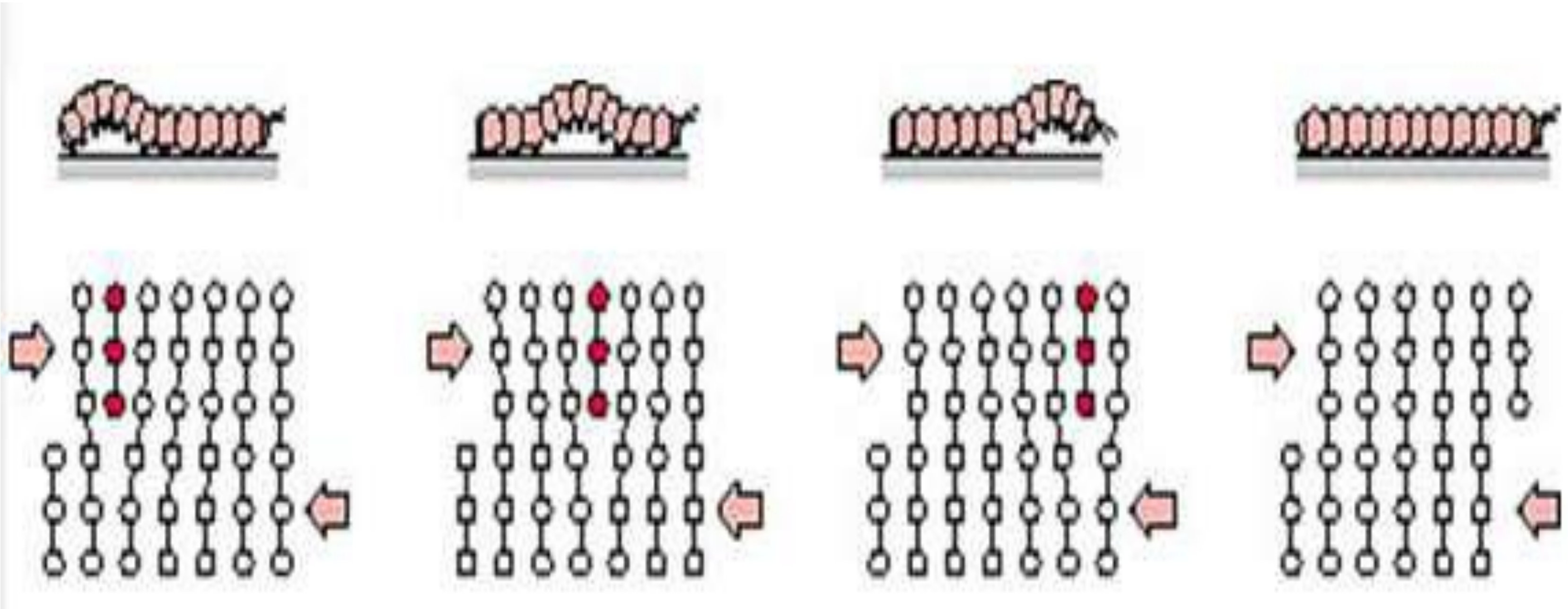
- If the solid body is loaded beyond the elastic limit, the body will experience a permanent change in shape and size, even if the load is removed.
- Plastic deformation of metals and alloys is generally studied under two categories

1. Plastic deformation of single crystals.
2. Plastic deformation of polycrystalline materials

Plastic deformation by slip

- Slip is the most common mode of plastic deformation among crystals.
- When a single crystal in tension is stressed beyond its elastic limit, a step appears such that the single crystal divides into two blocks
- When the tensile load is further increased, the blocks become again divided and relative displacement takes place.

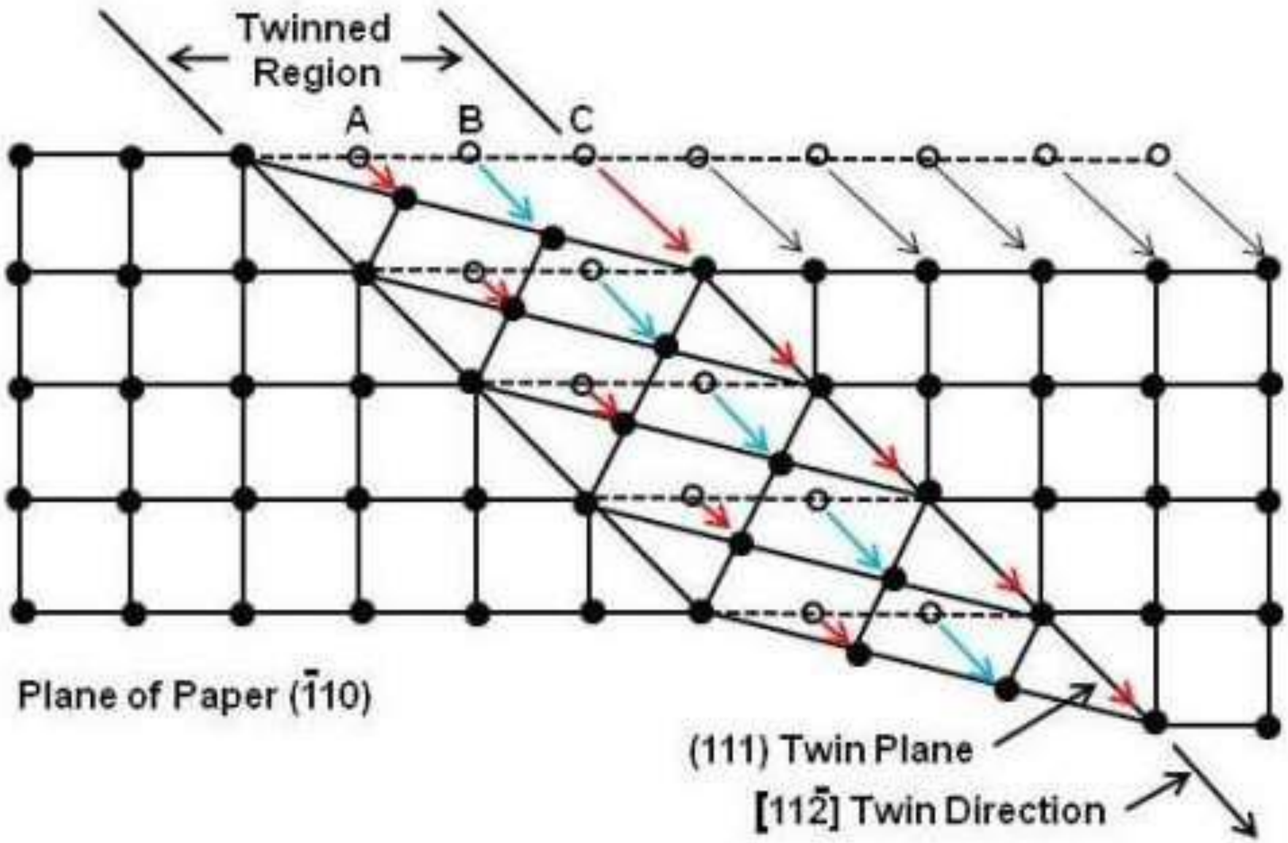
SLIP STEPS



PLASTIC DEFORMATION BY TWINNING

- In twinning each plane of atoms move through a definite distance and in the same direction.
- The extent of movement of each plane is proportional to its distance from the twinning plane.
- The atomic arrangement on either side of the twinned plane is in such a way that they are mirror reflections of each other

TWINNING



Schematic Diagram of Twinning in an f.c.c. Lattice

FRACTURE

Fracture is the separation of a solid body into two or more parts under the action of stress.

- Any fracture process involves two steps :
  i. Crack formation
  ii. Propagation
- For engineering materials, two fracture modes are possible
  1. Ductile
  2. Brittle

Types of fracture

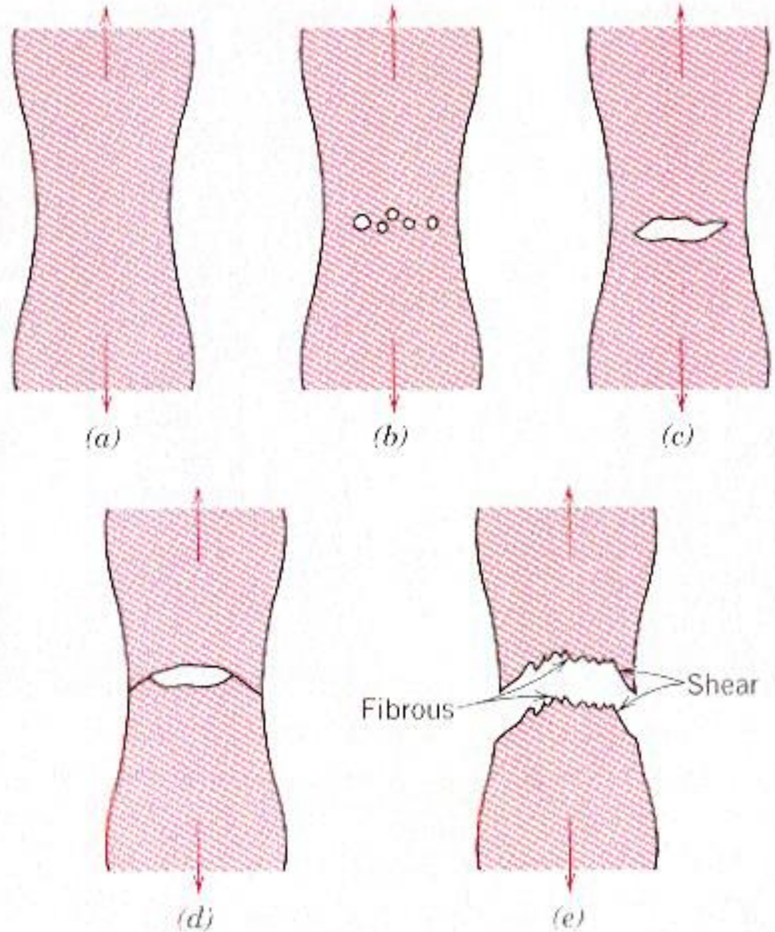


FIGURE 8.2 Stages in the cup-and-cone fracture. (*a*) Initial necking. (*b*) Small cavity formation. (*c*) Coalescence of cavities to form a crack. (*d*) Crack propagation. (*e*) Final shear fracture at a 45° angle relative to the tensile direction. (From K. M. Ralls, T. H. Courtney, and J. Wulff, *Introduction to Materials Science and Engineering*, p. 468. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

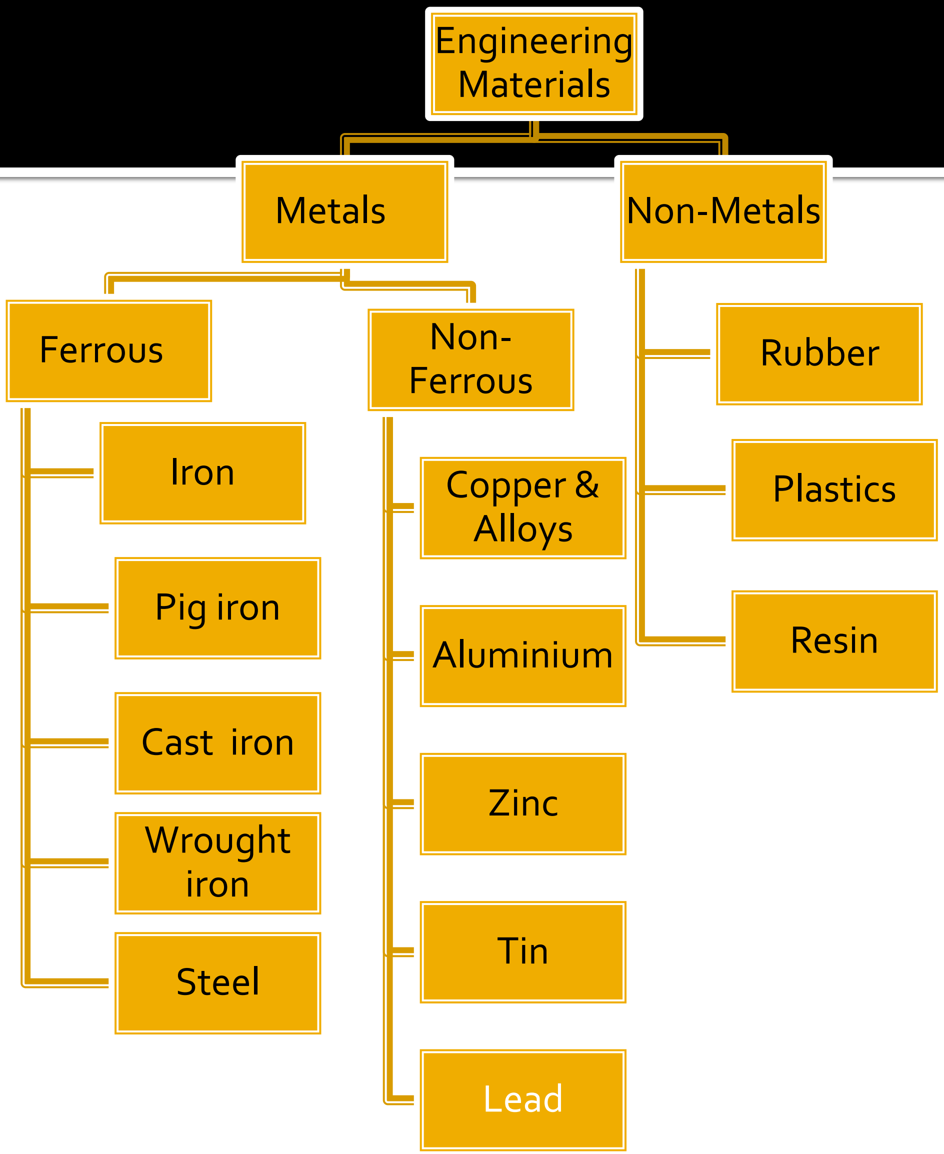
FATIGUE

The phenomenon that leads to fracture in metals and alloys under repeated fluctuating or alternating loads or stresses, too small to produce permanent deformation when applied statically, is called fatigue.

CREEP

The property of a material by virtue of which it undergoes slow plastic deformation under prolonged loading, usually at high temperature is called creep

METALS AND ALLOYS


Engineering Materials
Metals
Non-Metals
Ferrous
Non-Ferrous
Iron
Pig iron
Cast iron
Wrought iron
Steel
Copper & Alloys
Aluminium
Zinc
Tin
Lead
Rubber
Plastics
Resin

Metals

- **Metal** is an element, compound or alloy that is a good conductor of both electricity and heat
- **Metal crystal structure** and specific metal properties are determined by **metallic bonding** – force, holding together the atoms of a metal

Ferrous metals

- Iron
  - Pig iron
  - Cast iron
    - white cast iron
    - grey cast iron
  - Wrought iron

Iron

- **Iron** (Fe) – atomic number 26
- most widely used of all metals as base metal in steel and cast iron
- **Pig iron** - the intermediate product of smelting iron ore with a high-carbon fuel such as coke, usually with limestone as a flux

Cast iron

- **Cast iron** – is derived from pig iron
  - **White cast iron** is named after its white surface when fractured, due to its carbide impurities which allow cracks to pass straight through.

  - **Grey cast iron** is named after its grey fractured surface, which occurs because the graphitic flakes deflect a passing crack and initiate countless new cracks as the material breaks.

Wrought iron

- **Wrought iron** - iron alloy with a very low carbon content, in comparison to steel, and has fibrous inclusions (slag)

- tough, malleable, ductile and easily welded

Steel

- Steel
  - Cast steel
  - Stainless steel
  - High-speed steel

Steel

- **Steel** is an alloy that consists mostly of iron and has a carbon content between 0.2% and 2.1% by mass

- Carbon is the most common alloying material for iron, but various other alloying elements are used, such as **manganese, chromium, vanadium, molybdenum, tungsten, etc.**

Types of steels

- All of these steels are alloys of Fe and C
  - Plain carbon steels (less than 2% carbon and negligible amounts of other residual elements)
    - Low Carbon (less than 0.3% carbon)
    - Med Carbon (0.3% to 0.6%)
    - High Carbon (0.6% to 0.95%)
  - Low Alloy Steel
  - High Alloy Steel
  - Stainless Steels (Corrosion-Resistant Steels) – contain at least 10.5% Chromium

Plain Carbon Steel

Plain Carbon Steel

- **Lowest cost**
- **Should be considered first in most application**
- **3 Classifications**
  - Low Carbon (less than 0.3% carbon)
  - Med Carbon (0.3% to 0.6%)
  - High Carbon (0.6% to 0.95%)

Alloying Elements used in Steel

Manganese (Mn)

- combines with sulfur to prevent brittleness
- >1%
  - increases hardenability
- 11% to 14%
  - increases hardness
  - good ductility
  - high strain hardening capacity
  - excellent wear resistance
- *Ideal for impact resisting tools*

Alloying Elements used in Steel

Nickel (Ni)

- Provides strength, stability and toughness, Examples of Ni alloys:
  - 30xx – Nickel (0.70%), chromium (0.70%)
  - 31xx – Nickel (1.25%), chromium (0.60%)
  - 32xx – Nickel (1.75%), chromium (1.00%)
  - 33XX – Nickel (3.50%), chromium (1.50%)

Alloying Elements used in Steel

Chromium (Cr)

- Usually < 2%
- increase hardenability and strength
- Offers corrosion resistance by forming stable oxide surface
- typically used in combination with Ni and Mo
  - 30XX – Nickel (0.70%), chromium (0.70%)
  - 5xxx – chromium alloys
  - 6xxx – chromium-vanadium alloys
  - 41xxx – chromium-molybdenum alloys

Molybdenum (Mo)

- Usually < 0.3%
- increase hardenability and strength
- Mo-carbides help increase creep resistance at elevated temps
  - typical application is hot working tools

Alloying Elements used in Steel

Copper (Cu)

- 0.10% to 0.50%
- increase corrosion resistance
- Reduced surface quality and hot-working ability
- used in low carbon sheet steel and structural steels

Silicon (Si)

- About 2%
- increase strength without loss of ductility
- enhances magnetic properties

Stainless steel

- **Stainless steel** (**inox steel**) is a steel alloy with a minimum of 10.5 or 11% chromium content by mass.
- It does not corrode, rust, or stain with water as ordinary steel does.

High-speed steel

- **High speed steel** is commonly used in tool bits and cutting tools.
- It can withstand higher temperatures without losing its hardness. This property allows HSS to cut faster than high carbon steel, hence the name *high speed steel*.

The production of steel

1. Preparation of iron ore
   - Crushing
   - Screening
   - Roasting with limestone and coke in blast furnace

2. Pig iron = crude iron

   Main impurities: - carbon, silicon, manganese, sulphur, phosphorus

The production of steel

4. Cast iron – obtained by remelting pig

5. Steel alloys - to reach higher tensile strength, yield point, endurance limit, impact strength

Brief History

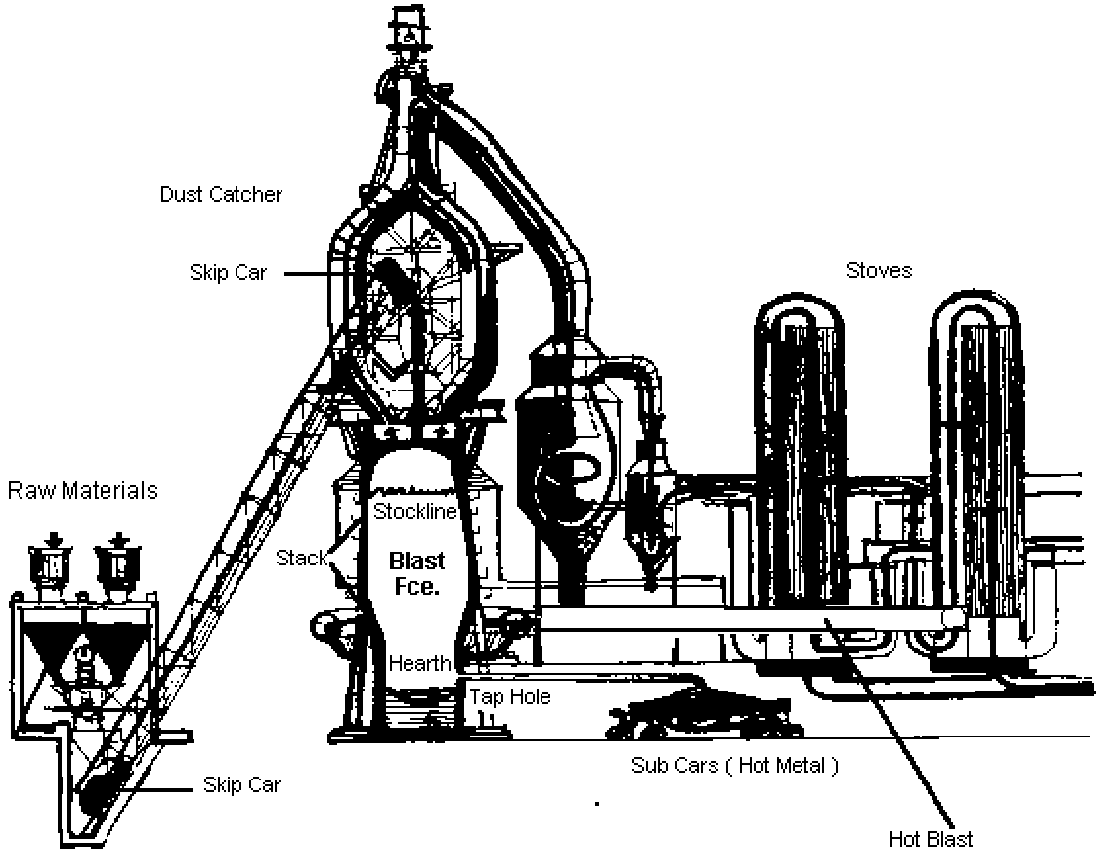
- Iron age (12th century BC) (mostly wrought iron) – weapons made with inefficient smelting methods. The best weapons? When iron combined with carbon!
- Became more common after more efficient production methods were devised in the 17th century.
- With invention of the Bessemer process in the mid-19th century, steel became relatively inexpensive, easily mass-produced and high quality.
- Blast Furnace then Bessemer Furnace

Low cost method for removing carbon and impurities

Raw material of Steel Making:

- Raw Material:
  - Carbon in the form of coke
  - Iron ore (Fe_2O_3)
  - Limestone ($CaCO_3$)
  - Air (lots of it!!)

Blast furnace



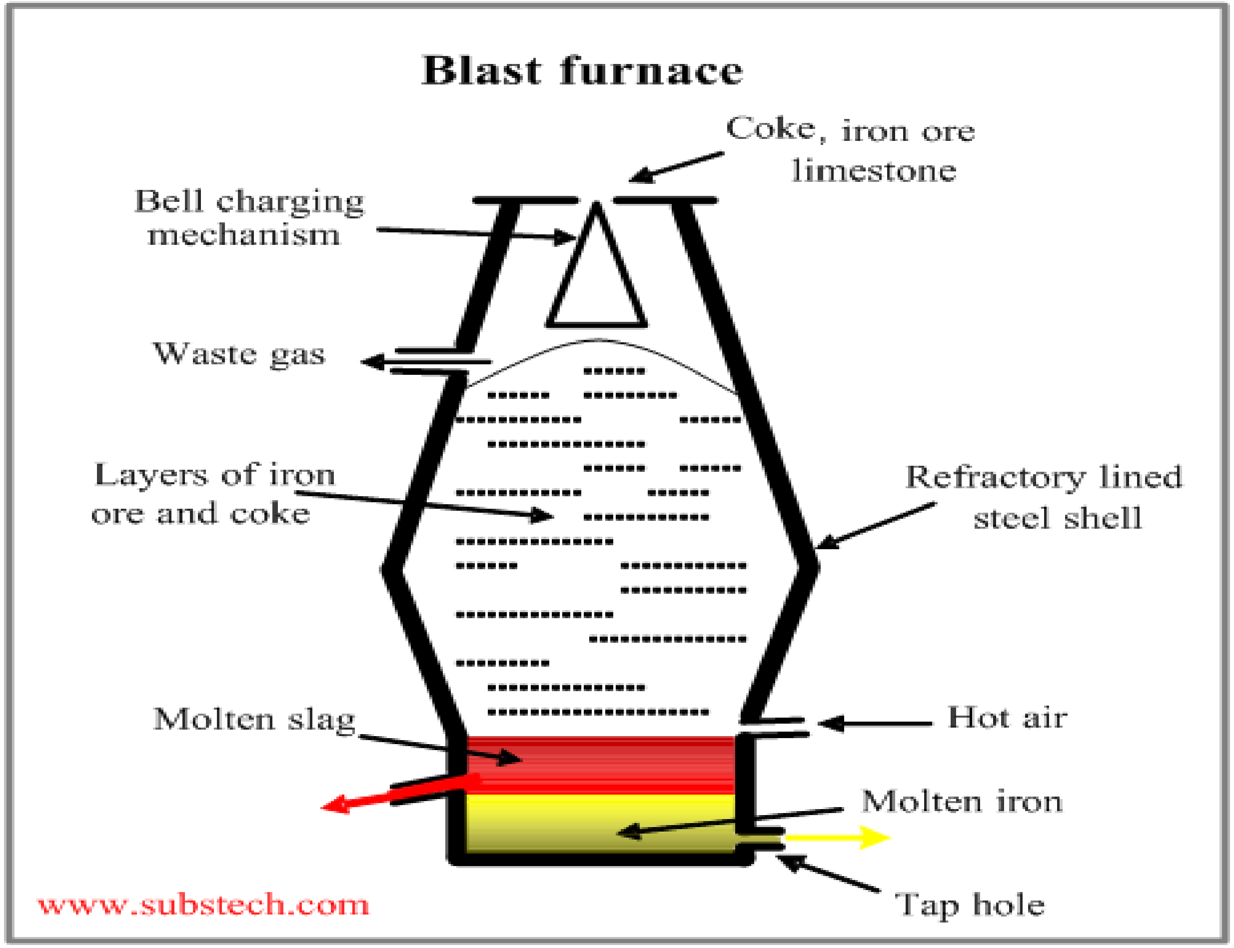
Blast furnace

- A **blast furnace** is a type of metallurgical furnace used for smelting industrial metals, generally iron.
- In a blast furnace, fuel, ore and limestone as flux are continuously supplied through the top of the furnace, while air (sometimes with oxygen enrichment) is blown into the bottom of the chamber, so that chemical reactions take place throughout the furnace as the material moves downward.

Blast furnace

- The end products are usually molten metal and slag phases tapped from the bottom, and flue gases exiting from the top of the furnace.

Blast furnace



Non-ferrous metals

- Copper
- Aluminium
- Zinc
- Tin
- Lead

Copper & Alloys

- **Copper –** Latin *cuprum* **(Cu)** – ranks next to iron in importance and wide range of application
- good heat and electrical conductivity
- resistance to corrosion
- **Alloys**: brass, bronze, cupro- nickel (copper nickel) alloys

Aluminium

- **Aluminium (BrE**) or **aluminum** (**AmE**) – Al, atomic number 13
- whitish with bluish cast
- the third most abundant element (after oxygen and silicon), and the most abundant metal in the Earth's crust

Aluminium

- low density and ability to resist corrosion; good conductivity
- structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials

Zinc

- **Zinc (Zn)**, atomic number 30
- bluish white
- corrosion resistant in air due to a thin oxide film forming on its surface
- used as a coating for protecting steel - **galvanisation** (or **galvanisation**) is the process of applying a protective zinc coating to steel or iron, in order to prevent rusting

Tin

- **Tin** – Latin *stannum* **(Sn)**, atomic number 50
- white, lustrous, soft, malleable, ductile, resistant to corrosion
- used as coating for steel and sheet iron
- **white metal** – tin based alloy with amounts of lead, copper and antimony – lining material

Lead

- **Lead** – Latin *plumbum* **(Pb)**, atomic number 82
- metallic lead has a bluish-white colour after being freshly cut, but it soon tarnishes to a dull grayish color when exposed to air
- has a shiny chrome-silver luster when it is melted into a liquid

Non-Metals

- **Non-Metals** are poor conductors of heat and electricity when compared to metals as they gain or share valence electrons easily (as opposed to metals which lose their valence electrons easily)
- usually have lower densities than metals;
they have significantly lower melting points and boiling points than metals
- brittle, non-ductile, dull (do not posses metallic luster)

Non-Metals

- Plastics
- Thermosetting polymer
  - Epoxy resin
- Thermoplastic
- Rubber

Plastics

- **Plastics:**
- immune to corrosion
- insulator
- unsuitable for higher temperatures
- to improve their properties additives are given

Thermosetting plastic

- A **thermosetting plastic**, also known as a **thermoset**, is polymer material that irreversibly cures. The cure may be done through heat (generally above 200 °C), through a chemical reaction (two-part epoxy, for example).

Thermosetting plastic

- **Thermoset materials** are usually liquid or malleable prior to curing and designed to be molded into their final form, or used as adhesives. Others are solids like that of the molding compound used in semiconductors and integrated circuits (IC).
- Once hardened, a thermoset resin cannot be reheated and melted back to a liquid form.

Epoxy resins

Epoxy resin – thermosetting plastic

- **usage**: chocking materials

Thermoplastic

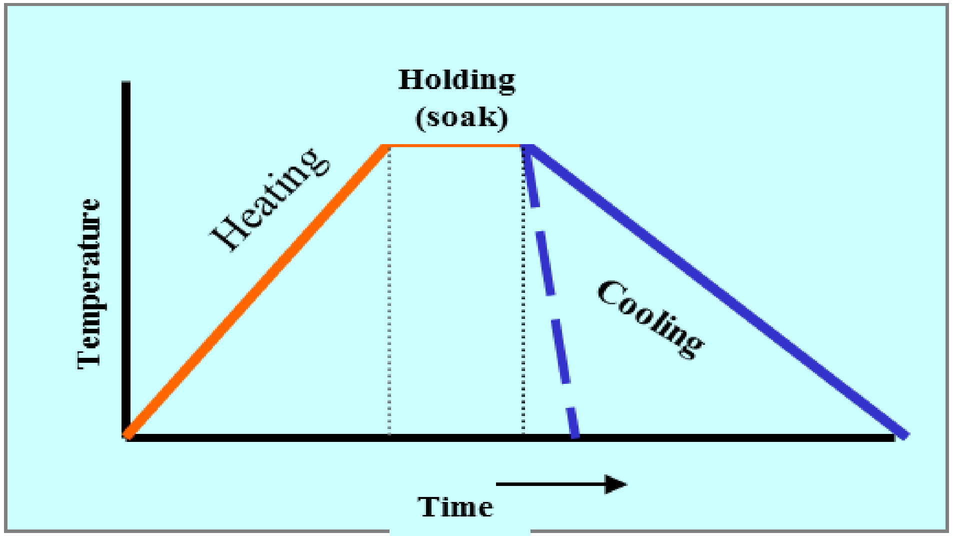
- **Thermoplastic**, also known as a **thermosoftening plastic** is a polymer that turns to a liquid when heated and freezes to a very glassy state when cooled sufficiently.
- Thermoplastic polymers differ from thermosetting polymers in that they can be remelted and remoulded.

Rubber

- **Rubber**
- rough, elastic material
- unaffected by water
- attacked by oil and steam
- **usage**: gaskets, flexible couplings, vibration mount

Theory of Heat Treatment

- Defined as the controlled heating and cooling of metals for the primary purpose of altering their properties (strength, ductility, hardness, toughness, machinability.



Purposes of Heat Treatment

- To relieve internal stress
- To improve machinability
- To refine grain size
- To soften the metal
- To improve the hardness
- To improve mechanical properties
- To increase resistance to wear, heat and corrosion.
- To improve ductility and toughness
- To change the chemical composition.

SOLID SOLUTION

When two metals are completely soluble into each other in the liquid state and retain this solubility and homogeneity even on solidification, the alloy so formed is called solid solution.

TYPES OF SOLID SOLUTION

1. Substitutional solid solution

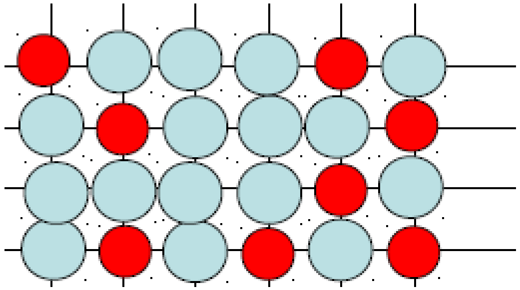
- When the atoms of solute substitute for the atoms of the solvent in its lattice, the solution is known as Substitutional solid solution.
- The solute may incorporate into the solvent crystal lattice substitutionally by replacing a solvent particle in the lattice.

Substitutional Solid Solution

Substitutional solid solution

Substitutional solid solution

Substitutional
element replaces host atoms in its lattice



Types of substitutional solution

1. Ordered substitutional solid solution

   The solute atoms occupy very orderly and definite positions in the crystal lattice of the solvent.

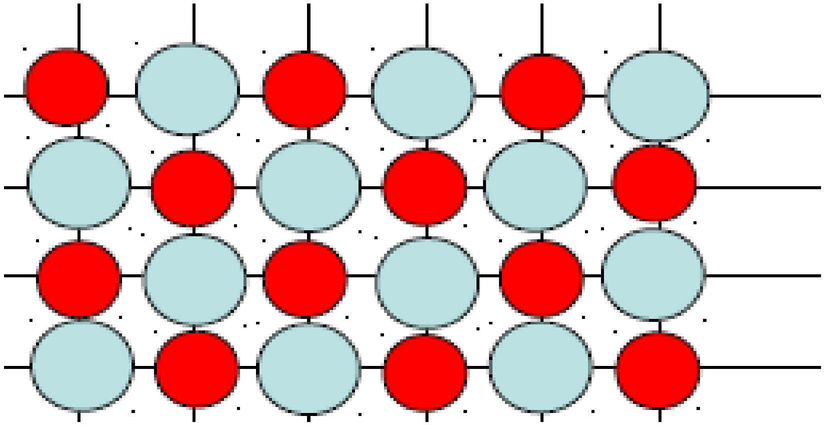
2. Disordered substitutional solid solution

   If the atoms of the solute are present randomly in the lattice of the solute, it is known as disordered solid solution.

Ordered substitutional solid solution

Substitutional

element replaces host atoms
in an orderly arrangement

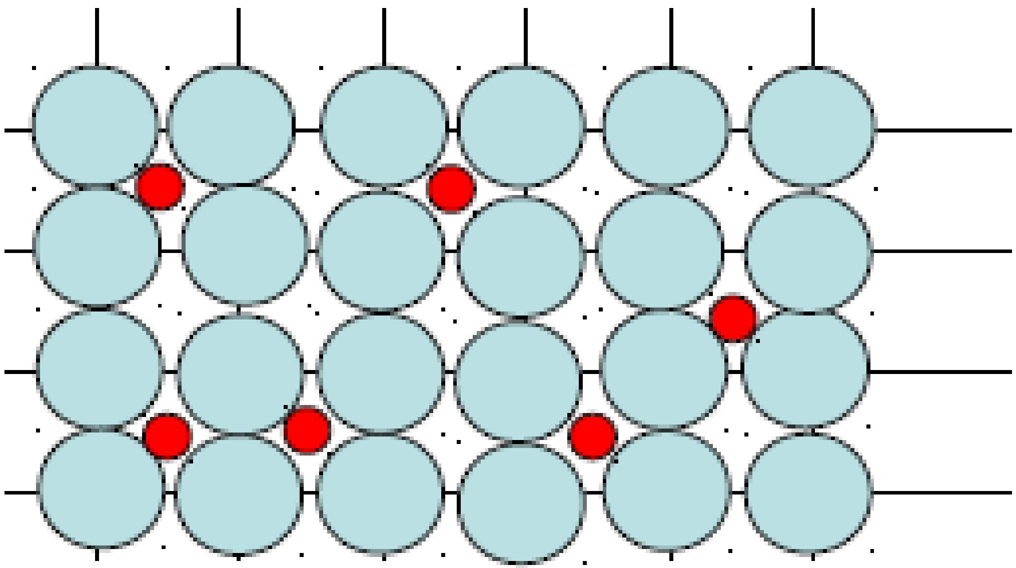


e.g., Ni-Al, Al-(Li,Zr)

Interstitial solid solution

- When the atoms of the solute occupy the interstitial spaces in the lattice of the solvent, it is known as Interstitial solid solution.
- If the size of the solute is less than 40% that of solvent, interstitial solid solution may be formed.
- The solute may incorporate into the solvent crystal lattice interstitially, by fitting into the space between solvent particles.

Interstitial solid solution



IRON-CARBON DIAGRAM

A map of the temperature at which different phase changes occur on very slow heating and cooling in relation to Carbon, is called

Iron- Carbon Diagram

Iron- Carbon diagram shows

- the type of alloys formed under very slow cooling,
- proper heat-treatment temperature and
- how the properties of steels and cast irons

Various Features of Fe-C diagram

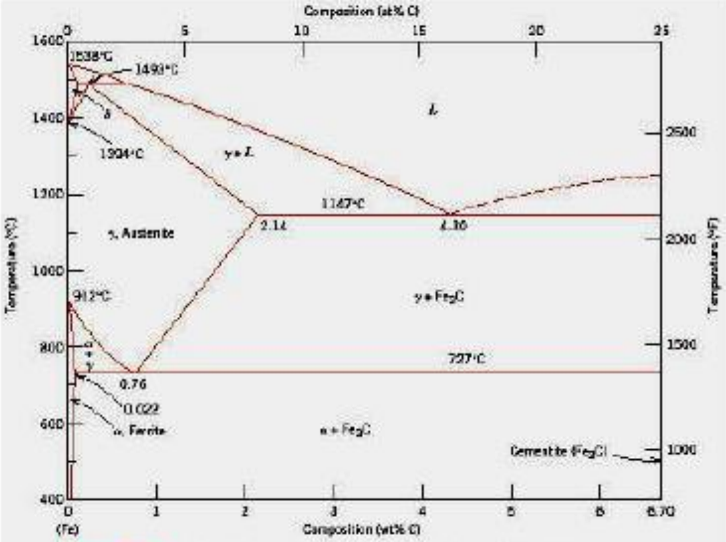


Figure 9.22 The iron–iron carbide phase diagram. (Adapted from *Binary Alloy Phase Diagrams*, 2nd edition, Vol. 1, T. B. Massalski, Editor-in-Chief, 1990. Reprinted by permission of ASM International, Materials Park, OH.)

Max. solubility of C in ferrite=0.022%

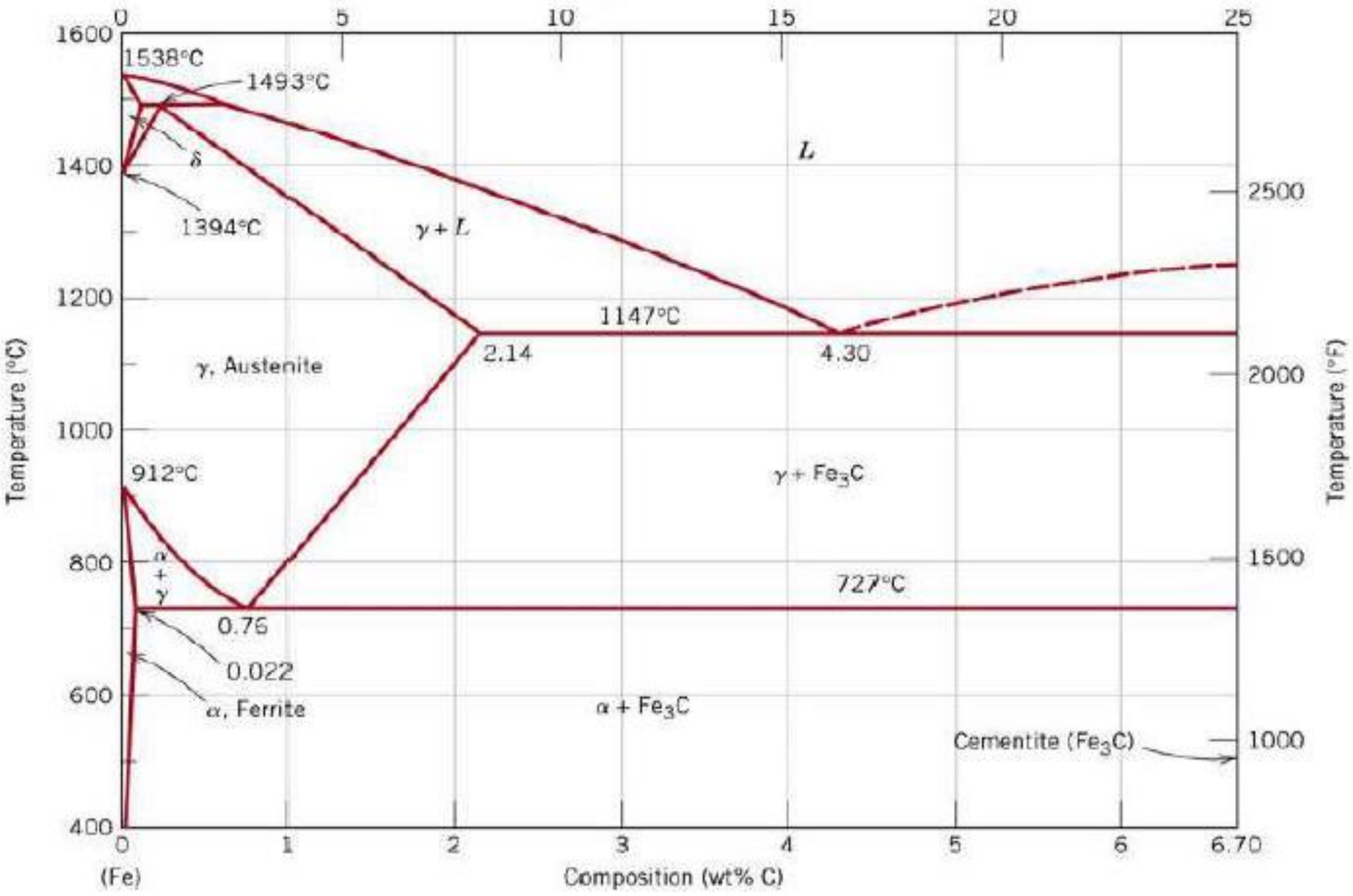
Max. solubility of C in %austenite=2%

• **δ–iron** exists between 1394°C and 1538 °C It may exist in combination with the melt to ~ 0.5 %wt C, with austenite to ~ 0.18 %wt C and in a single phase state to ~0.10 %wt C. Delta iron has the B.C.C crystal structure and is magnetic

• **Austenite- (γ) gamma-iron:** interstitial solid solution of carbon (up to 2.14wt%) dissolved in iron with a (F.C.C) structure. Stable up to 1394 °C. Non-magnetic phase.

• **Ferrite** - (α) ***alpha -iron***, which is an interstitial solid solution of a small amount (up to 0.022wt%) of carbon dissolved in iron with a B.C.C.crystal structure. Possesses polymorphic transformation to γ–iron at 912C It is the softest structure on the iron-iron carbide diagram. Magnetic below 768°C

Cementite - ***iron carbide:*** chemical formula, ***Fe_3C***, contains 6.67 % wt C. It is a typical hard and brittle interstitial compound of low tensile but high compressive strength.



1538°C
1493°C
δ
1394°C
L
γ + L
1147°C
2.14
4.30
γ, Austenite
912°C
γ + Fe3C
α
+
γ
727°C
0.76
0.022
α, Ferrite
α + Fe3C
Cementite (Fe3C)
Temperature (°C)
Temperature (°F)
Composition (wt% C)
(Fe)
1600
1400
1200
1000
800
600
400
2500
2000
1500
1000
0
5
10
15
20
25
0
1
2
3
4
5
6
6.70

Three Phase Reactions

- Peritectic, at 1490 deg.C, with low wt% C alloys (almost no engineering importance).
- Eutectic, at 1130 deg.C, with 4.3wt% C, alloys called cast irons.
- Eutectoid, at 723 deg.C with eutectoid composition of 0.8wt% C, two-phase mixture (ferrite & cementite).

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

- In order to understand the transformation processes, consider a steel of the eutectoid composition. 0.8% carbon, being slow cooled.
- At the upper temperatures, only austenite is present, with the 0.8% carbon being dissolved in solid solution within the FCC. When the steel cools through 723°C, several changes occur simultaneously.

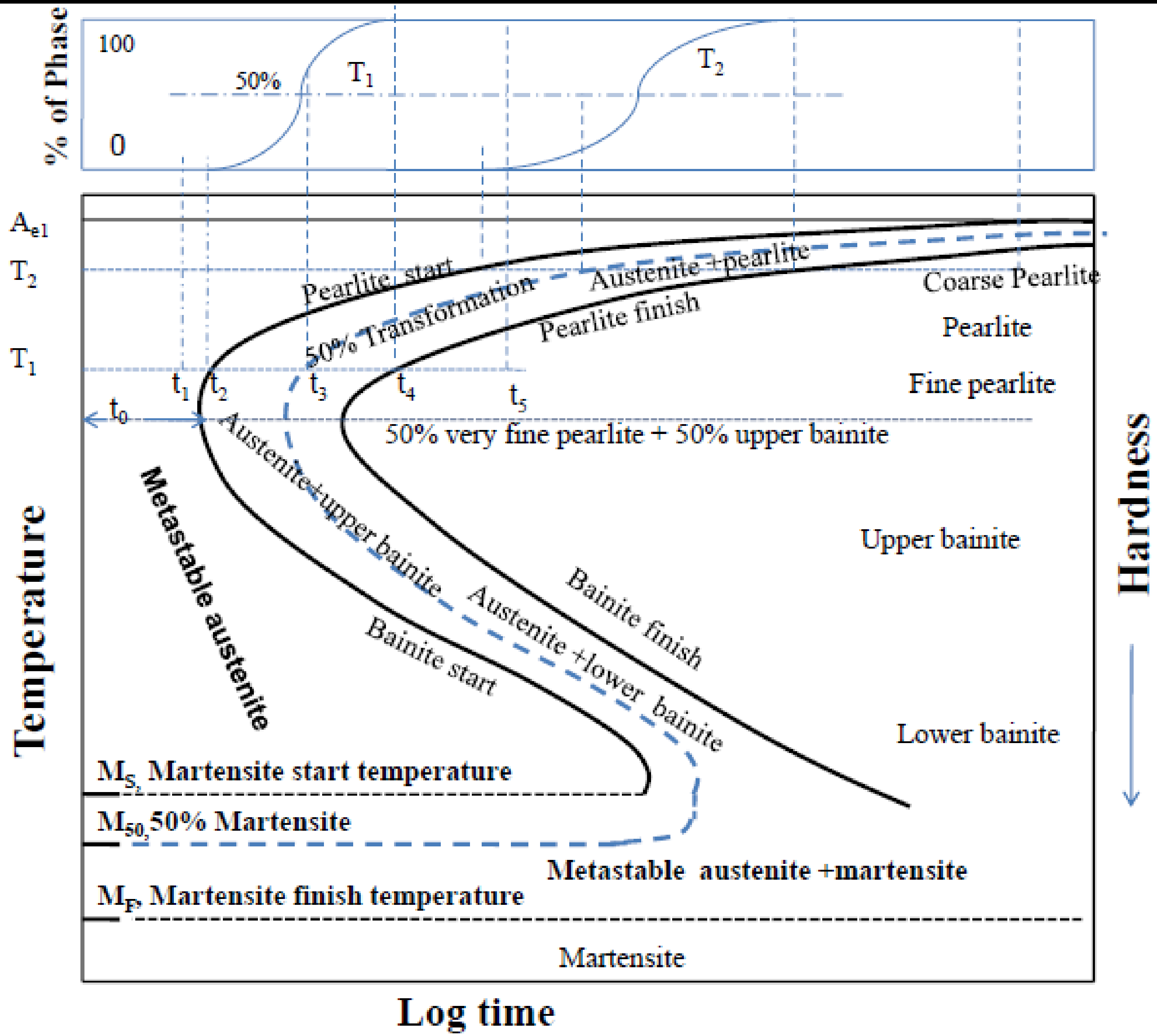
- The iron wants to change crystal structure from the FCC austenite to the BCC ferrite, but the ferrite can only contain 0.02% carbon in solid solution.
- The excess carbon is rejected and forms the carbon-rich intermetallic known as cementite.

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

- Indicates the amount of transformation at a constant temperature.
- 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.
- Obviously a large number of experiments are required to build up a complete TTT diagram.

TTT of a Eutectoid Steel



At T_1, incubation period for pearlite=t_2, Pearlite finish time =t_4

Minimum incubation period t_0 at the nose of the TTT diagram,

M_S=Martensite start temperature
M_{50}=temperature for 50% martensite formation
M_F= martensite finish temperature

TTT DIAGRAM

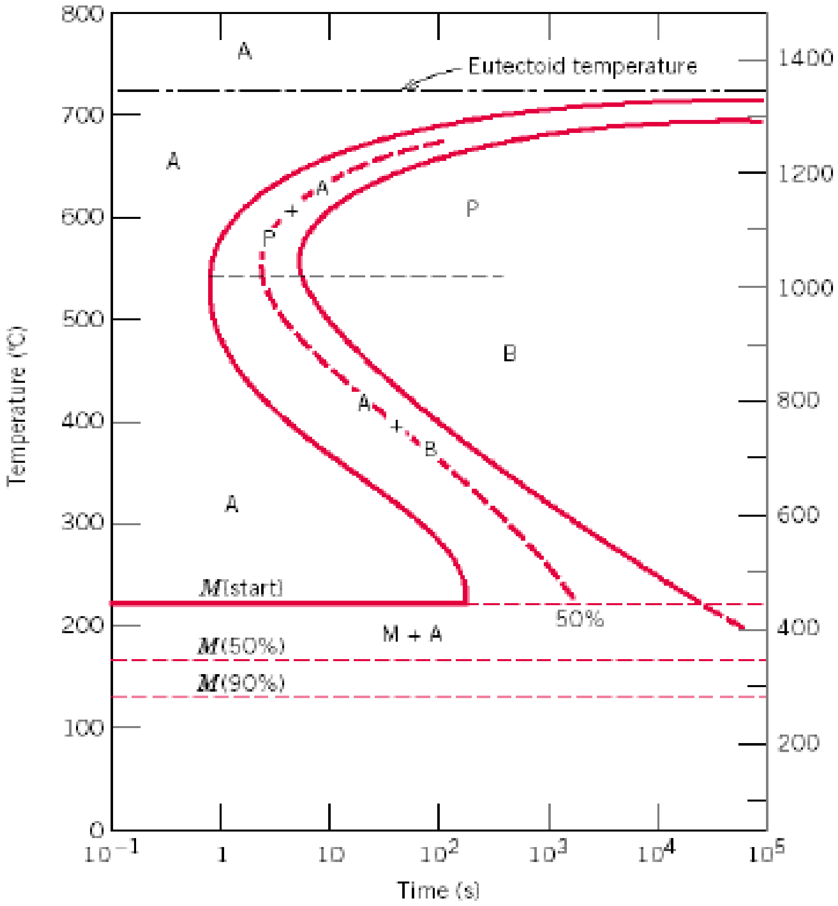
The complete TTT diagram for an iron-carbon alloy of eutectoid composition.

A: austenite

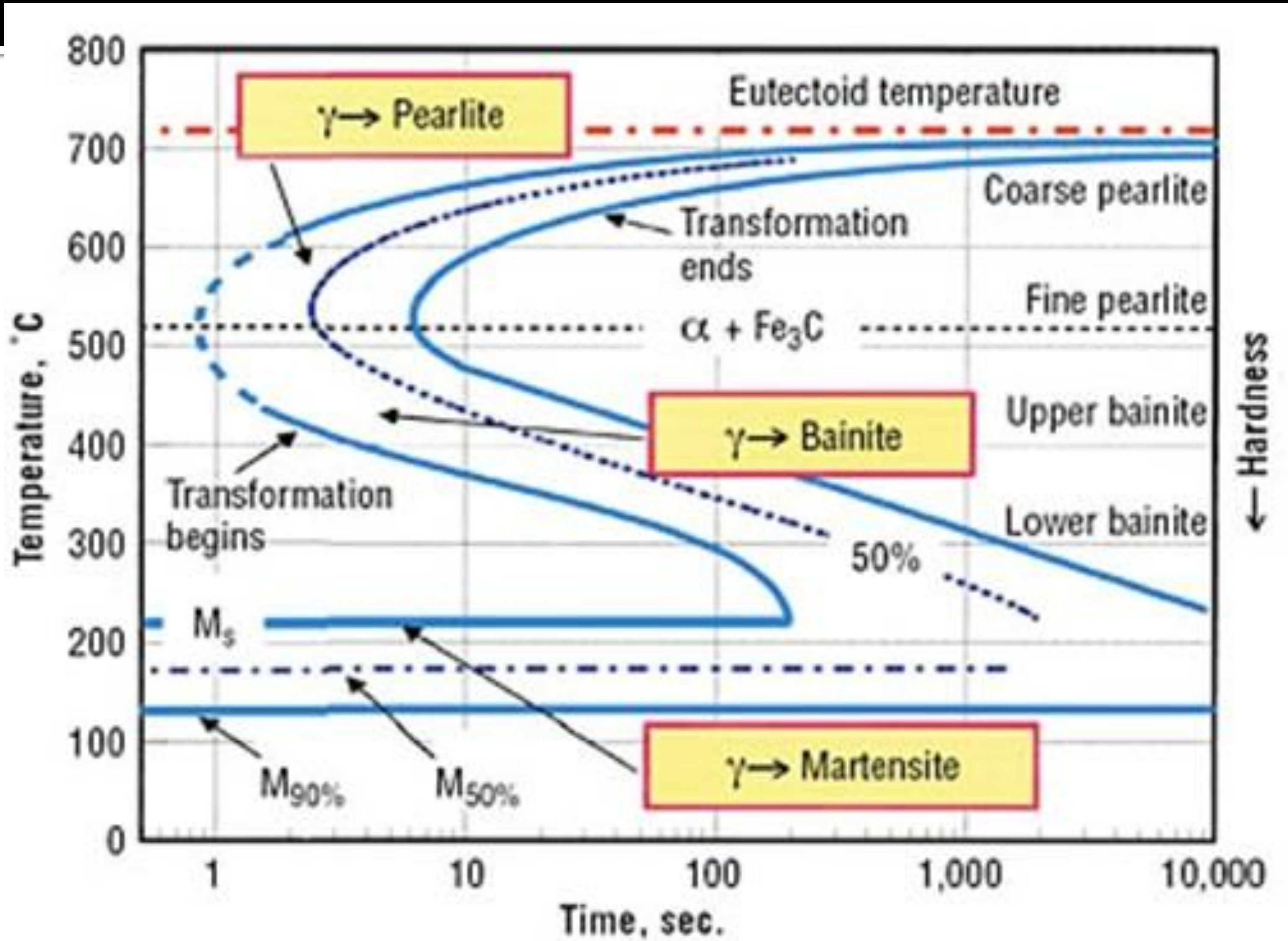
B: bainite

M: martensite

P: pearlite

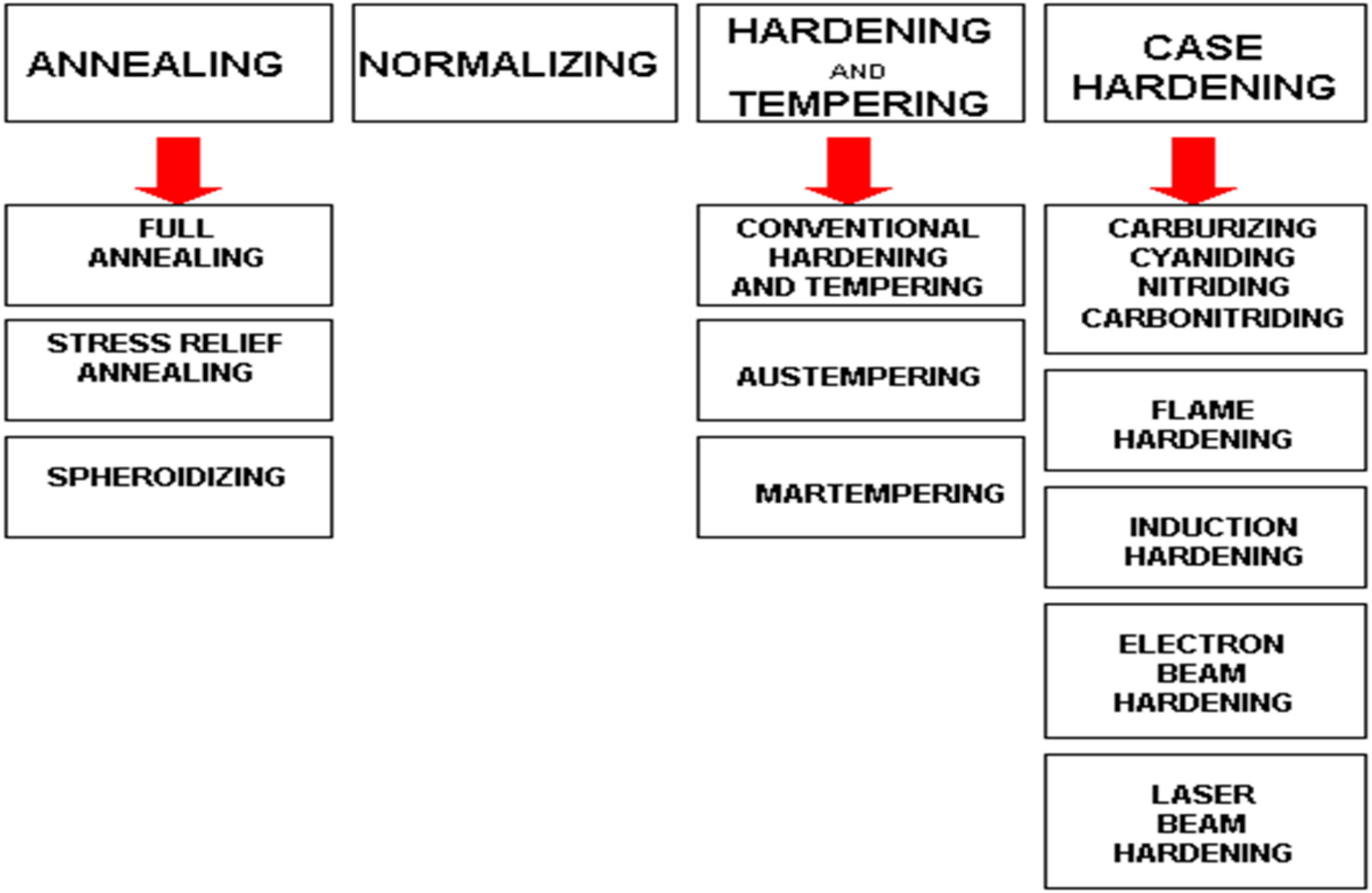


TTT



800
700
600
500
400
300
200
100
0
Temperature, °C
1
10
100
1,000
10,000
Time, sec.
γ→ Pearlite
Eutectoid temperature
Coarse pearlite
Transformation ends
Fine pearlite
α + Fe₃C
Upper bainite
γ→ Bainite
Lower bainite
Transformation begins
50%
Mₛ
γ→ Martensite
M90%
M50%
← Hardness

HEAT TREATMENT PROCESSES



Annealing

- It refers to a heat treatment in which the material is exposed to an elevated temperature for an extended time period and then slowly cooled.
- When an annealed part is allowed to cool in the furnace, it is called a "full anneal" heat treatment.

Types of Annealing

- Full Annealing
- Process Annealing
- Stress Relief Annealing
- Recrystallization Annealing
- Spheroidise Annealing

Full annealing

Main Objective:

- Soften the metal
- Relieve the stress
- Refine the structure.

Full Annealing

- Temp is 30 - 50° C above the upper critical temp for hypo eutectoid steel.
- 30 - 50° C above the lower critical temp for eutectoid steel.
- Cooling is done at the furnace at the rate of 10-30°C per hour.
- For hypo eutectoid steel the resulting microstructure is coarse pearlite and ferrite.

Stress Relief Annealing

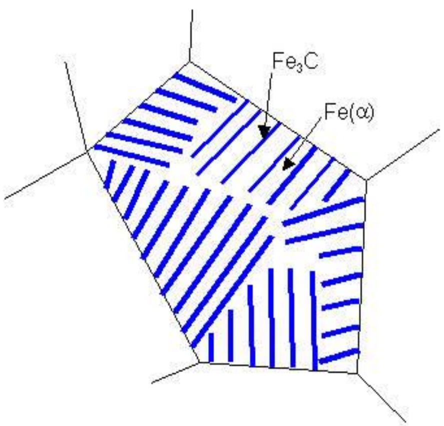
- Stress relief or recovery annealing.
- Annealing temp is at the range of 550-700°C.
- Uniform cooling is mandatory.
- It eliminates the stress formed during welding, cold working, casting, quenching, machining.

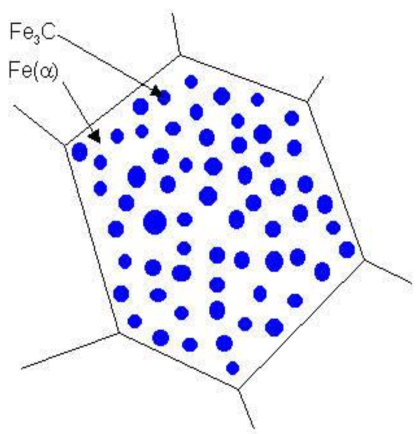
Recrystallization Annealing

- It is a process in which distorted grains of cool worked material are replaced by strain free new grains.
- Recrystallization annealing is an annealing process at temperatures above the recrystallization temperature of the cold-worked material, **without phase transformation.**
- The recrystallization temperature is not a constant for a material but depends on the amount of cold work, the annealing time, and other factors.

Spheroidizing

- Lamellar Pearlite → Globular Pearlite
- Plates of Cementite → Spheriods of Cementite





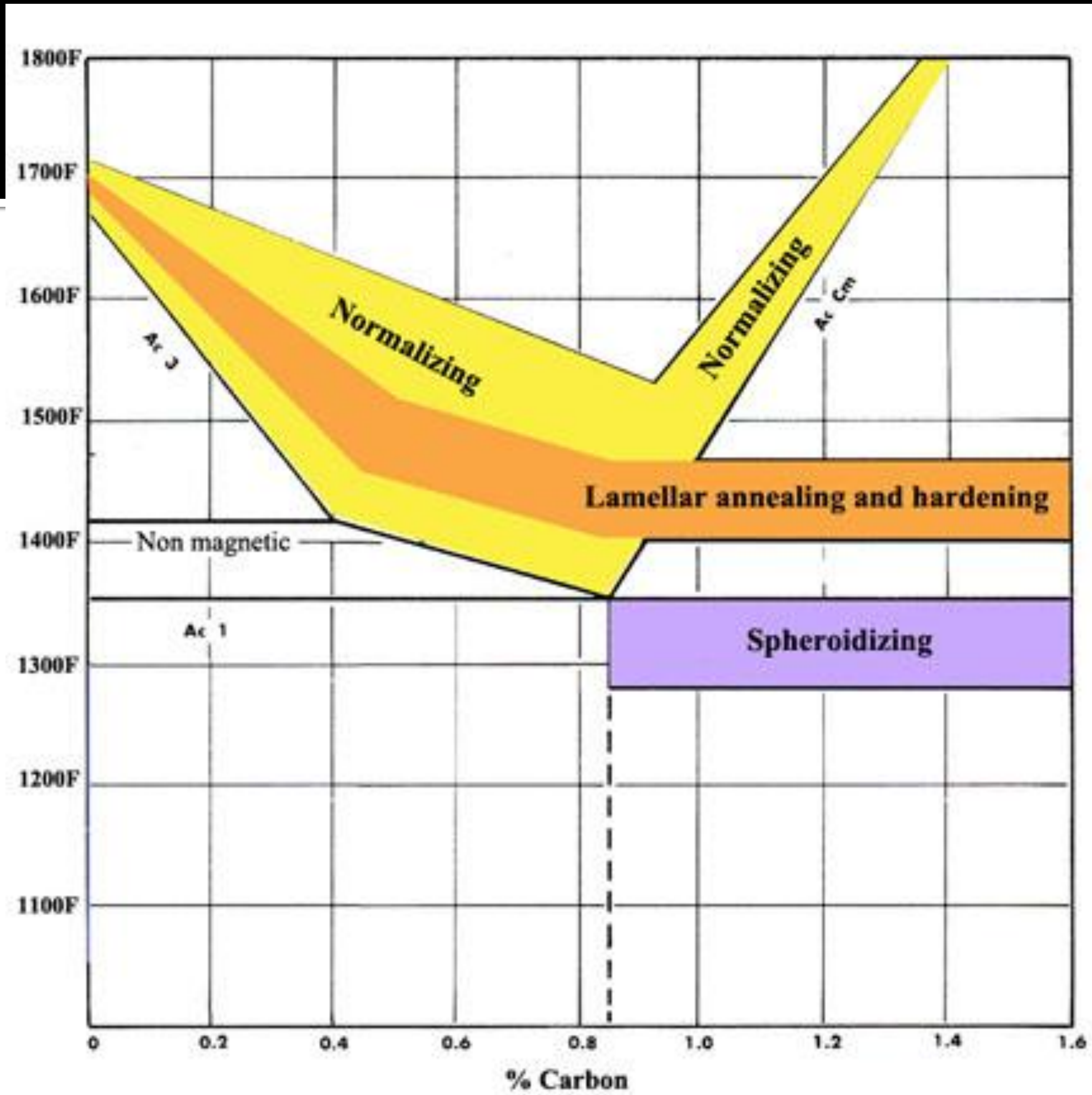
Spheroidized cementite in a ferrite matrix

Normalizing

- When an annealed part is removed from the furnace and allowed to cool in air, it is called a "normalizing" heat treatment.

Main Objectives:

- To refine grain structure.
- To remove strains
- To remove internal stress
- To remove dislocations
- To improve mechanical properties(strength, hardness and toughness)
- To improve machinability of low carbon steels.


1800F
1700F
1600F
1500F
1400F
1300F
1200F
1100F
Normalizing
Normalizing
Ac 3
Ac Cm
Ac 1
Lamellar annealing and hardening
Non magnetic
Spheroidizing
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
% Carbon

Hardening

- Increases the hardness
- Heat treatment which is used to produce Martensite predominately.

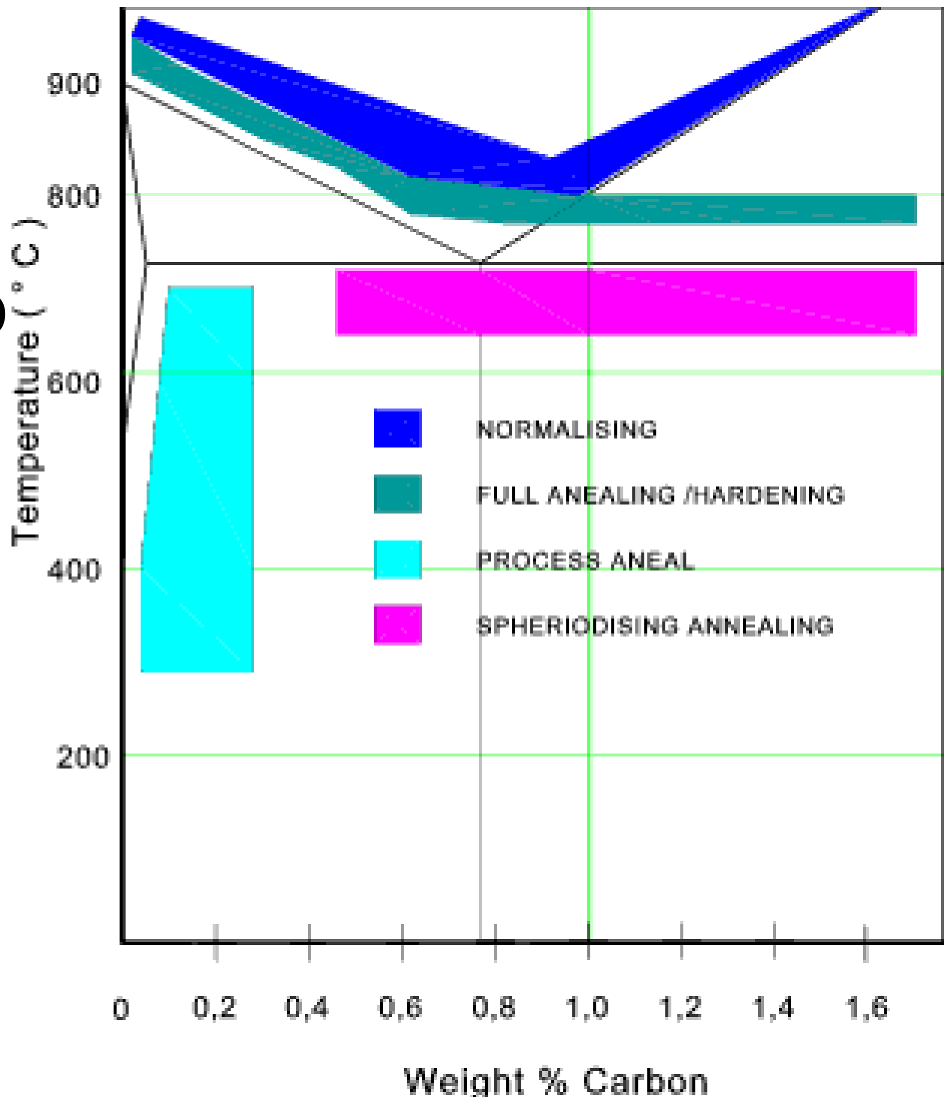
Objective:

- **To improve hardness**
- **To improve wear resistance**

Hardening

Steps:

- Heating
- Soaking → Comp
- Cooling.



TEMPERING

- It is heat treatment process in which extreme hardness and brittleness of an already hardened steel is reduced and its toughness is increased so as to make it suitable for particular purposes.

SURFACE HARDENING PROCESSES

- Low carbon steels cannot be hardened by heating due to the small amounts of carbon present.
- Case hardening seeks to give a hard outer skin over a softer core on the metal.
- The addition of carbon to the outer skin is known as carburising.

Pack carburising

- The component is packed surrounded by a carbon-rich compound and placed in the furnace at 900 degrees.
- Over a period of time carbon will diffuse into the surface of the metal.
- The longer left in the furnace, the greater the depth of hard carbon skin. Grain refining is necessary in order to prevent cracking.

- **Salt bath carburising.** A molten salt bath (sodium cyanide, sodium carbonate and sodium chloride) has the object immersed at 900 degrees for an hour giving a thin carbon case when quenched.
- **Gas carburising.** The object is placed in a sealed furnace with carbon monoxide allowing for fine control of the process.

NITRIDING

Nitriding is a surface hardening process in which a wear resisting surface can be produced by the absorption of nitrogen in certain type of steels (e.g containing AL, Cr, Mo) and no quenching is required.

CYANIDING

The process in which carbon and nitrogen are introduced into the surface of steel by heating it to a suitable temp. and holding it in contact with molten cyanide to form a thin skin or case which is quenched hardened.

ENGINEERING PLASTICS

PLASTICS

The plastics are synthetic organic materials which can be moulded into any desired shape when subjected to heat and pressure.

SOURCES OF PLASTICS

1. Plants -cellulose
2. Trees- latex, amber and resin can be extracted
3. Animals-horn and milk
4. Insects- shellac is obtained.

CLASSIFICATION OF PLASTIC

1. Thermoplastics

These are those plastics which do not become hard with the application of heat and pressure and no chemical change occurs in them. These can be used again and again.

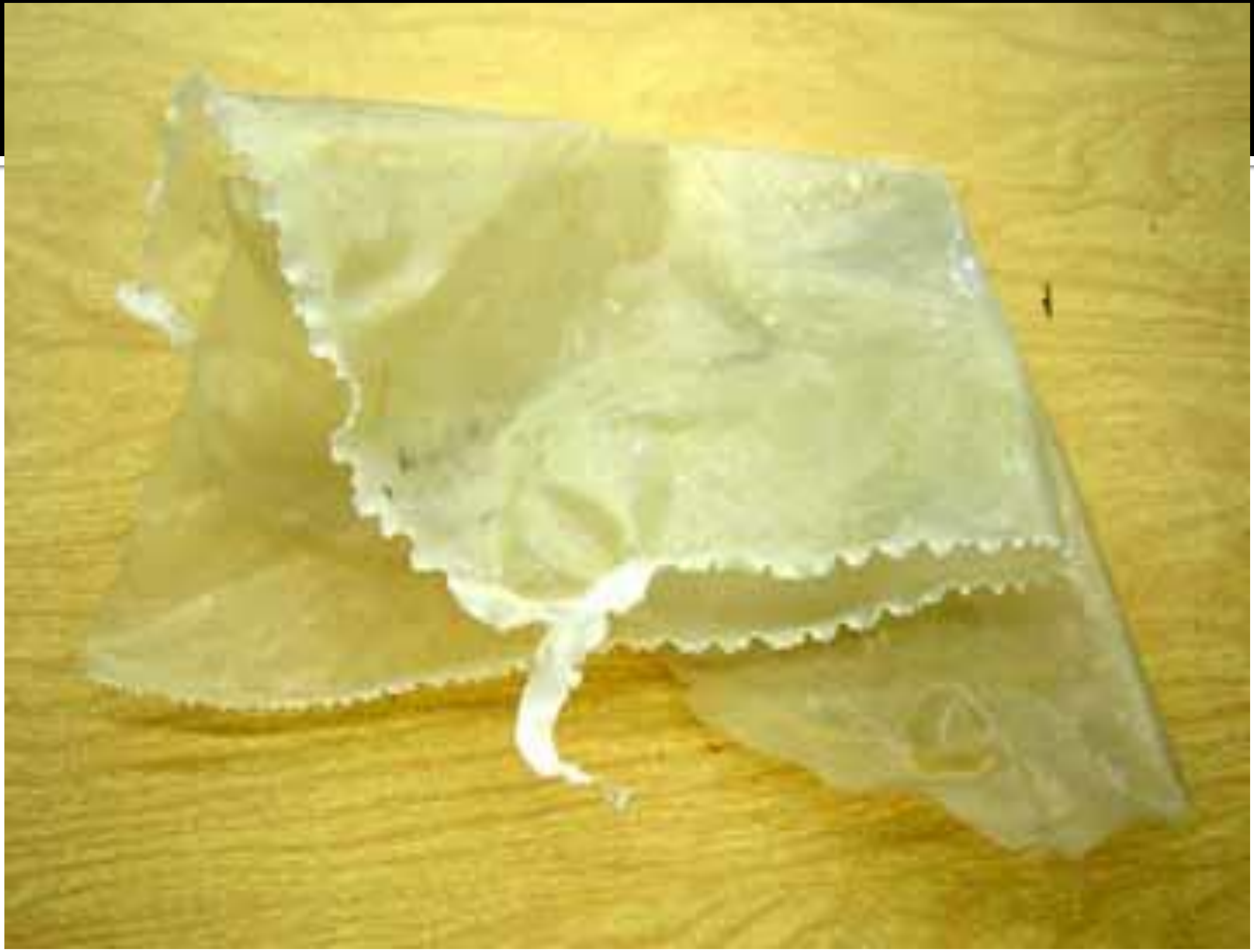
2. Thermosetting plastic

Those plastics which are formed into shape under heat pressure and result in permanently hard products.

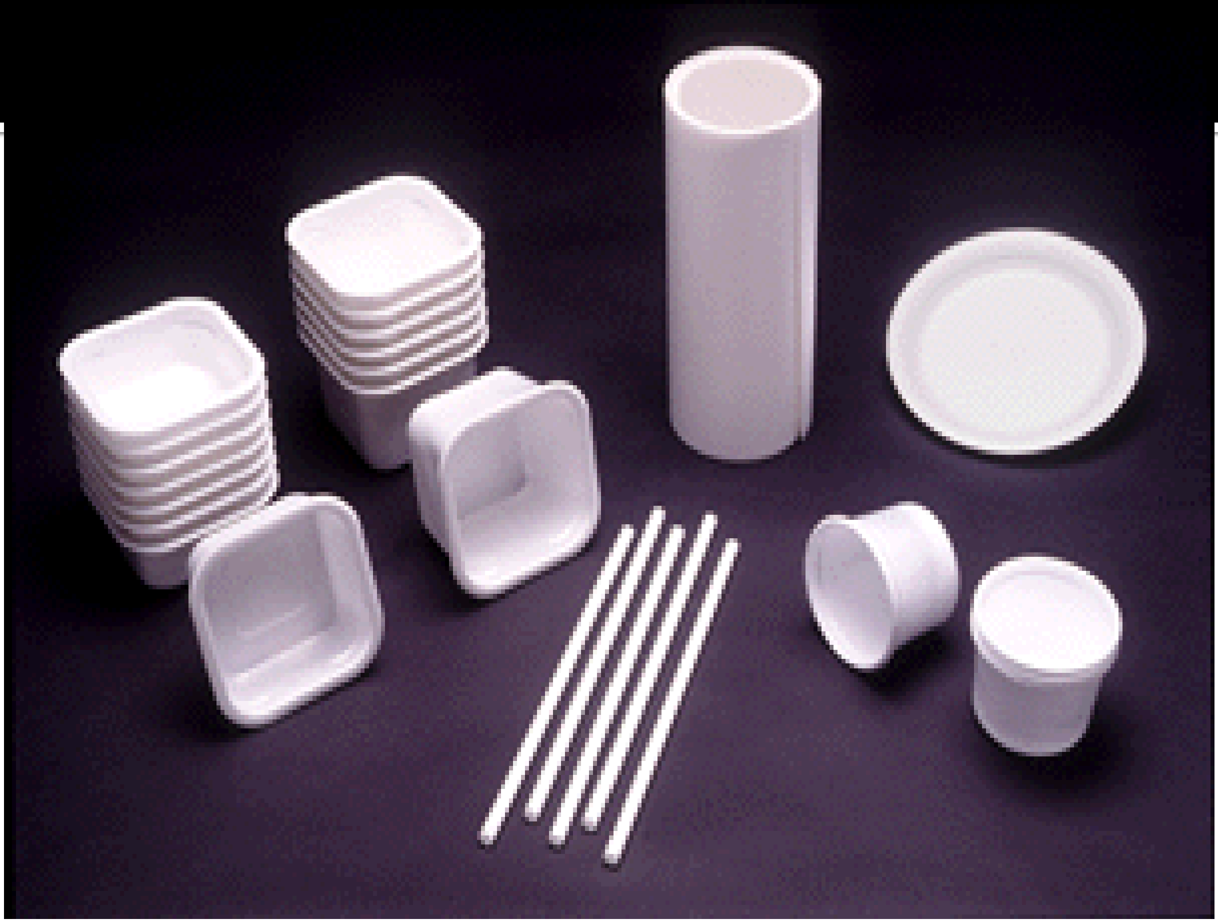
Types of thermoplastic resins

1. Polyethylene

- It is obtained by polymerization of ethylene.
- It is resistant to moisture and most chemicals.
- It is cheap
- It has good flexibility
- It is as bags for packaging, house ware dustbins and toys.



Polyethylene Plastic



Product Made Using Polyethylene

2. Polystrene

- it is obtained by polymerization of styrene in the presence of benzyl peroxide.
- It is brittle and lacks toughness.
- It has low impact resistance
- it is hard and brittle.
- Used in making toys, combs, buttons and radios.

Polystyrene Sheeting

3. Acrylic Resin

- It is produced by polymerization of ester or amide of acrylic acid.
- It has good light transmitting power
- It is moisture resistance and easily cut.
- It is used in making glasses, roof lights, shower doors and toilet articles.

Acrylic

Acrylic Shower Base, Screen and Door

4. Polyamide

- It is produced by reaction of a diamine with an organic acid.
- It is tough and stiff.
- It is good in wear resistance.
- It posses high temp. stability and good abrasion resistance.
- It is used for making gears, bushes and bearings.

5. Polyvinyl Chloride (PVC)

- Specific gravity about 1.39
- It's made from monomer, vinyl chloride
- Tensile strength low nearly like polystyrene
- It's an excellent insulator
- Used in raincoats and shower curtains
- Extensively used in floor tiles, electric cables, flexible sheeting, hoses, pipes, expansion joint filler, ,moldings, luggage, decorative wall coverings

Multi-Lock Industrial Warehouse Floor Tile Made Using PVC

PVC Vinyl Floor Tile

6. Polypropylene

- Has low specific gravity like polyethylene
- Low modulus of elasticity
- lightest material of all thermoplastics
- Has a higher softening point and shinier
- Good heat resistance but degrades under exposure to sunlight
- Has good abrasion resistance and hardness
- Used for pipes, sheets, geomembranes

Polypropylene Sheets Protector Pack

Types of thermosetting plastics
1. Phenolic Resin

- It is obtained by condensing phenol with formaldehyde in the presence of catalyst.
- It is hard, rigid and scratch resistant material.
- It has high electrical insulating property.
- It is cheapest materials in paints and varnishes.
- It is used in manufacturing cooking pots, knobs, caps, televisions and plugs.

2. Amino Resin

a) Urea formaldehyde

- It is manufactured by heating urea and formaldehyde.
- It has hard surface and high dielectric strength.
- It is light in weight.
- Used in making switch cover, plugs and buttons.

b) Melamine formaldehyde

- It is obtained from calcium carbide.
- It is odourless and tasteless.
- Used in making moulded cups, plates and bowls.

Rope Made Using Polyester

Beaker Made Using Phenol Formaldehyde

3. Silicon Resin

- It is synthesized from silicon tetrachloride and organic chloride.
- It is used as anti foaming agent.
- It has good resistance to water.
- It is good electrical resistor.
- Used in cosmetics, polishes and gaskets.

Advantages Of Plastic

- It has high damping capacity (ability to absorb part of the vibrational energy) that makes it suitable in application where vibration is encountered.
- Excellent water resistant.
  - It have low water-absorption properties making suitable as impervious membrane layers that could prevent movement of water. Application in foundation, water supply installation, for concrete curing

Conti…

- It's lower prices have contributed to the universal application of plastic. Low cost
- Plastics have a favorable strength / weight ratio. It has low density (less than half of the concrete and 1/7 steel)
- Since plastic is light, it present ease in handling, transportation, storage and assembly.
- Most plastics are generally maintenance free and have good corrosion resistance

Disadvantages Of Plastic

- It has low stiffness and strength which make it can be used for load bearing construction
- It is subject to creep, that is the increase in deformation, under load, with time
- Rate of creep of plastic higher than concrete
- Creep deformation increases with stress level
- Therefore, plastics become dimensionally unstable under load.

Plastic Coating

- It means to provide a layer of plastic on any surface of metal.
- It protects the surface of metal from corrosion.
- it should provide decorative finish.
- Appearance should be attractive.
- Have good adhesion property.

Methods of Plastic Coating

1. Dipping

   In this process dipping the cleaned base metal in hot condition to dip tank having coating material.

2. Vacuum Coating

- Plastic powder is collected in container
- Article to be coated is preheated
- Article and coating material both are placed in vacuum chamber
- Fusion process takes place on surface of coating material

ADVANCED MATERIALS

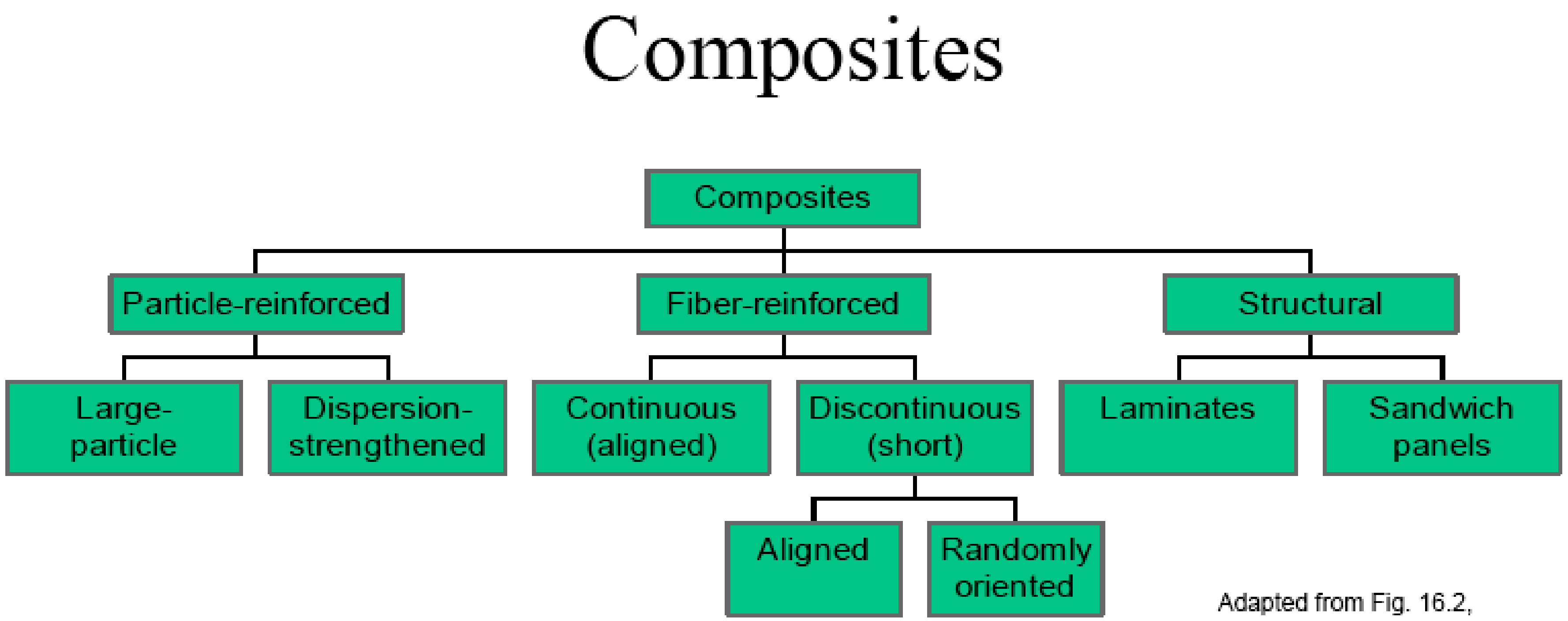
COMPOSITES

A materials system composed of two or more physically distinct phases whose combination produces aggregate properties that are different from those of its constituents

Examples:

- Cemented carbides (WC with Co binder)
- Plastic molding compounds containing fillers
- Rubber mixed with carbon black
- Wood (a natural composite as distinguished from a synthesized composite)

CLASSIFICATION OF COMPOSITES



Adapted from Fig. 16.2, *Callister 7e*.

Ceramics

Ceramics are inorganic, non metallic materials which are processed and used at high temperatures.

it includes substances such as glass, concrete, bricks and clay products etc.

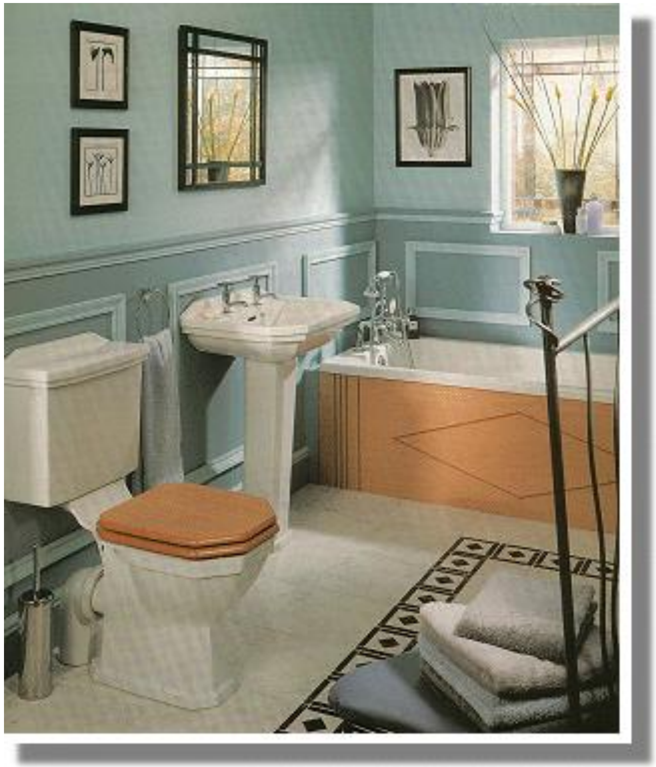
Types of Ceramics

- Whitewares
- Refractories
- Glasses
- Abrasives
- Cements

Whitewares

- Crockery
- Floor and wall tiles
- Sanitary-ware
- Electrical porcelain
- Decorative ceramics

Whiteware: Bathrooms

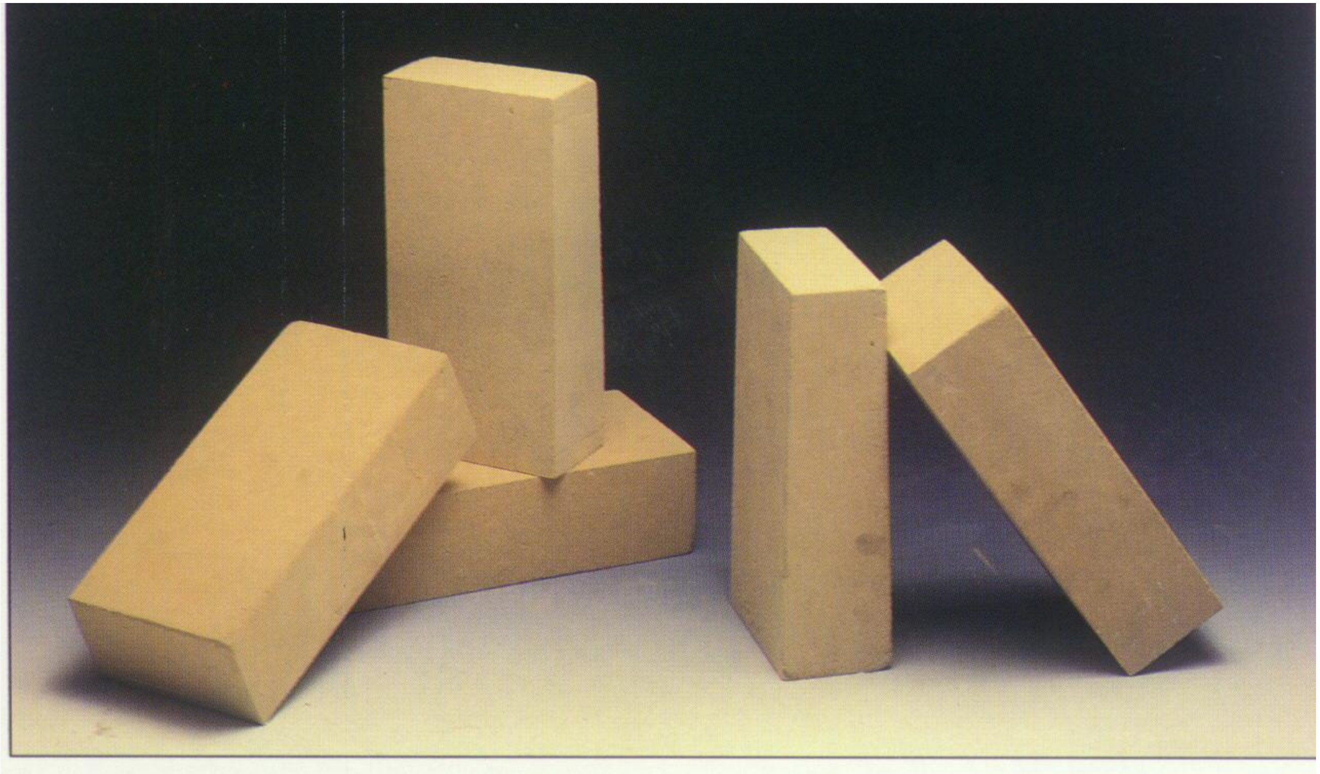


Refractories

Firebricks for furnaces and ovens. Have high Silicon or Aluminium oxide content.

Brick products are used in the manufacturing plant for iron and steel, non-ferrous metals, glass, cements, ceramics, energy conversion, petroleum, and chemical industries.

Refractory Brick



Amorphous Ceramics (Glasses)

- Main ingredient is Silica (SiO_2)
- If cooled very slowly will form crystalline structure.
- If cooled more quickly will form amorphous structure consisting of disordered and linked chains of Silicon and Oxygen atoms.
- This accounts for its transparency as it is the crystal boundaries that scatter the light, causing reflection.
- Glass can be tempered to increase its toughness and resistance to cracking.

Glass Types

Three common types of glass:

- Soda-lime glass - 95% of all glass, windows containers etc.
- Lead glass - contains lead oxide to improve refractive index
- Borosilicate - contains Boron oxide, known as Pyrex.

Glasses

- Flat glass (windows)
- Container glass (bottles)
- Pressed and blown glass (dinnerware)
- Glass fibres (home insulation)
- Advanced/specialty glass (optical fibres)

Glass in Buildings

Crystalline Ceramics

Good electrical insulators and refractories.

- Magnesium Oxide is used as insulation material in heating elements and cables.
- Aluminium Oxide
- Beryllium Oxides
- Boron Carbide
- Tungsten Carbide.
- Used as abrasives and cutting tool tips.

Abrasives

- Natural (garnet, diamond, etc.)
- Synthetic abrasives (silicon carbide, diamond, fused alumina, etc.) are used for grinding, cutting, polishing, lapping, or pressure blasting of materials

Cements

- Used to produce concrete roads, bridges, buildings, dams.

HEAT INSULATING MATERIALS

The material which retards or stops the flow of heat through its body is known as heat insulating material or thermal insulator

Examples

Cork, glass, wool and thermocole.

THANKYOU