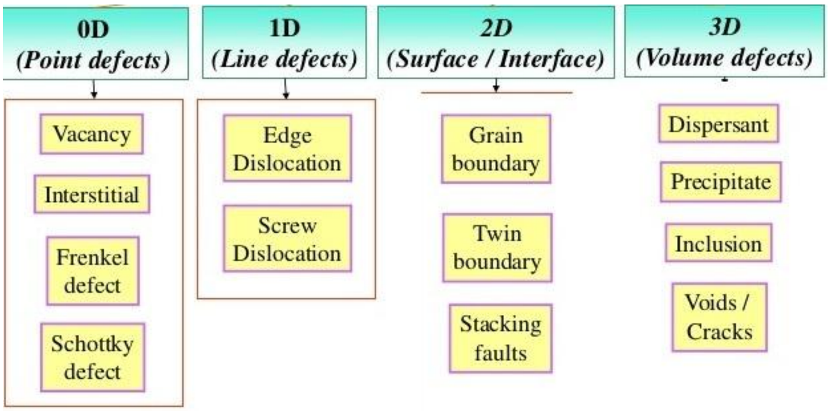
Imperfections in Crystals:

In reality a perfect crystal does not exist, Atoms or molecules in a crystal will not be of the same type & also their arrangements in the volume of a crystal will not be perfectly regular.

Imperfections have a beneficial effect on the mechanical properties of a material, So it is often intentionally created

They include



1) Point Defect (0D Defect) : When an Atom is missing in the regular lattice structure it is called as Point Defect, The Dimensions of a Point defect is close to a inter Atomic Space.

a) <u>Vacancy Defect</u>: A Vacancy refers to an Atomic site from where the Atom is missing. Due to Crystallisation or Thermal vibration of the Atoms

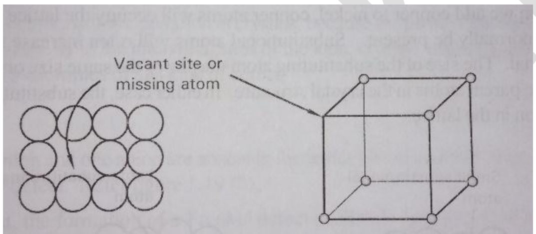


Figure 1.16 Vacancy defect

b) <u>InterStitial Defect:</u> A Small sized foreign atom occupies the space in between the Atoms of a crystal without dislodging any of the parent atom. Eg: Carbon in Iron

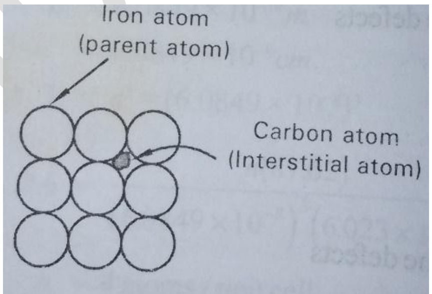


Figure 1.17 Interstitial defect

c) <u>Substitutional Defect:</u> Atom replaces parent atom & occupies its lattice site, this defect often increases strength of a material

Eg: Zn atom replaces Cu in FCC structure of Cu

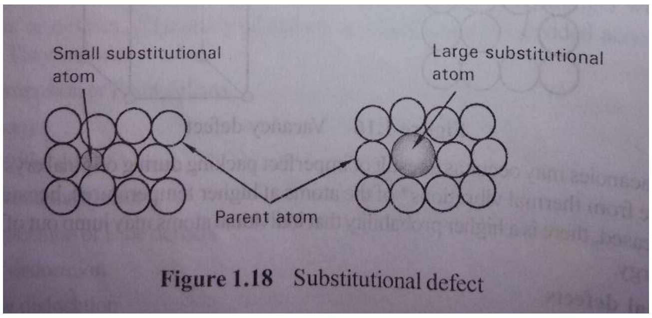
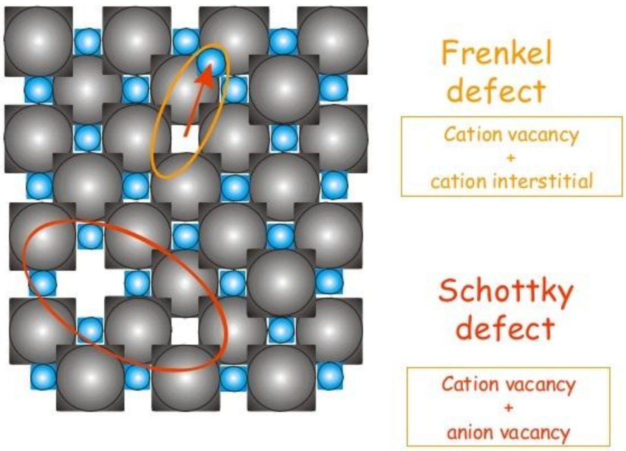


Figure 1.18 Substitutional defect

d) Frenkel Defect: When a +ve Cation vacates its position & moves in to the interstitial position in an ionic crystal , A Cation vacancy is created

it produces both Vacancy & interstitial Defect

Eg: imperfections of CaF & Silica Halides



e) Schottky Defect: Both Cation & Anions are missing but are found elsewhere in the same crystal

it creates only Vacancy, It decreases Density of crystals Eg: Nacl, KF

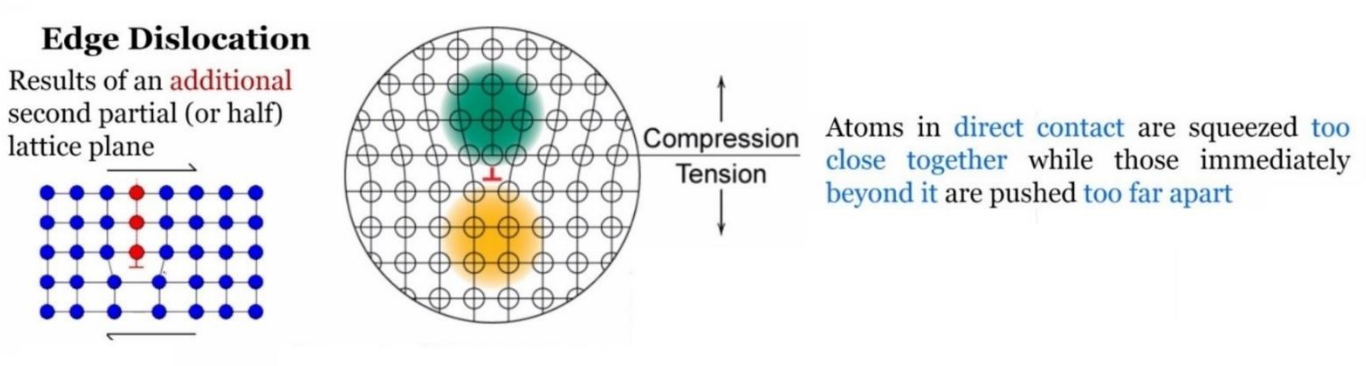
2) LineDefect (1D Defect)

Abrupt changes in the regular ordering of atoms along a Line in a crystal structure. Dislocations are introduced in to a crystals during Solidification of the metal or during permanent deformation. Defective points produced in the Lattice by the DisLocation, lie along a Line, So it is called Line Defect

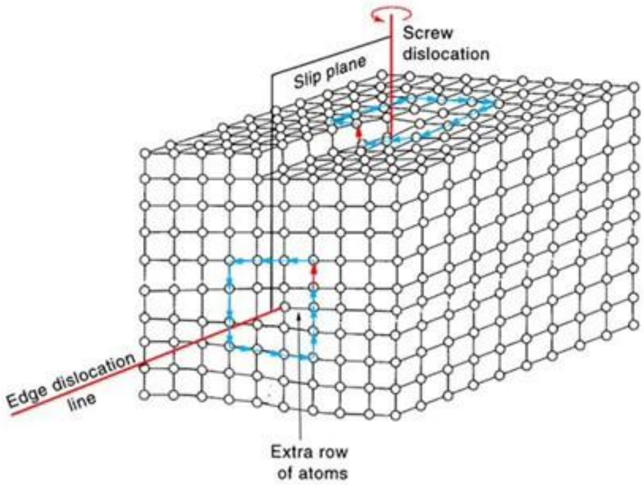
LineDefects are responsible for Slip.

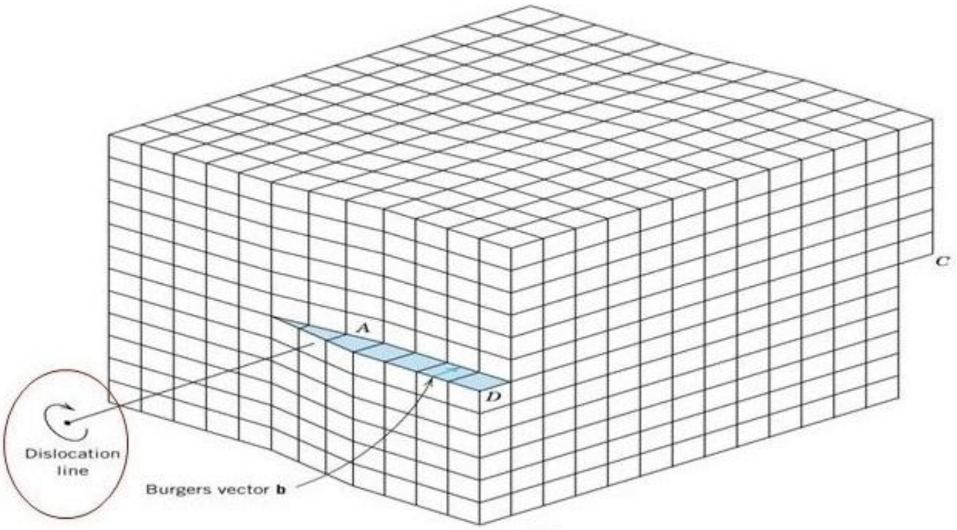
Types of LineDefect:

a) **<u>Edge Dislocation:</u>** Created due to the Insertion of an extra half Plane of Atom, Due to this Metal possesses High Plasticity, Ductility & malleability, Burger Vector is always Perpendicular to the Edge dislocation line

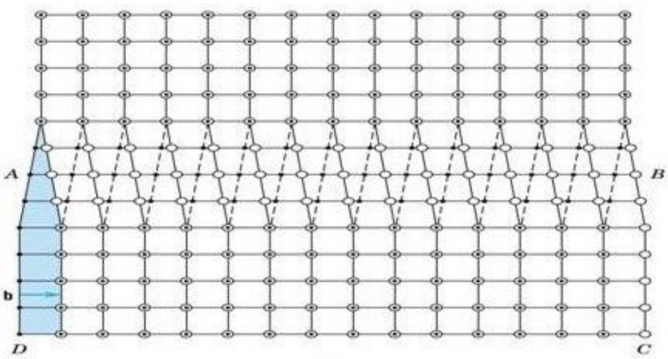


b) **<u>Screw Dislocation</u>:**
It is formed when a Crystal displaces angularly over the remaining part, Burger Vector is Always parallel to the Screw dislocation line





(a)



(b)

Screw Dislocation within a Crystal, Top View of the Above Sketch..

Screw Dislocation as a result of Shear Stress,

Burger Vector: Magnitude & Direction of the Displacement of Atoms in a Dislocation, It is important in closing the Circuit of the Dislocation Trajectories

Burger Vector is Always Parallel in Screw Dislocation

Dislocation Line Extends along the line AB. Atom position above the Slip plane are designated by Open Circles, those below the Solid circles

---

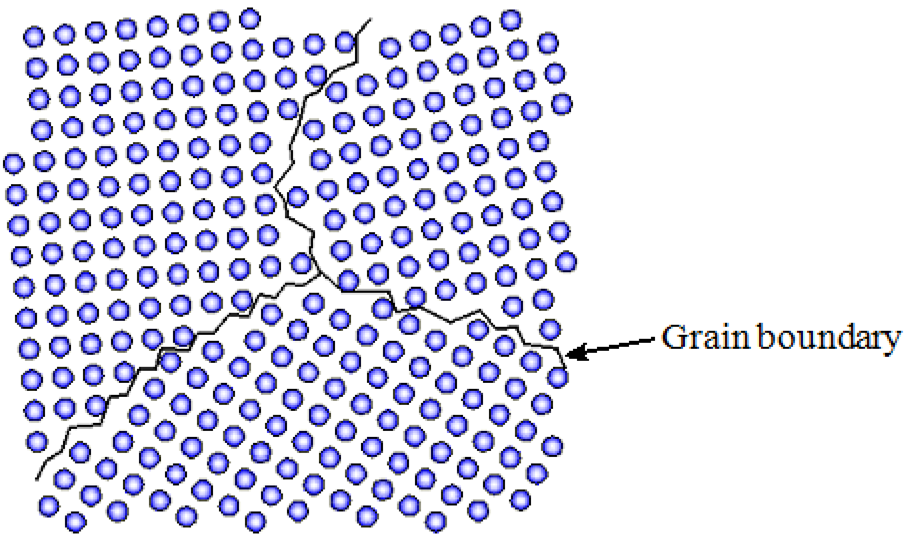
Surface Defects (2D Defect): it occurs due to the orientation of the atomic Planes & Stacking sequence of atoms in Planes

it occurs due to Solidification, Heat Treatment

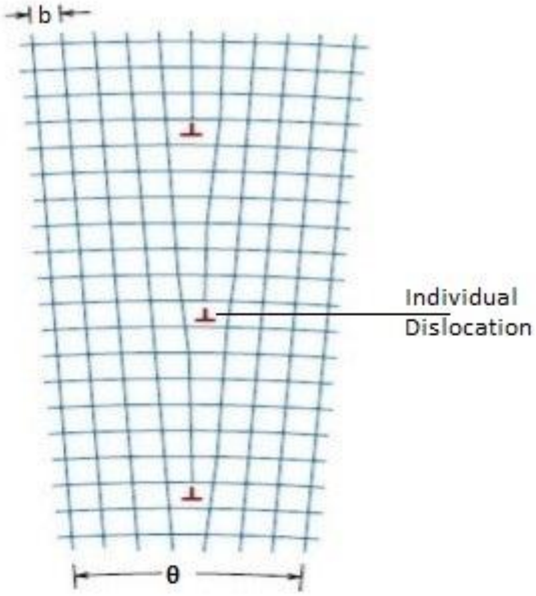
It effects the Electrical resistance, thermal conductivity & Corrosion resistance

Types

a) **Grain Boundaries:** Grain boundary is the interface between 2 Grains, or Crystallites, in a PolyCrystalline material. It is due to uneven growth when the solid is crystallising ,
Atomic packing is imperfect in crystalline boundaries, Atoms along the boundaries have higher energy than those within grains



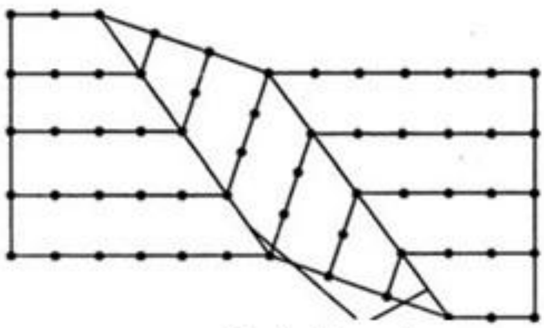
b) **Tilt Boundaries:** it is Due to the shear deformation. A Tilt boundary, between 2 slightly misaligned grains appears as an array of edge dislocations
Its orientation difference is only 10-15 degree & it can also be called Equally spaced Edge DisLocation



c) Twin Boundries:

Low Energy TwinBoundry with mirrored Atomic Positions across Boundary may be Produced by Deformation of materials. Twin boundries interfere with the Slip process & increses the strength of the metal , This will result in Shape Memory metals which can recover thier Original shape if heated to a High temp,
Shape memory alloys are Twinned & when they deformed they become UnTwin

Twin is Due to Atomic Displacement due to Shear force & also due to annealing heat treatments.



Twin Boundry

d) Stacking Faults

- Formed by fault in the stacking sequence of atomic planes in crystals.
- Considering stacking arrangement in FCC:

ABCABCABCABCABC
ABCABC BCABCABC

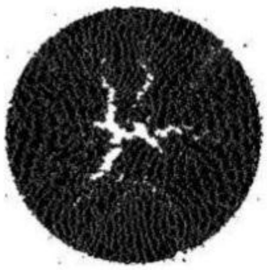
- This thin region is a surface imperfection and is called Stacking faults.

4) Volume Defect (3D Defect) :

Found inside the Solid metals, It is introduced during Processing & Fabrications. It is the most common type of defects among all other crystal imperfection

Bulk or Volume Defects

- **PRECIPITATES** : Fraction of a micron in size
- **DISPERSANTS** : may be large precipitates, grains, or polygranular particles distributed through microstructure
- **INCLUSIONS** : foreign particles or large precipitate particles ; undesirable ; harmful
- **VOIDS** : Trapped Gases ; Decreases mechanical strength



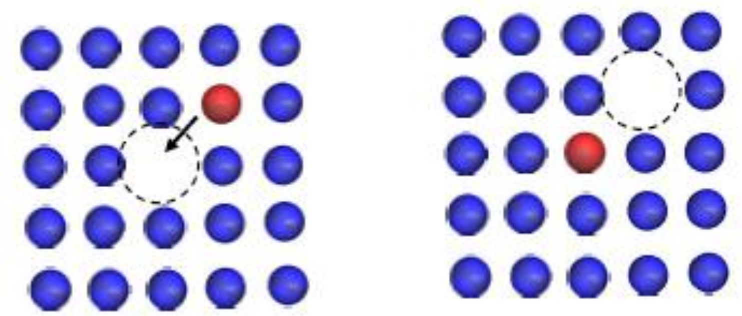
Cluster of microcracks in a melanin granule irradiated by a short laser pulse.

Atomic Diffusion

Diffusion refers to mass movement of Atoms or Molecules in a Solid.

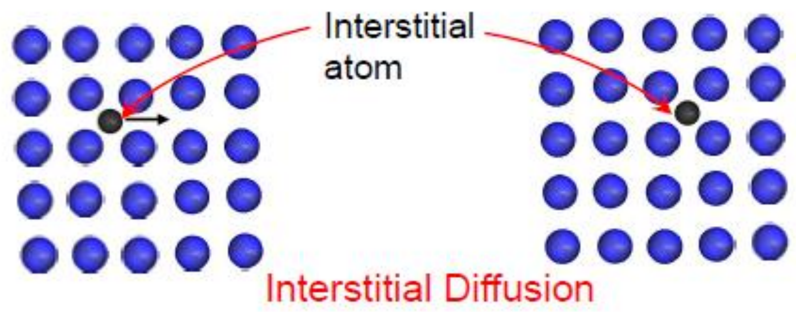
Mass flow process by which Atoms move from their original sites to neighbouring sites in a given phase under the influence of thermal energy & a Concentration Gradient

a) Atomic Diffusion by Vacancy Migration



- Movement of Atoms from Original Lattice position to an adjacent vacant Lattice site,.
- Atom can move into Vacant Site, only if it possesses sufficient activation Energy (Thermal energy of Atomic Vibration)
- Vacancy Diffusion is a Bulk Diffusion process & is responsible for Creep in materials

b) <u>Atomic Diffusion by Interstitial Migration</u>



- When a Solid is made from 2 or More Elements whose atomic radii differs, An Interstitial Diffusion occurs
- This mechanism involves migration of atoms from one interstitial site to a neighbouring empty interstitial site.
- This mechanism is more prevalent for impurity atoms such as hydrogen, carbon, nitrogen, oxygen which are small enough to fit in to an interstitial position.

Fick's 1st Laws of Diffusion: Flux of Atoms 'J' moving across a Plane of Unit area in unit time is Proportional to the concentration Gradient $dC/_{dX}$

$J \propto {dC}/{dX}$

$J = -D\, {dC}/{dX}$

- Where J = Flux used to Quantify how fast Diffusion occurs (Atoms/m^2sec)
- ${dC}/{dX}$ = Concentration Gradient (Atoms/m^3m)
- C = Volume Concentration of Atoms (Atoms/ m^3)
- X = Dist B/w Planes
- D = Diffusivity Coefficient (m^2/s)

dC represent difference in concentration over the distance dX

- Fick's 1st law can be used to describe flow under Steady State Condition: Flux is independent of time & remains the same at any cross sectional plane along the diffusion direction

Fick's 2nd Laws of Diffusion:

Rate of compositional change of material at a point is equal to Diffusivity times the rate of change of Concentration Gradient

$$\frac{dC}{dt} = D\left(\frac{d^2C}{dx^2}\right)$$

- Where ${dC}/{dt}$ = Rate of Concentration Gradient (Atoms/m^3Sec)
- C = Volume Concentration of Atoms (Atoms/ m^3)
- X = Dist B/w Planes
- D = Diffusivity Coefficient (m^2/s)
- dC represent difference in concentration over the distance dX
- Fick's 2nd law can be used to describe flow under UnSteady State Condition: Flux is dependent of time at any cross sectional plane along the diffusion direction
- Diffusivity: Amount of Substance diffusing in unit time across a unit area through a unit concentration gradient (m^2Sec), Varies with Structure of Crystals & temperature input

Factors Affecting Atomic diffusion

1) **Temperature :** High temperature provides the necessary activation energy to the atoms to begin diffusion. So a higher temperature initiates diffusion faster.
2) **Crystal structure :** If a crystal structure is distorted, i.e, if there are more imperfections, the rate of diffusion is increased.
3) **Atomic Packing factor :** If APF is high, the rate of diffusion will be decreased. Diffusion is much slower in FCC-iron than in BCC-iron.
4) **Grain Boundaries :** The diffusion process proceeds more rapidly along the grain boundaries since it is a zone of crystal imperfections.
5) **Grain Size :** Since diffusion through grain boundaries is faster than through the grains themselves, a material with finer grains will have a faster rate of diffusion.
6) **Atomic size :** Diffusion occurs more readily when the size of the diffusing atom is less. Ex. : Carbon in iron.
7) **Concentration Gradient :** Higher the concentration gradient higher will be the rate of diffusion.

Material Science & Metallurgy

Solid materials are broadly classified into 2 Groups based on regularity with, each atoms or Molecules are arranged w.r.t one another

1) Crystalline Solids
2) Amorphous Solids

<u>Crystalline Solids</u>: It Contains Atoms bonded together in a Regular pattern as shown in Fig. Eg: Sand, Metals, Alloys, Carbon

<u>Amorphous Solids</u>: It Contains Atoms bonded together in an irregular pattern with no systematic arrangements with the neighbouring atoms as shown in Fig

Eg: Glass, Rubber & Plastics

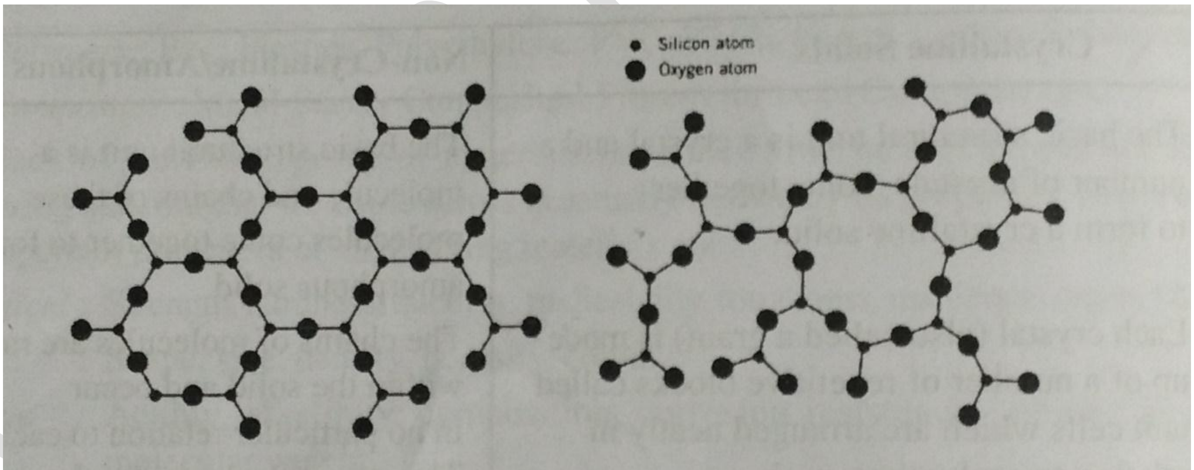
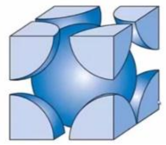


Fig. 1.1a : Crystalline Silica (SiO_2)   *Fig. 1.1b : Non-Crystalline Silica (SiO_2)*

<u>Fundamentals Concepts of Crystal Geometry:</u>

Unit Cell: Smallest structural unit that can describe the Crystal structure is called UnitCell



Crystal Structure: The Regular & Periodic arrangements of atoms or molecules in Space is called Crystal Structure

Lattice: Lattice is used to describe the arrangement of atoms or molecules in Space.

A lattice is a Mathematical Abstraction that describes the way the atoms or group of atoms or molecules are repeated in Space

in 2D there are 5 Lattices

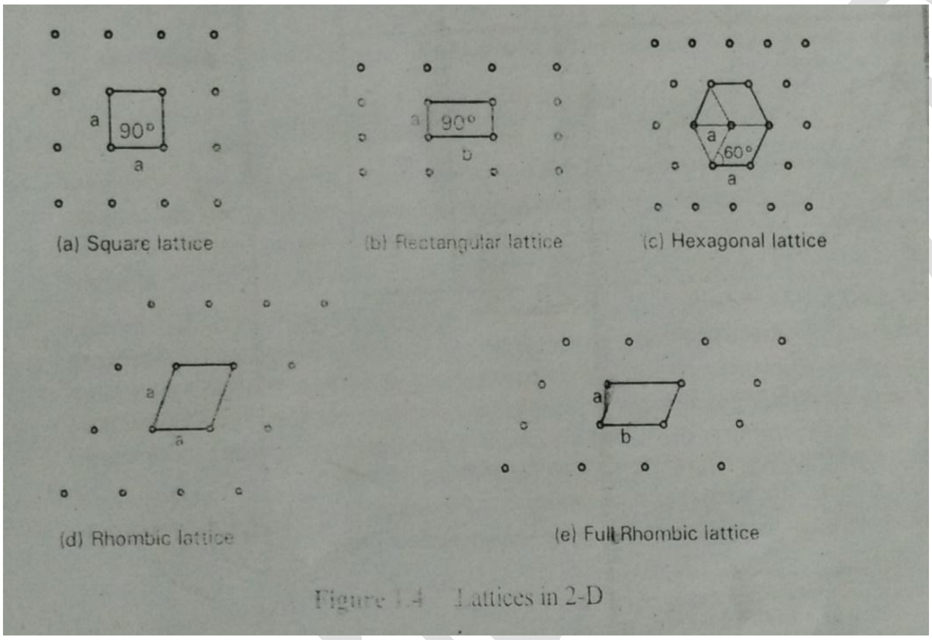
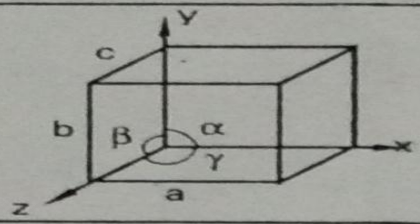
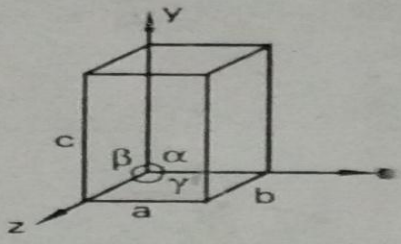
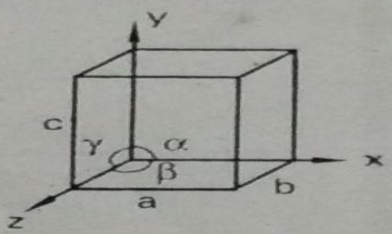
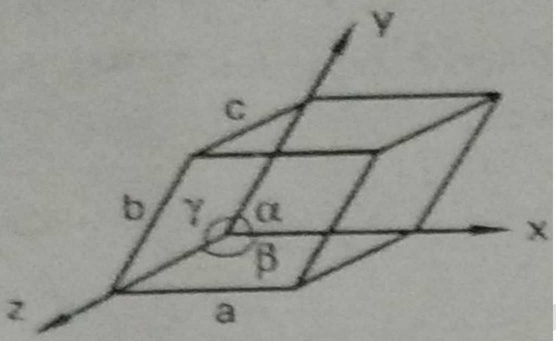
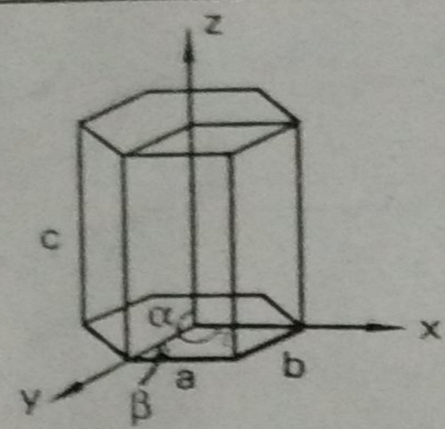
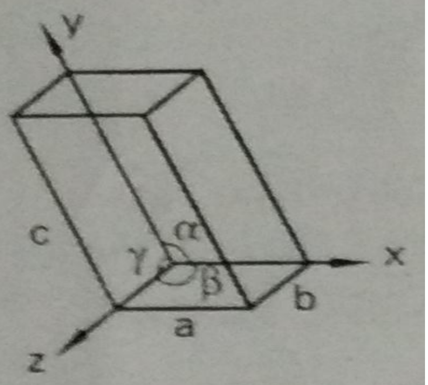
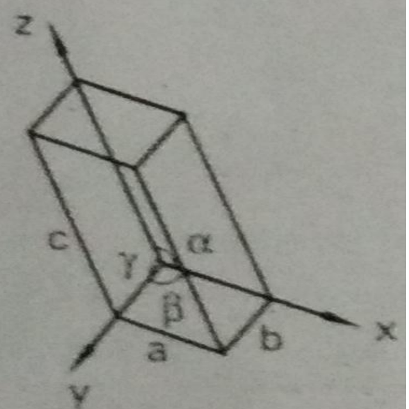


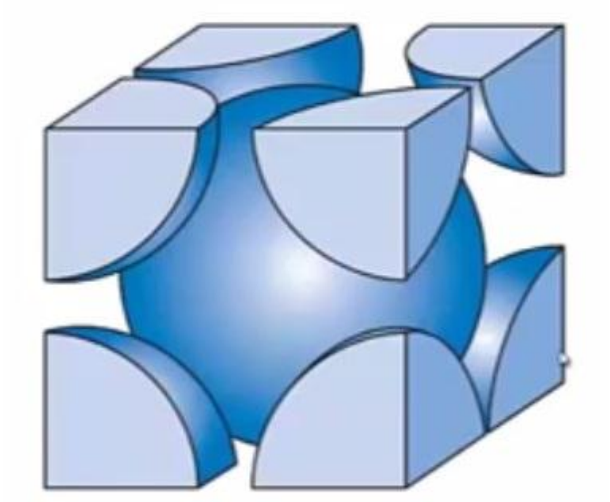
Figure 1.4 Lattices in 2-D

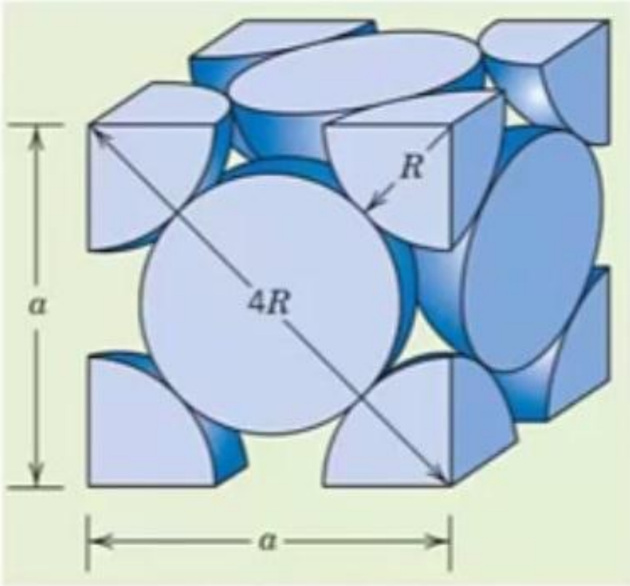
In 3D, The Lattices are called Space Lattices or Bravais Lattices.

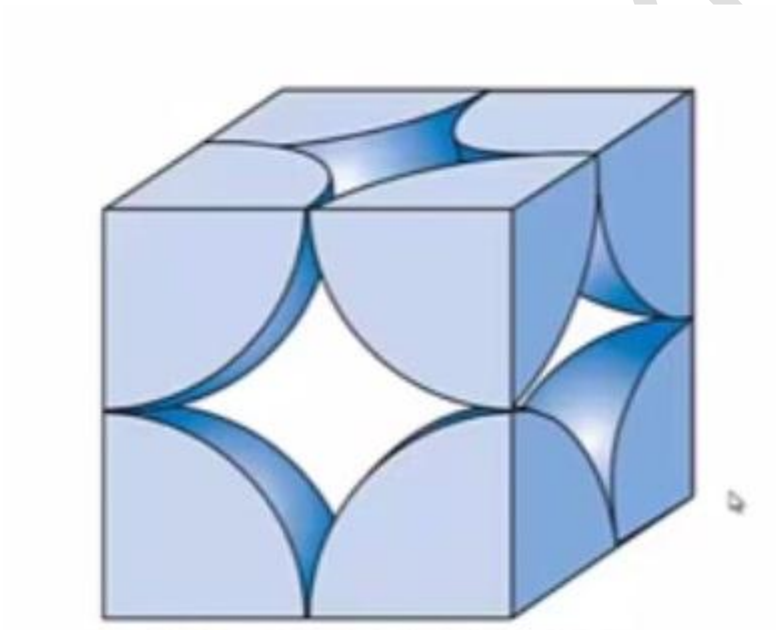
There are 7 basic shapes of unit cells having 14 various arrangements of atoms among them.

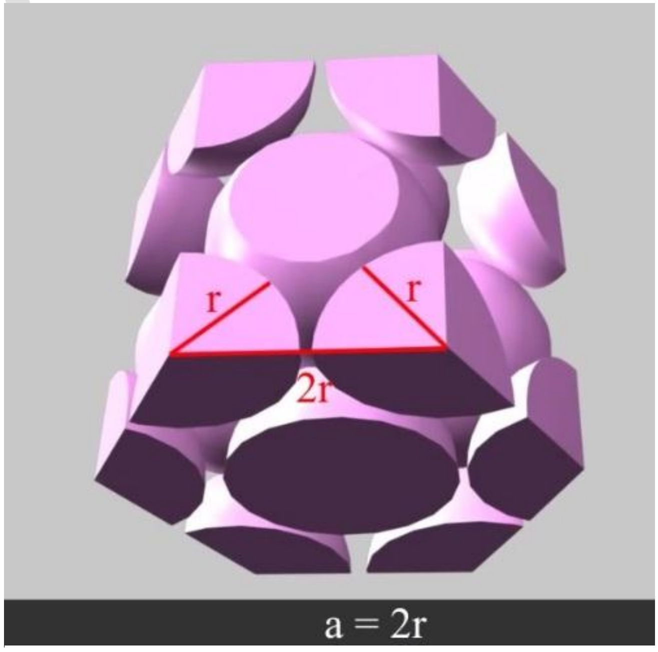
Sl.No.	Crystal System	Unit cell
1	Cubic a = b = c $\alpha = \beta = \gamma = 90°$	
2	Tetragonal a = b ≠ c $\alpha = \beta = \gamma = 90°$	
3	Orthorhombic a ≠ b ≠ c $\alpha = \beta = \gamma = 90°$	

Sl.No.	Crystal System	Unit cell
4	Rhombohedral or Trigonal a = b = c $\alpha = \beta = \gamma \neq 90^\circ$	
5	Hexagonal a = b ≠ c $\alpha = \beta = 90^\circ$ $\gamma = 120^\circ$	
6	Monoclinic a ≠ b ≠ c $\alpha \neq \beta = 90^\circ \neq \gamma$	
7	Triclinic a ≠ b ≠ c $\alpha \neq \beta \neq \gamma \neq 90^\circ$	









CoOrdination Number (Z): Number of nearest & Equidistant neighboring atoms that each atom has, in a Space Lattice.

Z = SimpleCubic - 6, BCC - 8, FCC - 12 & HCP – 12

Atomic Packing Factor: APF Represents the Percentage of Atoms occupied & Void, in an unit cell

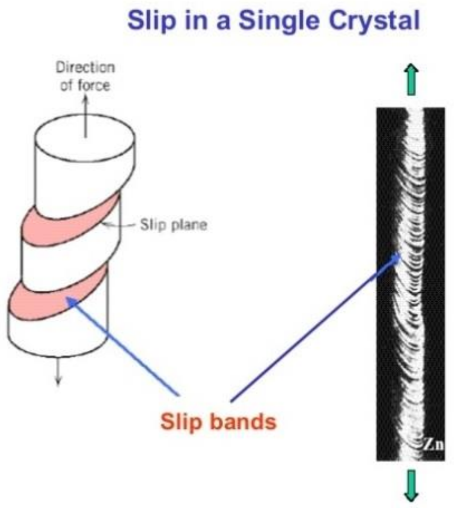
APF = Volume of Atoms per UnitCell / Volume of UnitCell

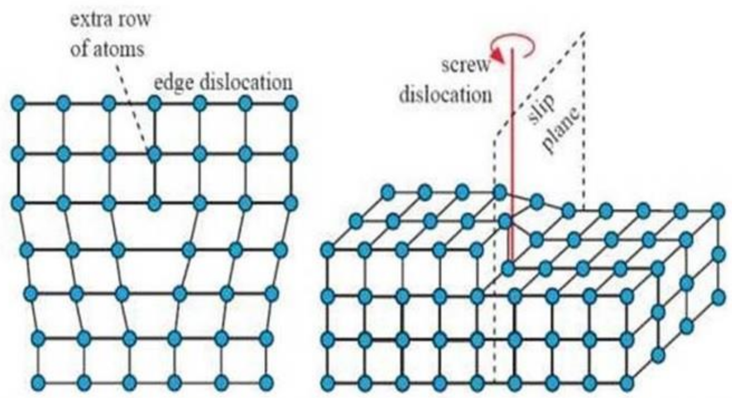
= (Volume of Each Atom * Number of atoms per unitcell) / Volume of UnitCell

Slip

- Slip involves sliding of blocks of crystal over one other along definite Crystallographic planes, called slip planes. It is analogous to a deck of cards when it is pushed from one end.

- Slip occurs when shear stress applied exceeds a critical value.

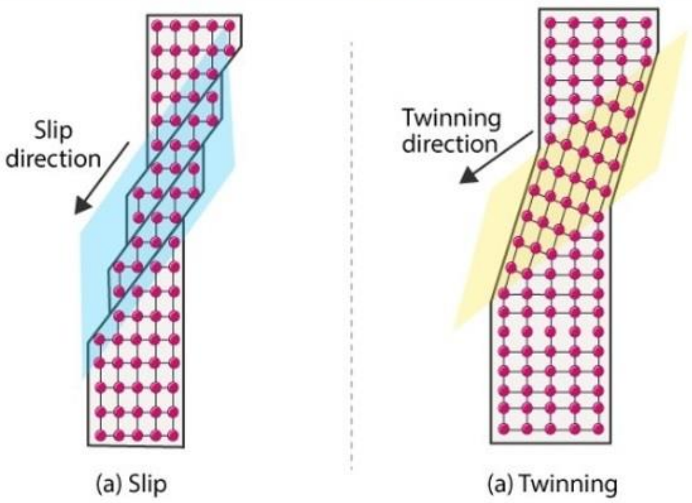


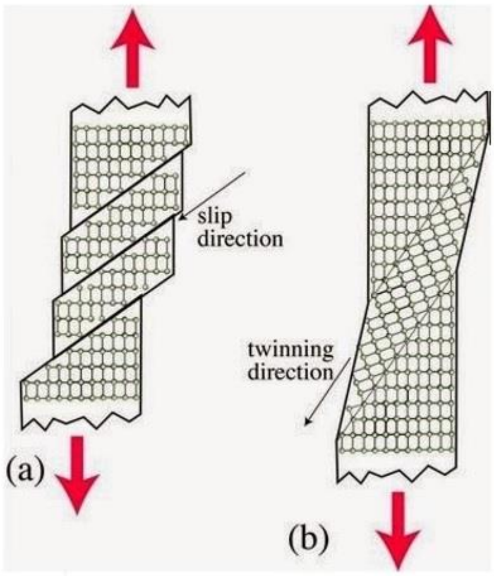


Edge dislocations form the edge of an extra layer of atoms within the crystal lattice and move perpendicular to the dislocation line

Screw dislocations form a line along which the crystal lattice jumps one lattice point and moves parallel to the dislocation line

Depiction of slip and twinning deformation in a face-centred cubic crystal





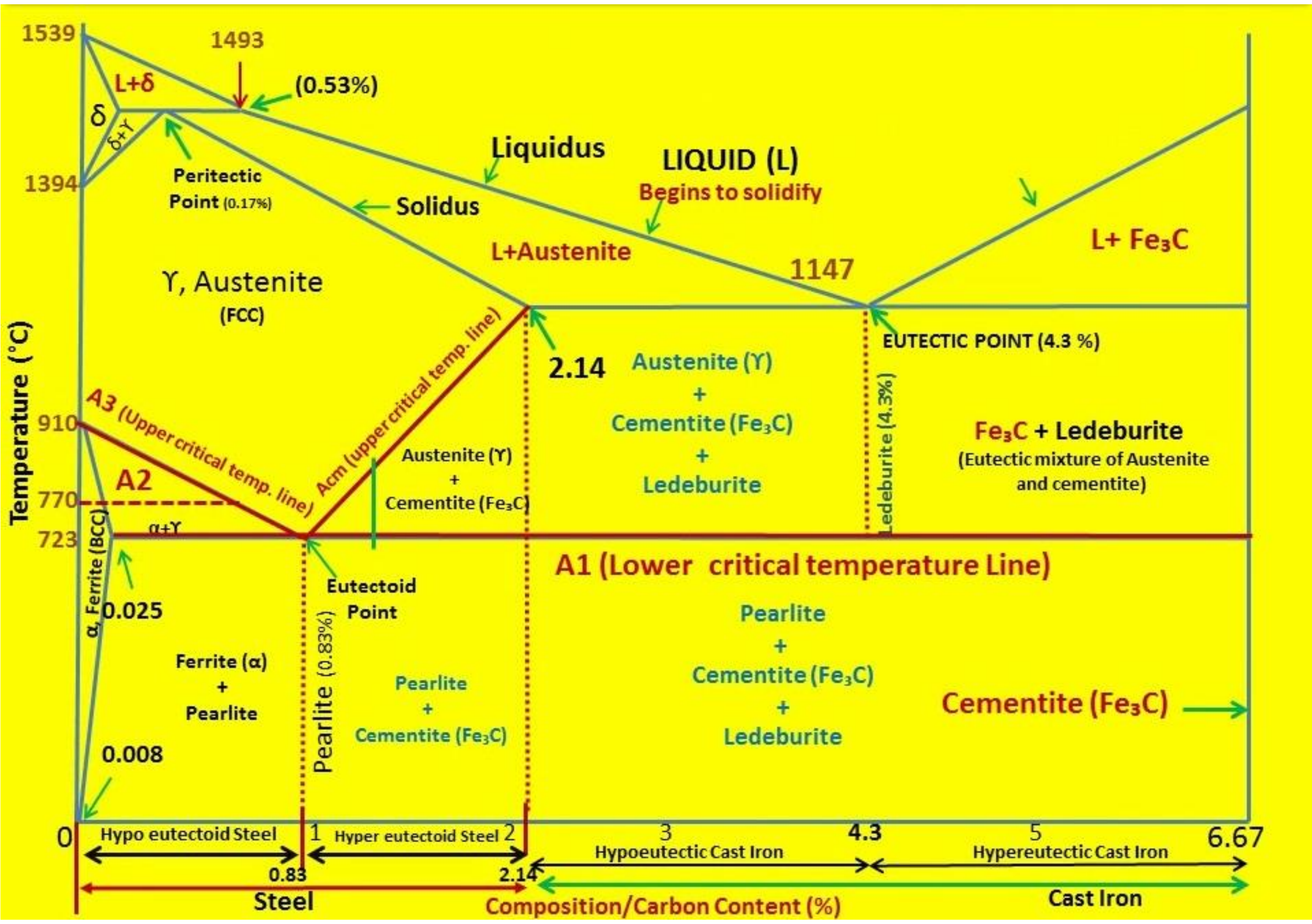
Twinning

- Portion of crystal takes up an orientation that is related to the orientation of the rest of the untwined lattice in a definite, Symmetrical way.
- Twinned portion of the crystal is a mirror image of the parent crystal.
- Twinning may be caused by Impact, or by Thermal treatment or by Plastic deformation.
- Annealing Twins is most observed in FCC & Mechanical twins in BCC & HCP

Difference between Slip & Twinning

Slip	Twinning
To undergo Slip, Shear Stress required to Less	To undergo Twinning, Shear Stress required to High
Highest when CRSS reaches Threshold	CRSS has no role
Slip occurs Homogenous & Occurs under Static Loading	Localized & Occurs under Shock Loading
Common in FCC & BCC	Common in HCP
Time required is Milli Seconds	Time required is Micro Seconds

Iron-Carbon phase diagram describes the iron-carbon system of alloys containing up to 6.67% of carbon, discloses the phases compositions and their transformations occurring with the alloys during their Cooling or Heating.



Following phases are involved in the transformation, occurring with iron-carbon alloys:

δ-iron: Solid solution of carbon in iron. BCC Structure, Maximum concentration of carbon is is 0.1% @ 1493^0c

γ Austenite – Interstitial solid solution of carbon in Iron, Austenite has FCC Structure, Maximum concentration of carbon is is 2.1% @ 1148^0c

Ledeburite : It is the Eutectic lamellar of (γ + Fe_3C) , Eutectic reaction occurs @1147^0c for 4.3% C

Pearlite : It is the eutectoid lamellar of (α + Fe_3C), Eutectoid reaction occurs @727^0c for 0.8% C

α ferrite - Interstitial solid solution, BCC Structure, Maximum concentration of carbon is @727^0c for 0.025%

Cementite – Iron carbide, Intermetallic compound having ortho rhombic crystal structure, having fixed composition of Fe_3C. Cementite is a hard and brittle substance

Invariant Reactions:

@ 1493^{0}c for 0.18%C Peritictic Reaction

Liq + δ ⇄ γ Austenite

Applying Gibbs Phase rule,

P+F=C+1

F=0 ∵ C=2 & P = 3 phases (Li + δ + γ)

@ 1147^{0}c for 4.3%C Eutectic Reaction

Liq ⇄ γ + Fe3c (Leduberite)

Applying Gibbs Phase rule,

P+F=C+1

F=0 ∵ C=2 & P = 3 phases (Li + γ + Fe3c)

@ 723^{0}c for 0.83%C Eutectoid Reaction

Solid ⇄ α + Fe_3C (Pearlite)

Applying Gibbs Phase rule,

P+F=C+1

F=0 ∵ C=2 & P = 3 phases (α + γ + Fe3c)

Critical temperatures:

A1 - Critical temp of Eutectoid transformation. Upon cooling Transformation of γ in to pearlite take place

A2 - At this temp, Iron loses its magnetic property

A3 - Above this temp Hypo Eutectoid Steel gets transformed into γ iron

Acm - Above this temp Hyper Eutectoid Steel gets transformed into γ iron

Effect of Carbon on Properties of Steel:

Steel (Iron + Carbon) :

Carbon has a direct effect on Physical property of a Steel, It forms the factor for difference between Steel & Cast iron. Less than 2% Carbon content gives you Steel, More than 2% Cast iron.

Steel with Lower Carbon content has the same property as iron i.e Soft & easy Formed. As the Carbon content increases Metal becomes Stronger, Harder, High Tensile Strength & Responsive to Heat treatment

However increase in the Carbon content makes the Steel more Brittle

Manganese: It acts as a DeOxidiser & Also impart Strength & Responsiveness to Heat Treatment, Range of Composition 0.5 - 2%

Chromium: It Decreases Machinability But imparts Good Wear Resistance & High Hardness, Also Strength & Responsiveness to Heat Treatment is Good. Range of Composition 0.5 - 1.5%

Nickel: Increases Toughness in Steel 1-4%

Silicon: It acts as a DeOxidiser &Graphitizer, 1-2.5%, Silicon imparts Strength, Hardness & High Magnetic Permeability for a Steel

---

Carbon Steel: iron + Carbon (0.03 - 2%)

Low Carbon Steel:

Composition: 0.03 - 0.25% C

MicroStr: Alpha Ferrite & Small Qnty of Pearlite

Property: Soft, Ductile, Tough, Good machinabilty&Weldability

Adv: Less Cost

Medium Carbon Steel:

Composition: 0.25 - 0.59% C

MicroStr: Dark Pearite with Light Coloured Ferrite & iron Carbide

Property: Strong, WearResistant, Heat treated to Have a Good Balance of Strength & Ductility

Adv: Automobile Body Parts, Structural Shapes Etc..

High Carbon Steel:

Composition: 0.6 - 1% C

MicroStr: Majorly Pearite with Light Coloured Ferrite & Cementite

Property: hardest, Strongest, Least Ductile

Adv: Cutting & Machining Tools

Ferrous & Non Ferrous Metals ?

Composition	- 2.5% - 4% carbon 1% - 3% silicon, rest iron
Microstructure	- α-ferrite and flake graphites (fig 7.2)
Properties	- High fluidity, very high compressive strength, very effective in damping vibrations, low cost.
Fracture surface	- Greyish, blackish surface when fractured (because of graphite flakes). Hence the name grey iron too.
Applications	- Pressure vessels, cylinder heads, pistons, clutch plates, base structure for machines and heavy equipment that are exposed to vibrations, valves, fittings, levers etc.

Ferrite + Graphite Flakes

Grey cast iron is a type of cast iron that has a Graphitic Microstructure. It is named after the Gray colour of the Fracture it forms, which is due to the presence of Graphite. It is the most common cast iron and the most widely used

It is used for housings where the stiffness of the component is more important than its tensile strength, such as internal combustion engine cylinder blocks, pump housings, valve bodies, electrical boxes, and decorative castings. Grey cast iron's high thermal conductivity and specific heat capacity are often exploited to make cast iron cookware and disc brake rotors

Grey cast iron has good wear resistance because the graphite flakes self lubricate. The graphite also gives gray iron an excellent damping capacity because it absorbs the energy and converts it into heat.

Grey iron cannot be worked (forged, extruded, rolled etc.) even at high temperature.

Gray iron is generally considered easy to weld

Malleable Cast Iron

The Characteristics of malleable iron are

Composition	- 1.8% - 3.2% carbon, 0.3% - 1.8% silicon rest iron
Microstructure	- dark graphite rosettes (temper carbon) in an α - ferrite matrix (fig 7.4)
Properties	- Highly malleable, very good machinability, good magnetic properties, wear resistance
Applications	- Connecting rods, transmission gears, flanges, pipe fittings, differential cases for automative industry, valves, parts for rail roads and marine works.


Ferrite + Temper Carbon

Malleable Cast Iron are those alloys where almost all the carbon is in the free form in the shape of irregular particles known as temper Carbon

Malleable Cast Iron are Produced by Heat treatment of White Cast iron

Malleable iron exhibits good ductility.

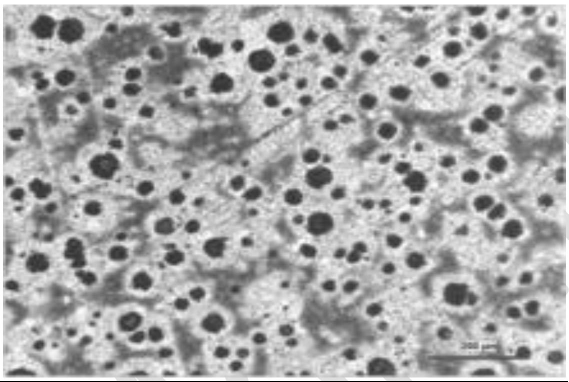
Malleable iron also exhibits better fracture toughness properties in low temperature environments

Applications of Malleable Cast Iron:

It is often used for small castings requiring good tensile strength and the ability to flex without breaking (ductility). Uses include electrical fittings, hand tools, pipe fittings, washers, brackets, fence fittings, power line hardware, farm equipment, mining hardware, and machine parts

Spheroidal Graphite Iron

Composition	-	3% - 4% Carbon, 1.6% - 2.8% Silicon, rest iron
	-	Very low percentage of phosphorus and sulphur
Microstructure	-	Dark graphite nodules surrounded by α - ferrite matrix (fig 7.5)
Properties	-	Highly ductile, very good machinablility, high corrosion resistance and good creep properties at elevated temperatures.
Applications	-	Flywheels, furnace doors, wrenches, lathe chucks, motor frames, pump bodies etc.,



Ferrite + Nodular Carbon

Spheroidal Graphite Iron: It is characterised by the presence of Free carbon in the shape of Compact Spheroids

it is well know for its Ductility

SG iron is a type of cast iron invented in 1943 by Keith Millis. While most varieties of cast iron are brittle, ductile iron has much more impact and fatigue resistance, due to its nodular graphite inclusions.

In ductile irons, graphite is in the form of nodules rather than flakes as in grey iron

Rounded nodules inhibit the creation of cracks, thus providing the enhanced ductility that gives the alloy its name.

Nodule formation is achieved by adding nodulizing elements, most commonly Magnesium (note magnesium boils at 1100°C and iron melts at 1500°C) and, less often now, Cerium

Applications of SG Iron

Much of the annual production of ductile iron is in the form of ductile iron pipe, used for water and sewer lines. It competes with polymeric materials such as PVC, HDPE, LDPE and polypropylene, which are all much lighter than steel or ductile iron; being more flexible, these require protection from physical damage.

Steel

Today, steel is one of the most common materials in the world, with more than 1.3 billion tons produced annually. It is a major component in buildings, infrastructure, tools, ships, automobiles, machines, appliances, and weapons. Modern steel is generally identified by various grades defined by assorted standards organizations.

Steels based on the chemical compositions are classified into four major groups. They are:

a) Carbon steels (Plain carbon steels)
- Mild steel or Low carbon steel
- Medium carbon steel
- High carbon steel
- Ultra high carbon steel

b) Alloy steels
- High-strength low-alloy steels
- Medium-alloy nickel-chromium steels
- Maraging steels
- Manganese steels

c) Stainless steels
- Austenitic steels
- Ferrite steels
- Martensitic steels
- Duplex steels
- Precipitation hardened steels

d) Tool steels
- Cold work tool steels
- Shock resisting tool steels
- Mold tool steels
- High speed tool steels
- Special purpose tool steels

- Steel is an alloy of iron and other elements, primarily carbon, widely used in construction and other applications because of its high tensile strength and low cost. The base metal, iron, is able to take on two crystalline forms BCC & FCC depending on its temperature.
- The carbon in typical steel alloys may contribute up to 2.1% of its weight.
- The carbon content of steel is between 0.002% and 2.1% by weight for plain iron-carbon alloys. These values vary depending on alloying elements such as manganese, chromium, nickel, iron, tungsten, carbon and so on.

- Too little carbon content leaves (pure) iron quite soft, ductile, and weak. Carbon contents higher than those of steel make an alloy, commonly called pig iron, that is brittle (not malleable).
- Smelting take place in a low-oxygen environment

Using carbon to reduce iron oxides, Results in an alloy (pig iron) that retains too much carbon to be called Steel. The excess carbon and other impurities are removed in a subsequent step.

Other materials are often added to the iron/carbon mixture to produce steel with desired properties.

Nickel and manganese in steel add to its tensile strength and make the austenite form of the iron-carbon solution more stable,

Chromium increases hardness and melting temperature and vanadium also increases hardness while making it less prone to metal fatigue.

To inhibit Corrosion, at least 11% chromium is added to steel so that a hard oxide forms on the metal surface; this is known as stainless steel.

Tungsten interferes with the formation of Cementite, allowing Martensite to peferentially form at slower quench rates, resulting in high speed steel.

On the other hand, sulfur, nitrogen, and phosphorus make steel more brittle, so these commonly found elements must be removed from the steel melt during processing.

A Ceramic is an inorganic, Nonmetallic solid material comprising metal, Nonmetal or Metalloid atoms primarily held in ionic and covalent bonds

General properties such as high melting temperature, high hardness, poor conductivity, high moduli of elasticity, chemical resistance & Low ductility

Examples of Ceramic may be Carbides, Oxides, Nitrides, Borides & Silicides Etc..

Ceramics Always composed of more than one element Like Al_2O_3, SiO_2, MgO, SiC Etc..

Bond between 2 atoms in Ceramics are Either Totally Ionic, Or combination of ionic & Covalent

Oxides are totally ionic in character, whereas, Carbides, Nitrides, Borides and Silicides are partially ionic but mostly Covalent Bonding

- ionic bond occurs between a Metal & NonMetal and involves the attraction of opposite charges when electrons are transferred from the metal to the NonMetal

- Covalent Bond occurs between two Nonmetals and involves sharing of Electrons or atoms

The strength of an ionic bond depends on the size of the charge on each ion and on the radius of each ion.

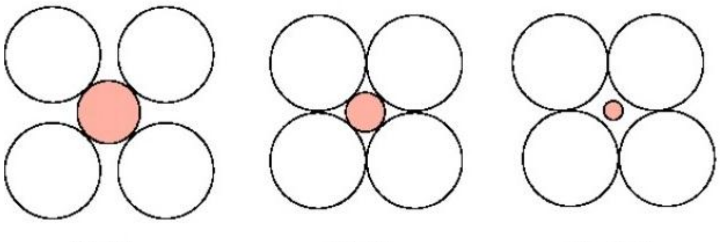
The greater the number of electrons being shared, is the greater the force of attraction, or the stronger the covalent bond.

These types of bonds result in high elastic modulus and hardness, high melting points, low thermal expansion, and good chemical resistance

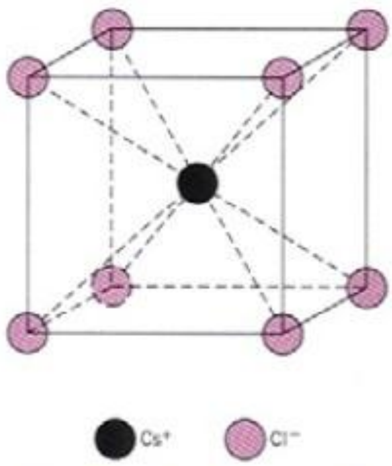
Cement is another very important group of ceramics, which is used and one of the highest tonnage materials produced across the world. It is basically a combination of calcium oxide, silica and aluminium oxide.

Structure Of Ceramics

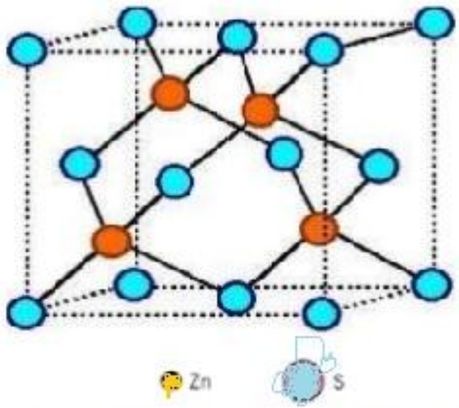
The properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together. The type of bonding and structure helps determine what type of properties a material will have



- **Cesium chloride structure** Radius ratio for CsCl is 0.94
  - CN=8, 8 anions at cube corners and 1 cation at center of cube, simple cubic (not BCC)
- **Zinc Blende structure** Radius ratio for ZincBlend is 0.39
  - CN=4, FCC structure of S with Zn at interior tetrahedral positions

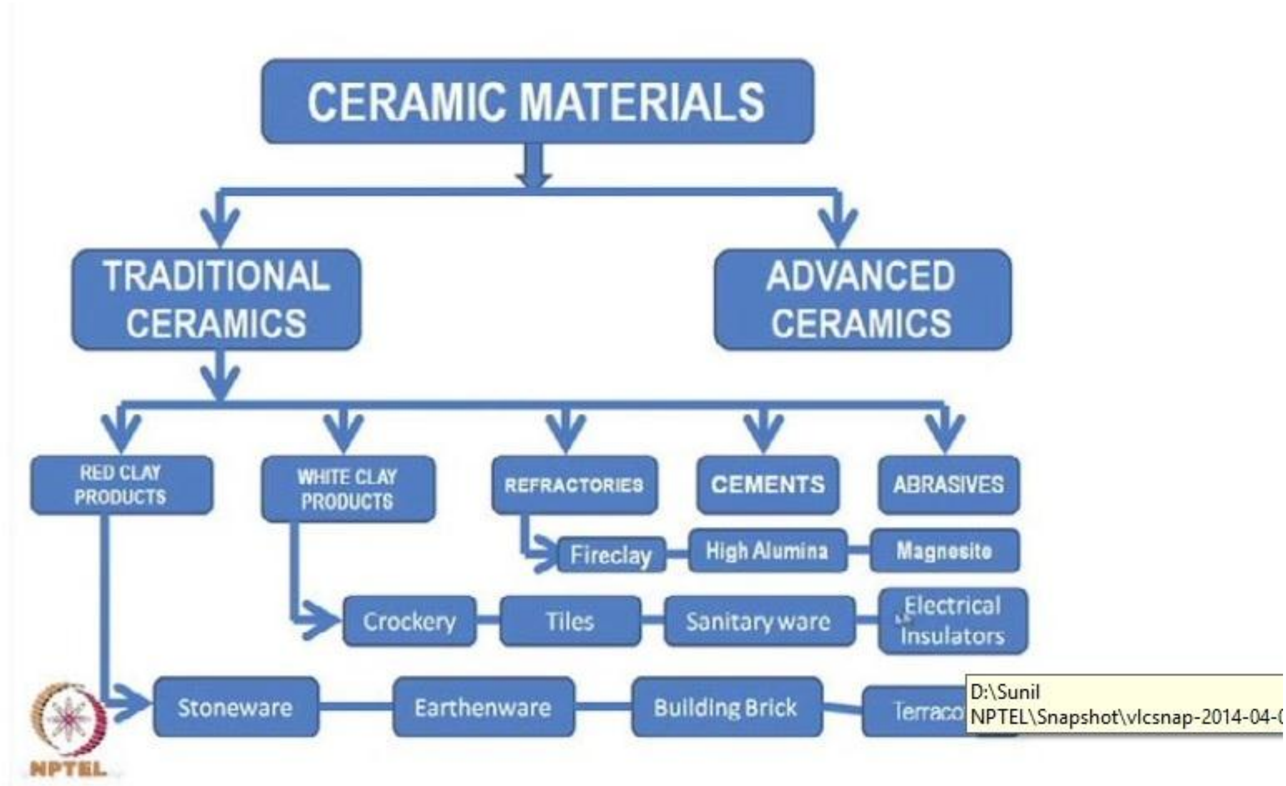


A unit cell of cesium chloride



A unit cell of zinc blende

Types Of Ceramics



Properties of ceramic materials

Properties of ceramic materials, like all materials, are dictated by the types of atoms present, the types of bonding between the atoms, and the way the atoms are packed together.

1) Hardness is high relative to metals & Polymer, Compressive strength is 5 times higher than tensile strength
2) Elastic Modulus is high relative to metals & Polymer
3) Temperature Strength is high relative to metals & Polymer
4) Ductile, High corrosion & wear resistance
5) Electric conductivity is low but few are super conductors, Some are PiezoElectric in nature
6) Low thermal conductivity & high heat resistance (Refractory property)

Processing of Ceramics:

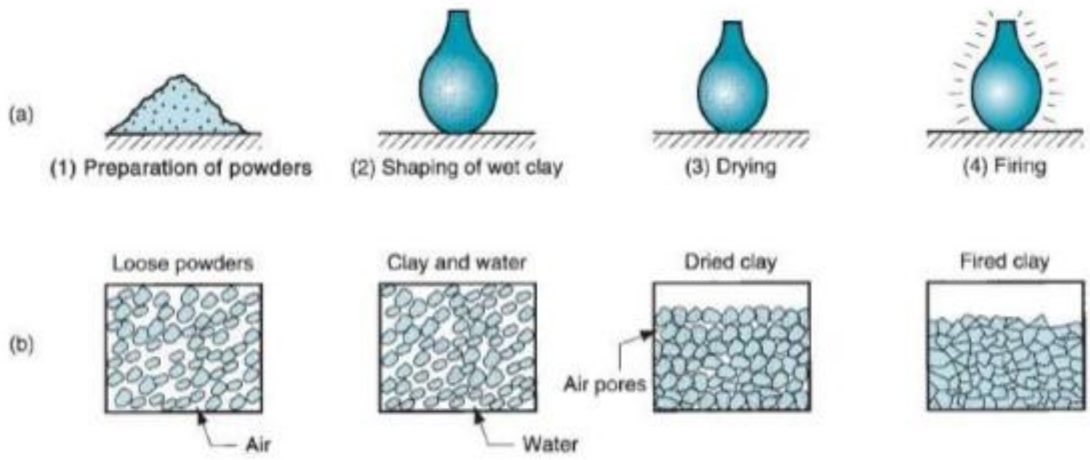
Basic steps in processing of ceramics are

1) Material preparation

2) Casting

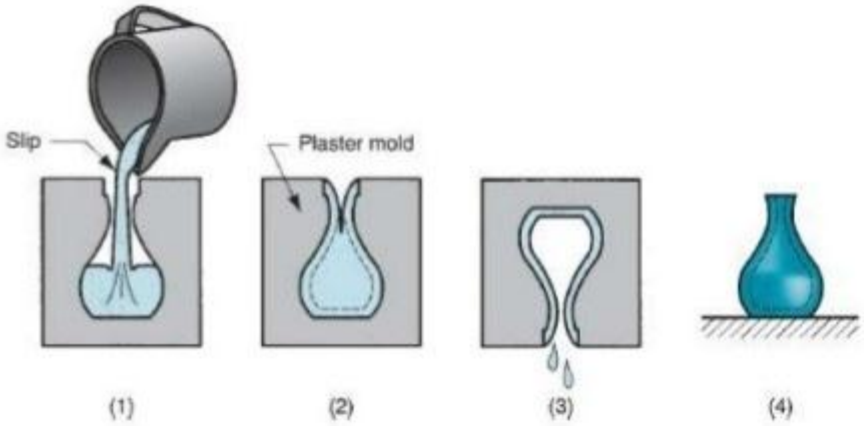
3) Drying & Sintering

Shaping Ceramics:



Usual steps in traditional ceramics processing: (1) preparation of raw materials, (2) shaping, (3) drying, and (4) firing. Part (a) shows the workpart during the sequence, whereas (b) shows the condition of the powders.

Slip Casting:



Sequence of steps in drain casting, a form of slip casting:

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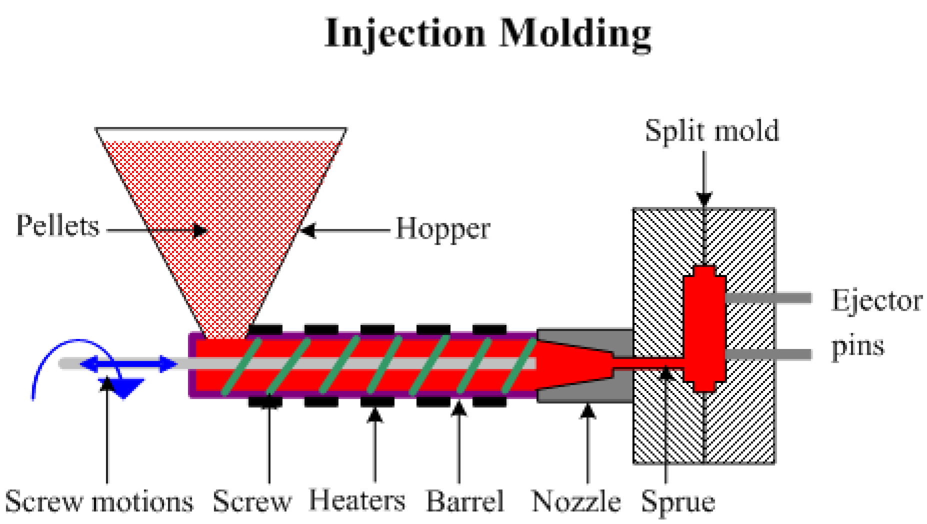

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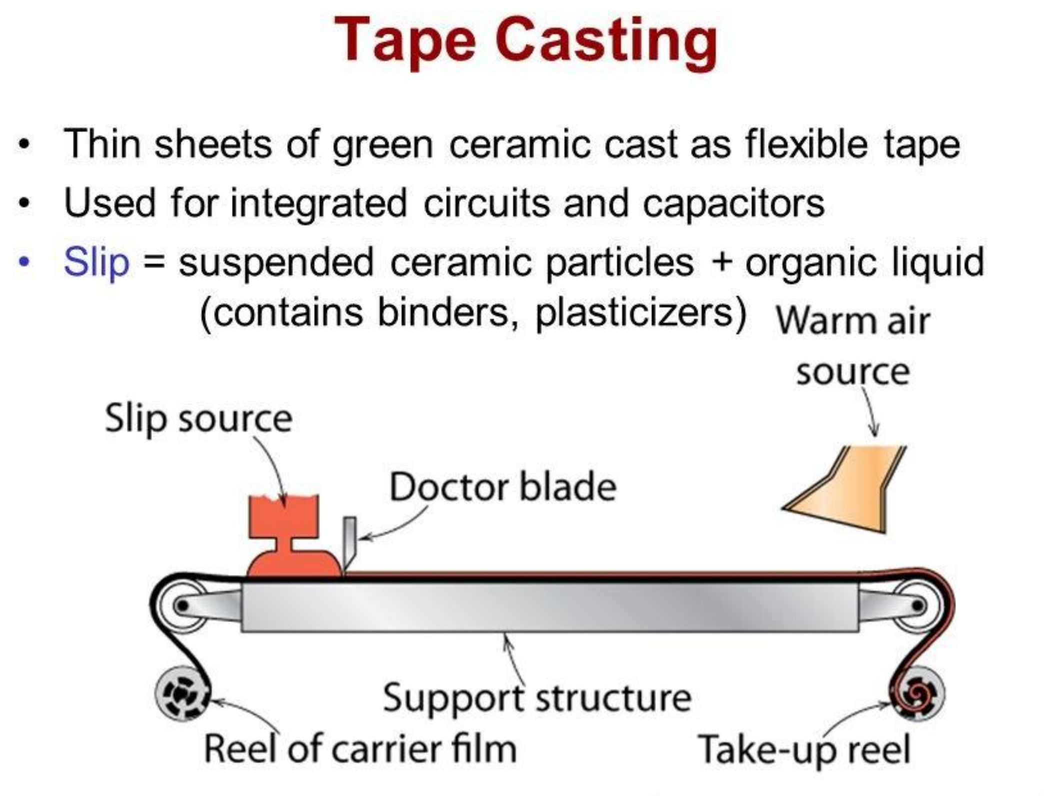

Applications of Ceramics:

Traditional ceramics mainly used with low technology applications

Advanced ceramics have superior mechanical properties like corrosion resistance, electrical & optical properties & magnetic properties so, widely used

Automotive Industry: In engines heat-resistant ceramic parts like valve components, backings in the crankshaft housing, Water & Fuel pumps

High level of corrosion resistance makes the ceramics safe than other materials in equipment & mechanical use cutting tools & mechanical pumps

Aerospace: Airframes, Rocket nozzles

Zirconium dioxide ceramics are used in the manufacture of knives.

Ceramics such as alumina, boron carbide and silicon carbide have been used in bulletproof Vests

Silicon nitride parts are used in ceramic ball bearings

Advantages of Ceramic

- **Durable**
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- **Easy to clean**
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- **Design options**
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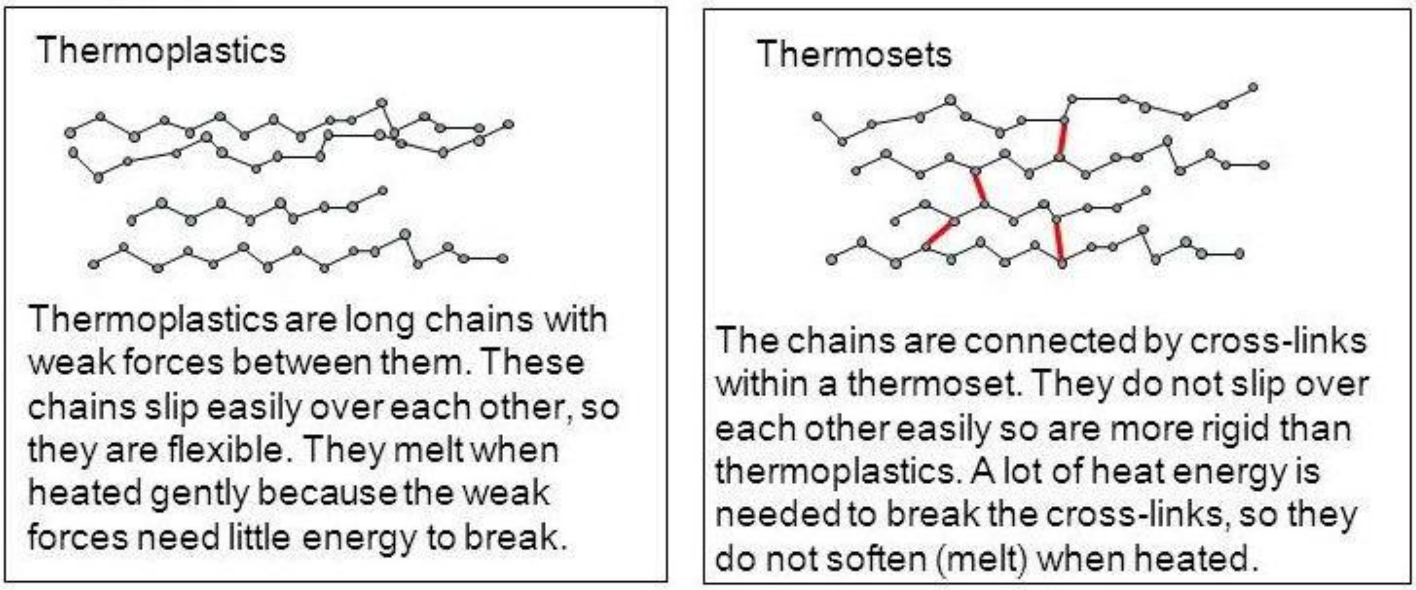
Plastics

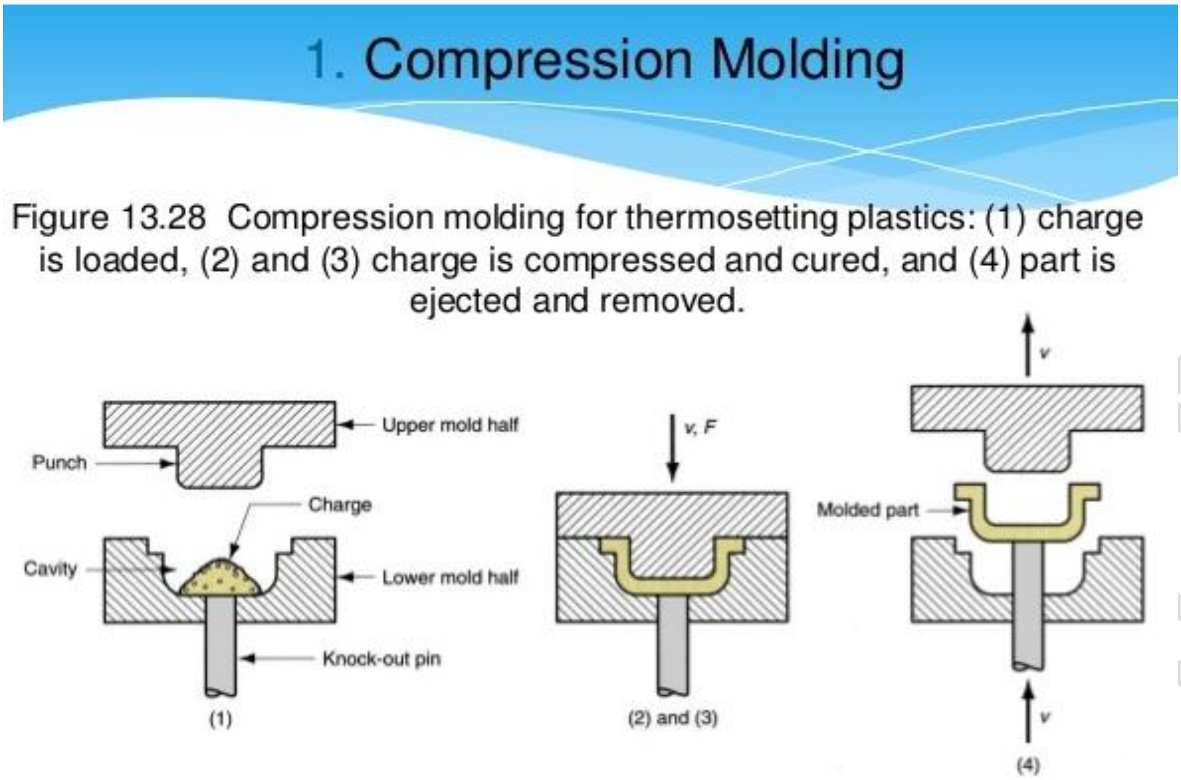
Plastics are a synthetic materials made from a wide range of organic polymers such as Polyethylene, PVC, Nylon, etc., that can be moulded into shape while soft, and then set into a rigid or slightly elastic form

Types:

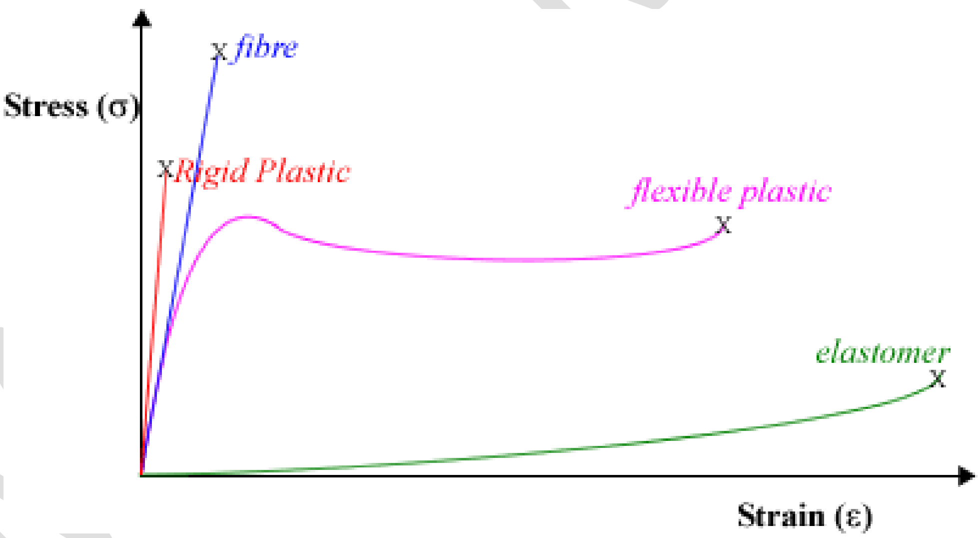


ThermoPlastics	ThermoSets
Little cross linkage	Large cross linkage
Ductile	Hard & Brittle
Soften with heat	Doesnt Soften with heat
Eg: PolyEthylene, PolyPropylene,PolyStyrene	Eg: Epoxies, Polyester, Resins, Vulcanised rubber

Processing of Plastics:



Properties of Plastics:



Distinguish between the properties of Ceramics, Metals & Plastics

	Ceramic	Metal	Polymer
Hardness	↑	↓	↓
Elastic modulus	↑	↑	↓
High temperature strength	↑	↓	↓
Thermal expansion	↓	↑	↑
Ductility	↓	↑	↑
Corrosion resistance	↑	↓	↓
Resistance to wear	↑	↓	↓
Electrical conductivity	↕	↑	↓
Density	↓	↑	↓
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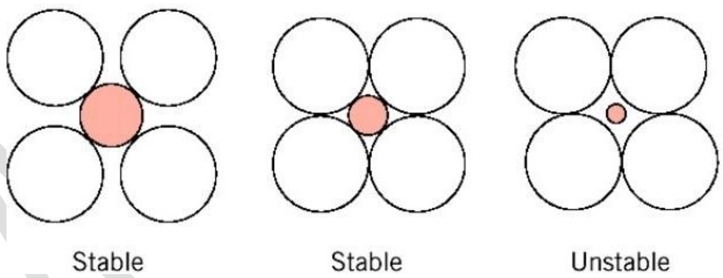

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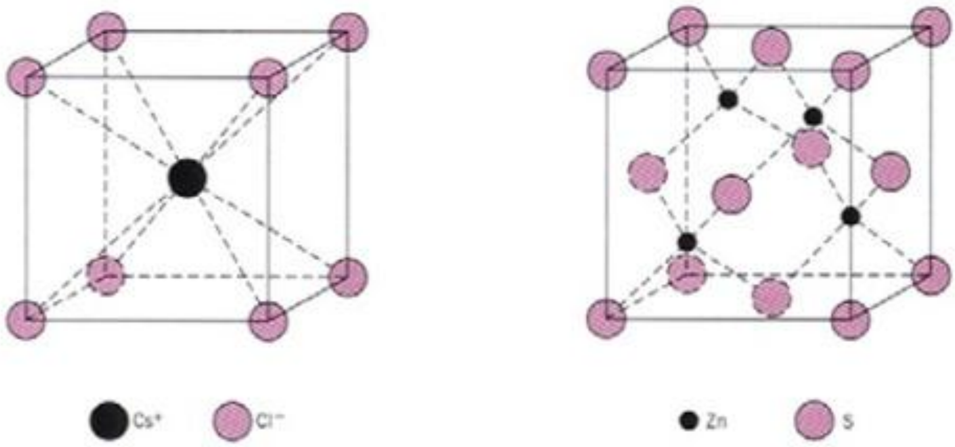
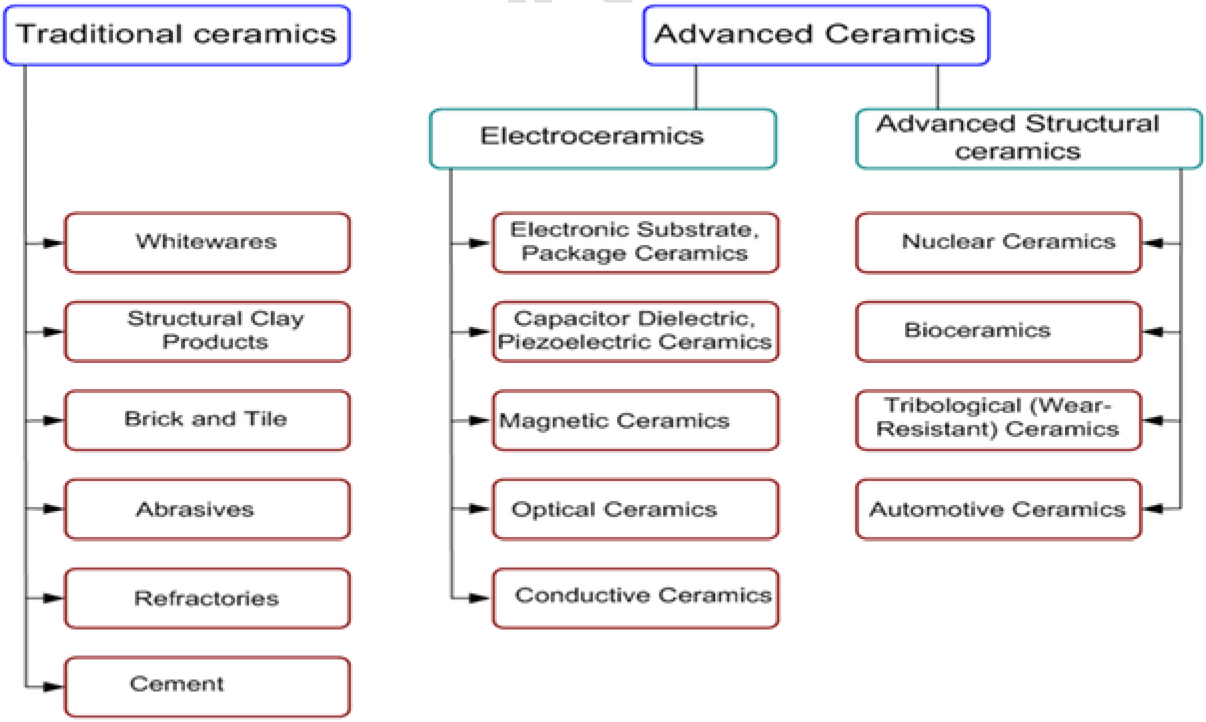


A unit cell of cesium chloride   A unit cell of zinc blende

Types Of Ceramics



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4) Ductile, High corrosion & wear resistance

5) Electric conductivity is low but few are super conductors, Some are PiezoElectric in nature

6) Low thermal conductivity & high heat resistance (Refractory property)

Properties:-

- These materials are insulator of heat and electricity and more resistance to high temperature.
- These materials are stronger than that of metals because of their covalent and ionic bonding.
- These materials are less density it means they are lighter than metals.
- The inability of slip of ceramic materials can cause more difficult in the processing and performance.
- Some oxide of ceramic show magnetic behaviors such as Fe_3O_4.
- They are brittle materials.

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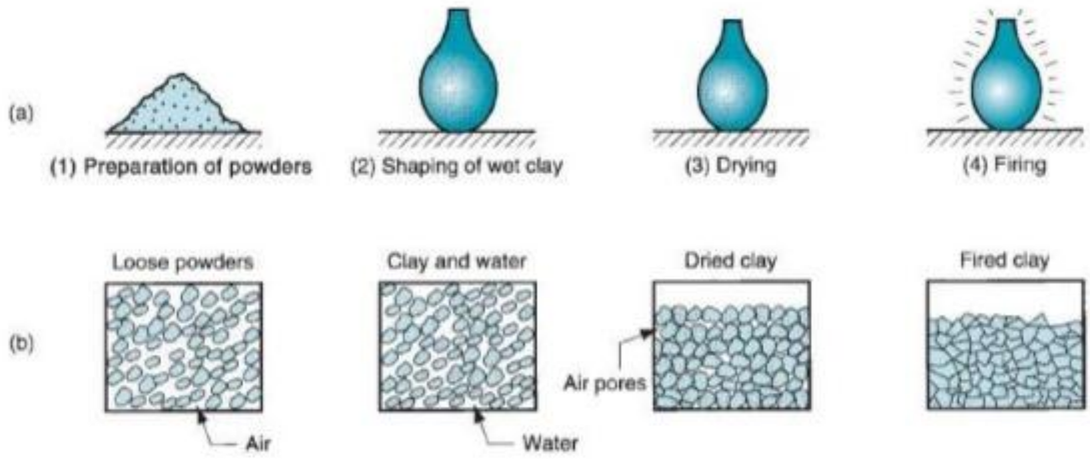

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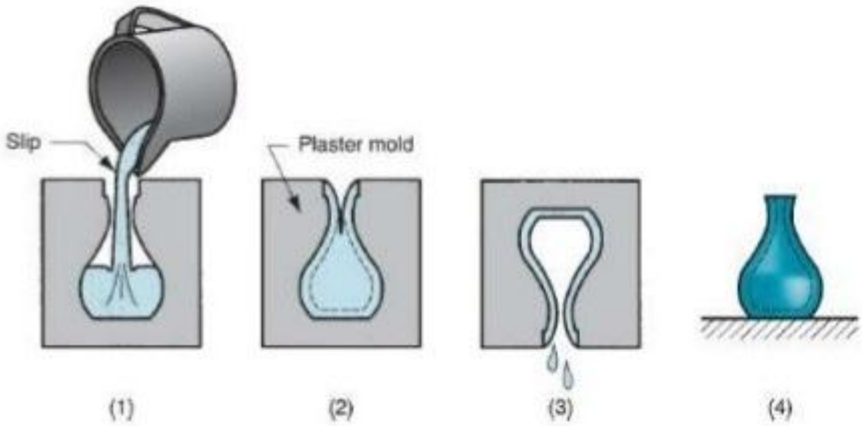

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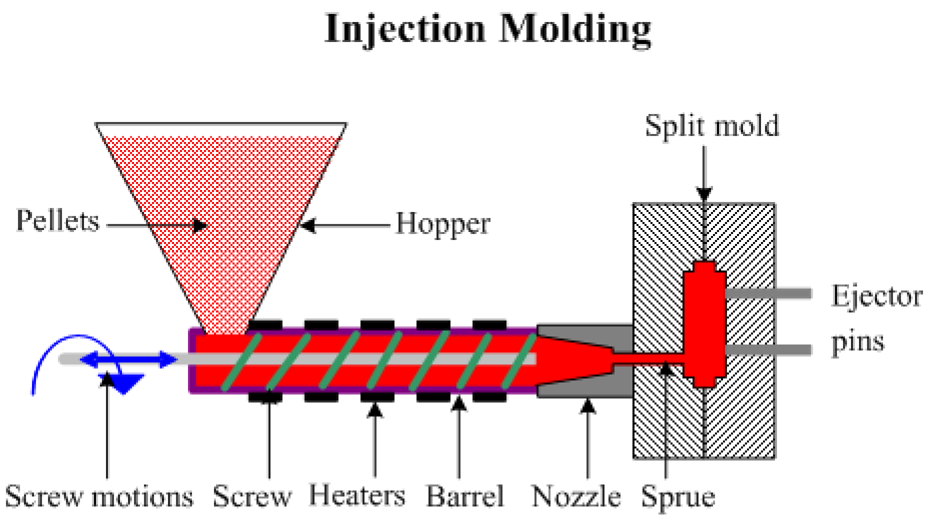

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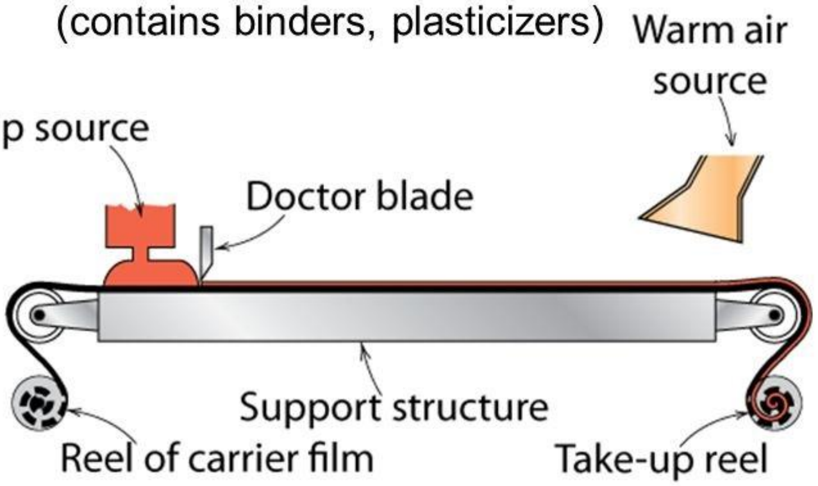
Tape Casting

- Thin sheets of green ceramic cast as flexible tape
- Used for integrated circuits and capacitors
- Slip = suspended ceramic particles + organic liquid (contains binders, plasticizers)



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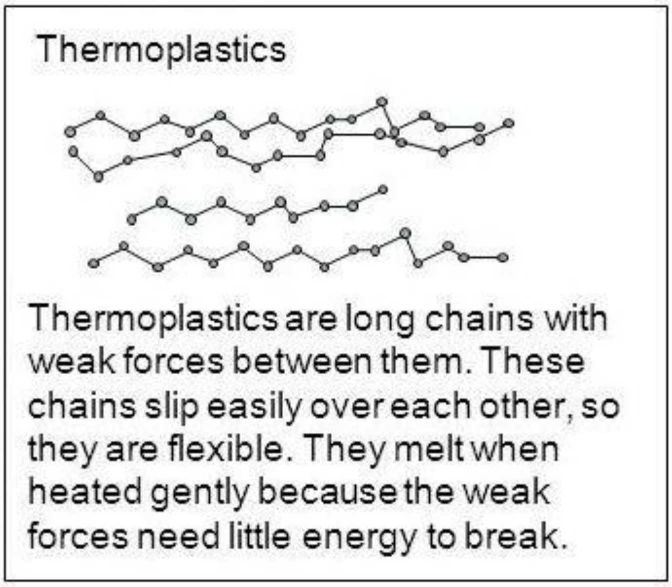
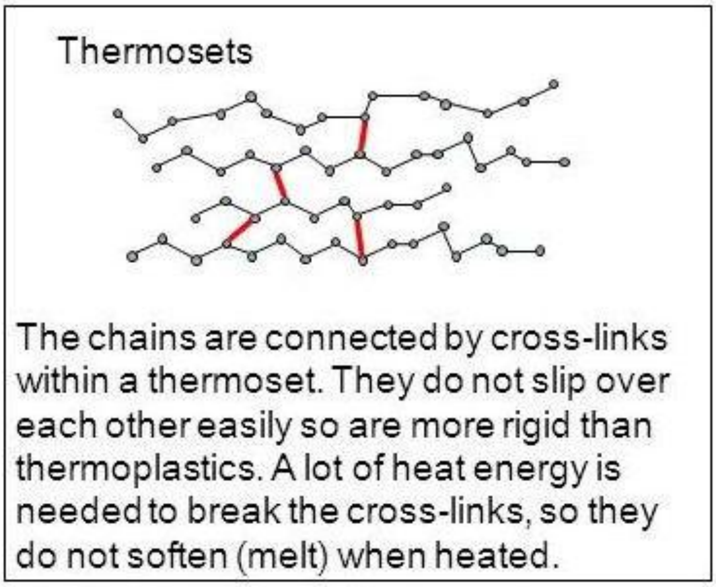
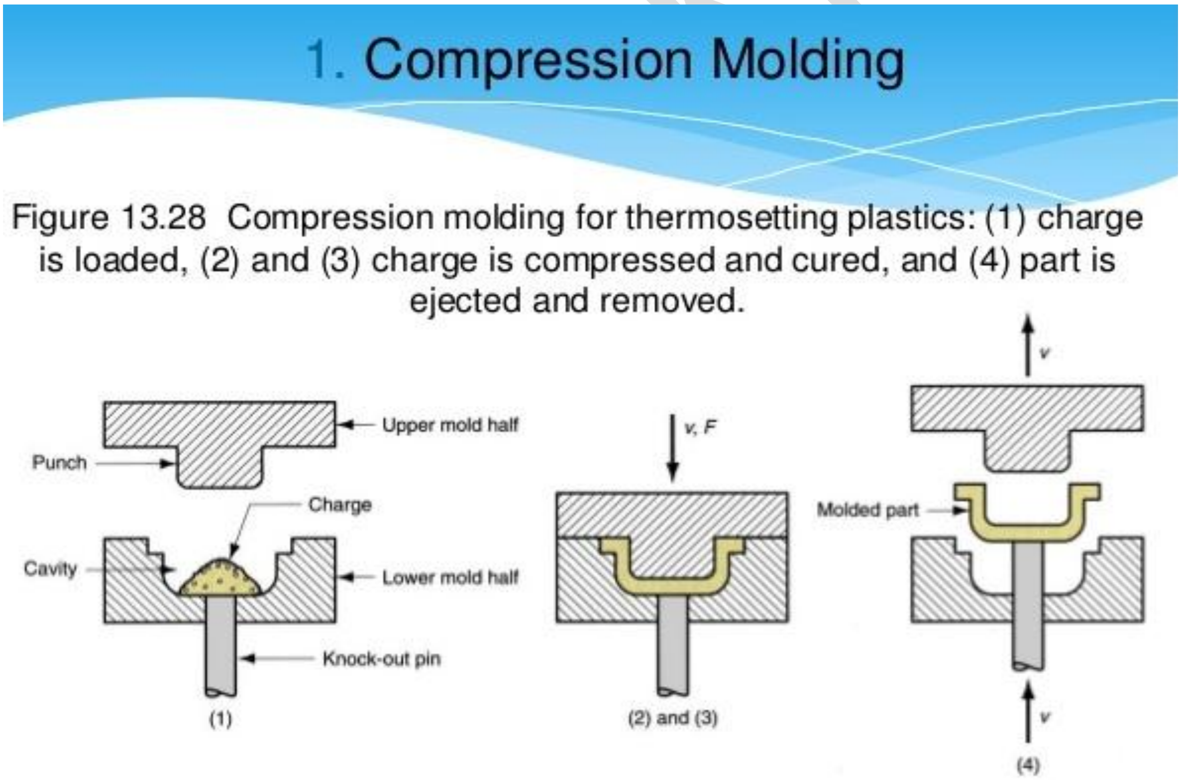


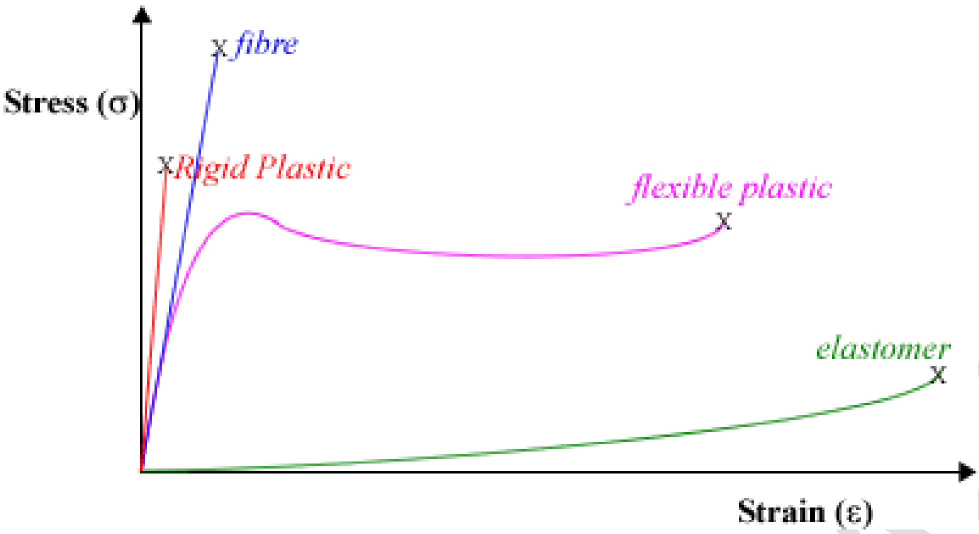


ThermoPlastics	**ThermoSets**
Little cross linkage	Large cross linkage
Ductile	Hard & Brittle
Soften with heat	Doesnt Soften with heat
Eg: PolyEthylene, PolyPropylene,PolyStyrene	Eg: Epoxies, Polyester, Resins, Vulcanised rubber

Processing of Plastics:



Properties of Plastics:



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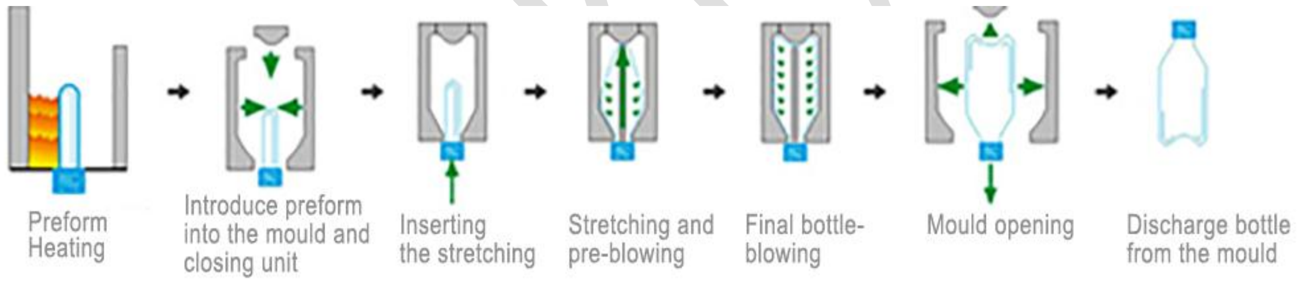
Ductility	↓	↑	↑
Corrosion resistance	↑	↓	↓
Resistance to wear	↑	↓	↓
Electrical conductivity	↕	↑	↓
Density	↓	↑	↓
Thermal conductivity	↕	↑	↓

↑ Tendency to high values ↓ Tendency to low values

PROPERTIES OF CERAMICS

- Extreme hardness:
  - High wear resistance
  - Extreme hardness can ***reduce wear caused by friction***
- Corrosion resistance
- Heat resistance:
  - Low electrical conductivity
  - Low thermal conductivity
  - Low thermal expansion
  - Poor thermal shock resistance
- Low ductility:
  - Very brittle
  - High elastic modulus
- Low toughness:
  - Low fracture toughness
  - Indicates the ability of a crack or flaw to produce a catastrophic failure
- Low density:
  - Porosity affects properties
- High strength at elevated temperatures

PET-Plastic Bottle Manufacturing Process Flow Chart



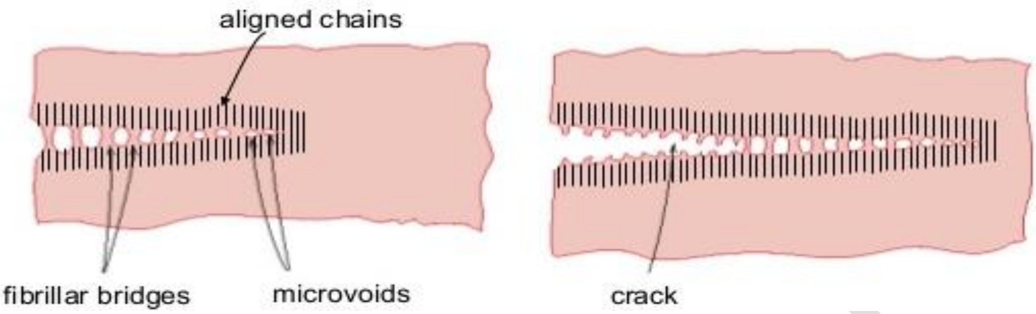
Fracture of Polymers

❑The fracture strengths of polymers are low relative to ceramics and metals.

❑The fracture mode in thermosetting polymers (heavily crosslinked networks) is typically brittle.

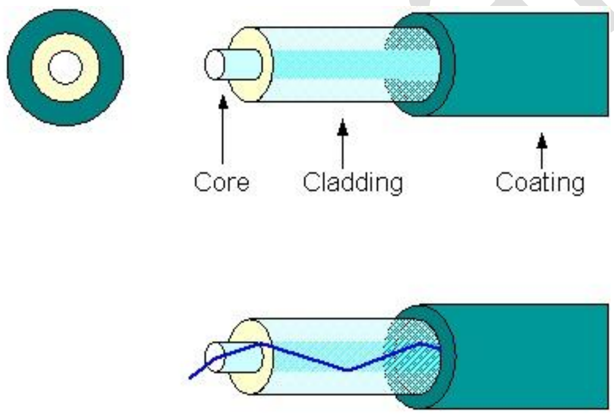
❑For thermoplastic polymers, both ductile and brittle modes are possible. Reduced temperature, increased strain rate, sharp notches, increased specimen thickness are some factors that can influence a brittle fracture.

❑One phenomenon that occurs in thermoplastics is crazing, very localized plastic deformation and formation of microvoids and fibrillar bridges

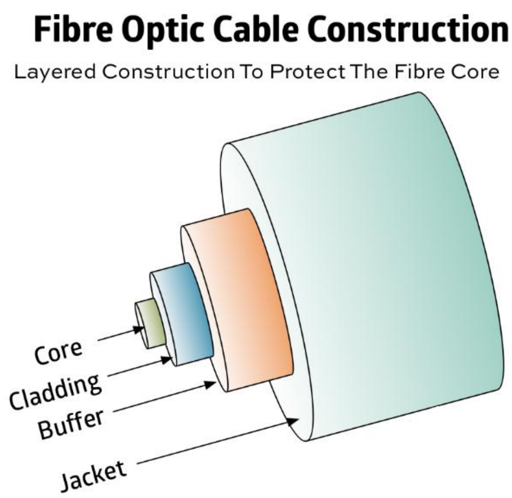


Optical Fiber

An optical fiber is a flexible, transparent fiber made by Silica or Plastic to a diameter slightly thicker than that of a human hair. Optical fibers are used most often as a means to transmit light between the 2 Ends of the fiber and find wide usage in fiber-optic communications, where they permit transmission of Data over longer distances and at higher bandwidths (data rates) than metal wire cables.



The Optical Fiber carries the light in its core, whose Refractive Index is greater than that of the cladding

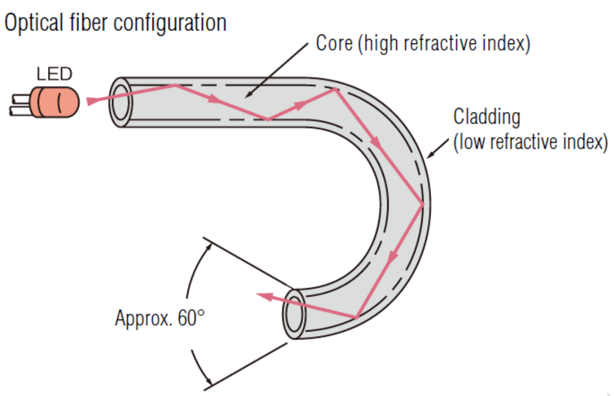


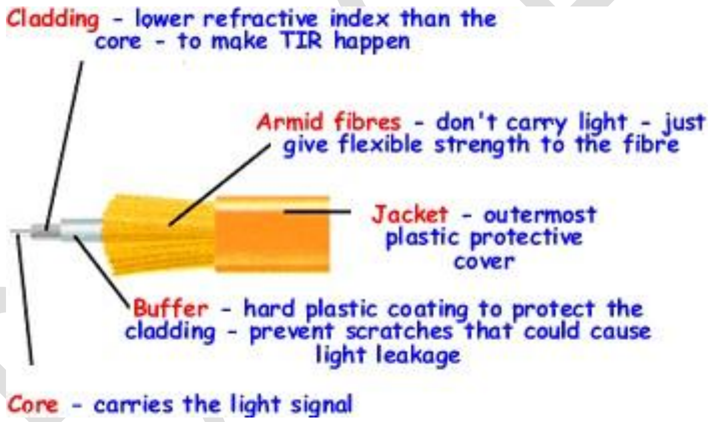
Fibers are used instead of metal wires because signals travel along them with less loss; in addition, fibers are immune to electromagnetic interference, a problem from which metal wires suffer excessively

Optical fibers typically include a core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by the phenomenon of total internal reflection which causes the fiber to act as a waveguide

Principle of operation

An optical fiber is a cylindrical DiElectric waveguide of conduit that transmits light along its axis, by the process of Total internal reflection. The fiber consists of a Core surrounded by a Cladding layer, both of which are made of Dielectric materials. To confine the optical signal in the core, the refractive index of the core must be greater than that of the cladding.



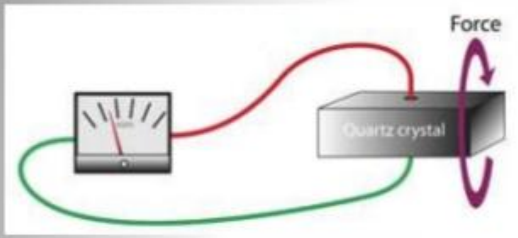


Applications of Fiber Optics:

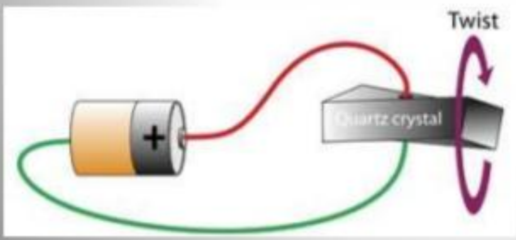
- The optical fibers have many applications. Some of them are as follows -
- Used in telephone systems
- Used in sub-marine cable network
- Used in data link for computer networks, CATV Systems
- Used in CCTV surveillance cameras
- Used for connecting fire, police, and other emergency services.
- Used in hospitals, schools, and traffic management systems.

Piezo Electricity:

Piezoelectricity

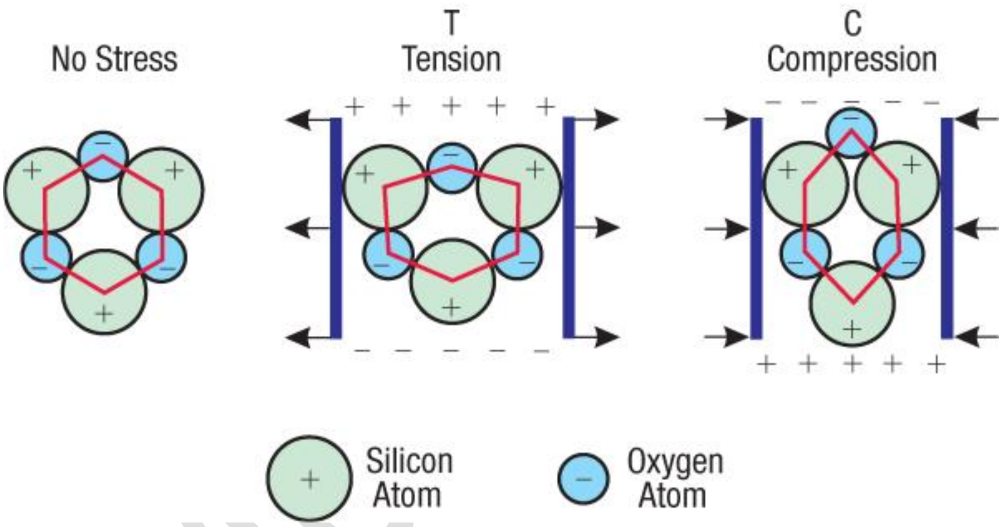


Piezoelectricity is the ability of certain materials (piezoelectric materials) to produce a voltage when subjected to mechanical stress.



Piezoelectric materials also show the opposite effect, where application of an electrical field creates mechanical stress (size modification) in the crystal.

Piezoelectric Effect in Quartz



Types of Piezoelectric Materials

- <u>Naturally occurring crystals</u>:
  cane sugar, Quartz, Rochelle salt, Topaz, Tourmaline Group Minerals, and dry bone (apatite crystals)

- <u>Man-made crystals</u>:
  Gallium orthophosphate ($GaPO_4$), Langasite ($La_3Ga_5SiO_{14}$)

- <u>Man-made ceramics:</u>
  Barium titanate ($BaTiO_3$), Lead titanate ($PbTiO_3$), Lead zirconate titanate ($Pb[Zr_xTi_{1-x}]O_3$ $0<x<1$) - More commonly known as *PZT*, Potassium niobate ($KNbO_3$), Lithium niobate ($LiNbO_3$), Lithium tantalate ($LiTaO_3$), Sodium tungstate (Na_xWO_3), $Ba_2NaNb_5O_5$, $Pb_2KNb_5O_{15}$

- <u>Polymers:</u>
  Polyvinylidene fluoride (PVDF)

<u>Smart Materials</u>

Smart materials are Designed materials & these materials are able to sense changes in their environments and then respond to these changes in predetermined manners.

Changing Stimuli may be Stress, Temp, pH, Light Moisture, Electric & magnetic Field.

Components of a smart material include a type of sensor (that detects input) and an actuator (that performs a responsive and adaptive function).

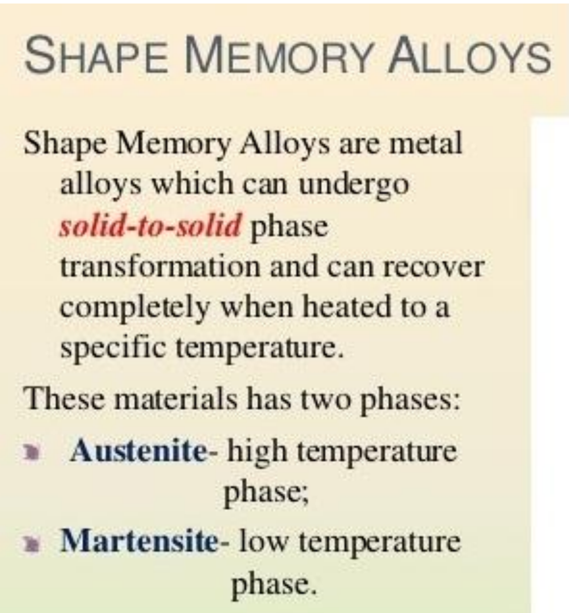
A common example being the coating on spectacles which reacts to the level of UV light, turning your ordinary glasses into sunglasses when you go outside and back again when you return inside.

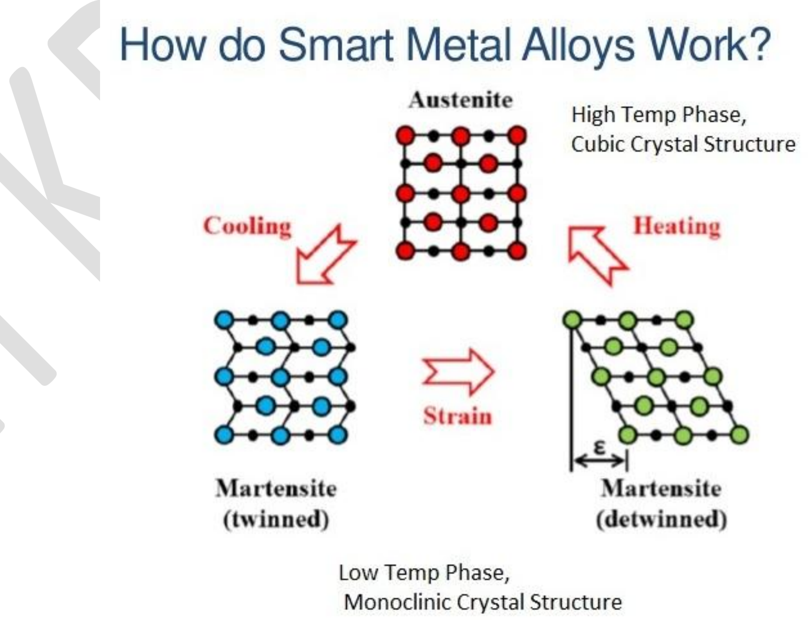
This coating is made from a smart material which is described as being PhotoChromic.

4 Common type of Smart Materials:

- Shape-memory – Metals that, after being deformed, revert back to their original shape with a temperature change.
- PiezoElectric Ceramics – Expand and contract in response to applied electric fields. They also generate an electric field when deformed.
- MagnetoStrictive – Similar to piezoelectric except for magnetic fields.
- Electro Rheological fluids – liquids that experience dramatic changes in viscosity upon application of electric fields. MagnetoRheological fluids also exist.

Shape Memory Alloy





Nitinol:

Nickel titanium, also known as Nitinol is a metal alloy of nickel and titanium, where 2 elements are present in equal atomic percentages

Nitinol alloys exhibit 2 closely related and unique properties:

shape memory effect (SME) & Superelasticity . Shape memory is the ability of Nitinol to undergo deformation at one temperature, then recover its original, undeformed shape upon heating above its "Transformation temperature".

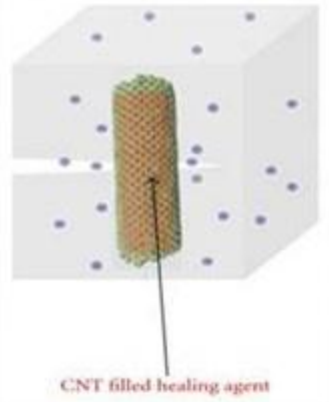
Superelasticity occurs at a narrow temperature range just above its transformation temperature; in this case, no heating is necessary to cause the undeformed shape to recover, and the material exhibits enormous elasticity

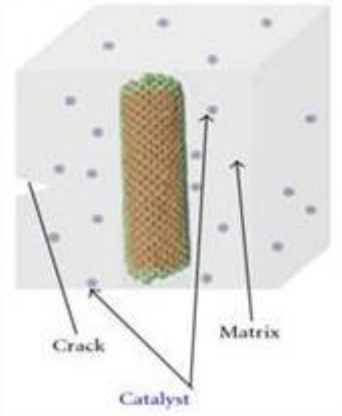
SELF-HEALING MATERIALS

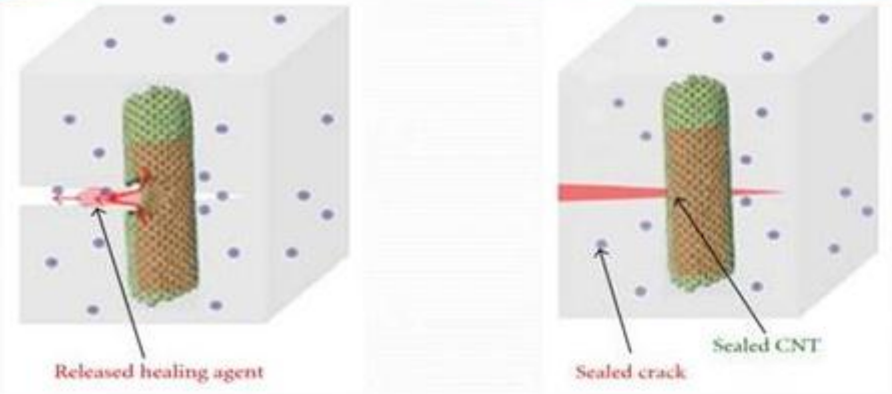
Self-healing materials are a class of smart materials that have the structurally incorporated ability to repair damage caused by mechanical usage over time. The inspiration comes from biological systems, which have the ability to heal after being wounded.

The nature of the self-healing approach depends on

- the nature and location of the damage,
- the type of self-healing resins, and
- the influence of the operational environment







- When a micro crack forms in the composite material, it will spread through the material.
- By doing so, this crack will rupture the microcapsules and release the healing agent.
- This healing agent will flow down through the crack and will inevitably come into contact with the Grubbs' catalyst, which initiates the polymerization process.
- This process will eventually bond the crack closed.
- The self-healed composite material regained as much as 75 percent of its original strength.

Characteristics of Metals used in implants:

Performance of any material in the Human body is controlled by 2 sets of Characteristics:

BioFunctionality & BioCompatibility

When metals and alloys are considered, the susceptibility of the material to corrosion and the effect the Corrosion has on the Tissue are the central aspects of Biocompatibility.

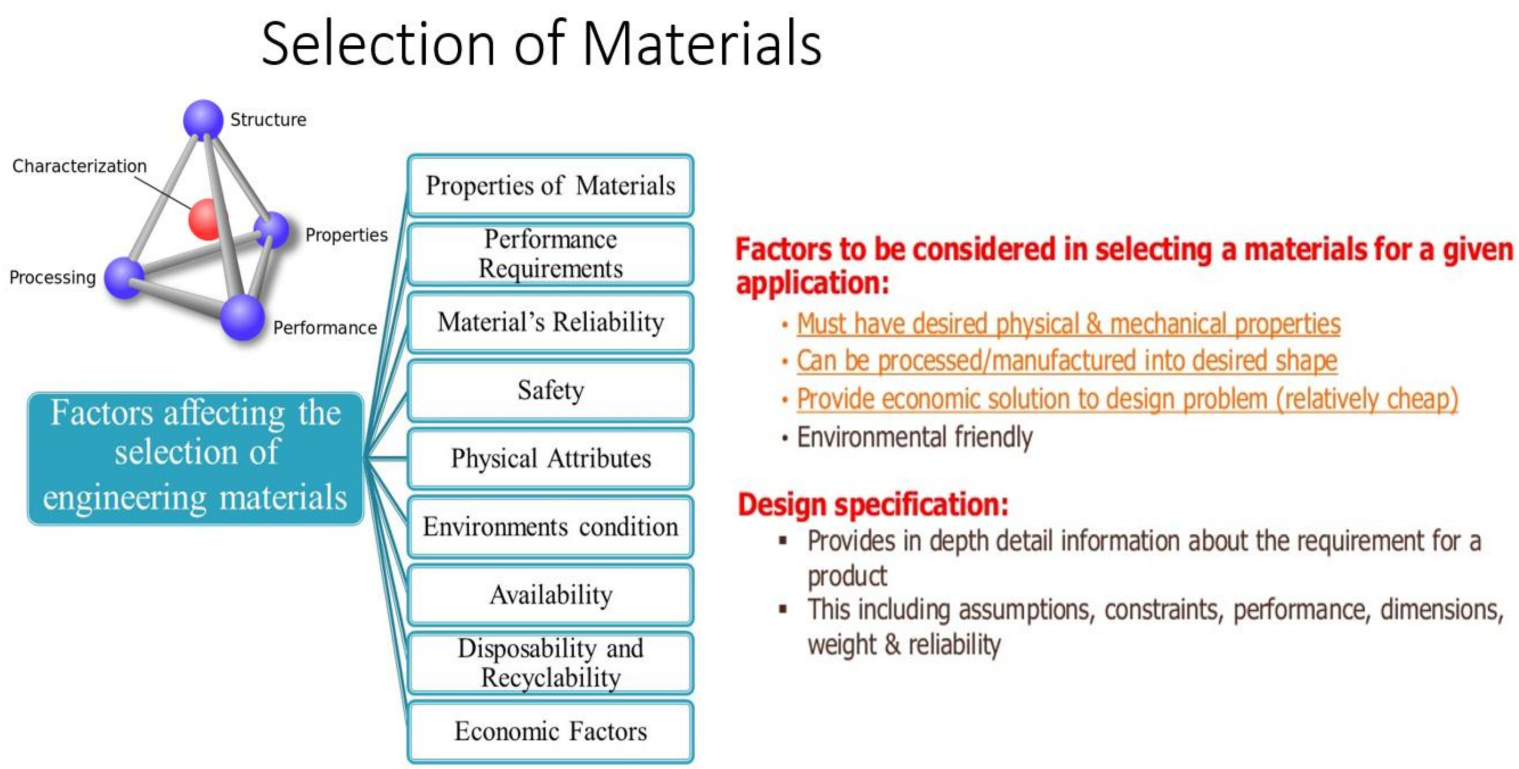
Corrosion Resistance of the currently used **316L Stainless steel, Cobalt-chromium, & Titanium-based implant alloys** relies on their passivation by a thin surface layer of oxide.

Stainless steel is the least corrosion resistant, and it is used for temporary implants only.

Titanium & Co-Cr alloys do not corrode in the body

Ceramics like Zirconia & Calcium Phosphate are used in Dental & Orthopedic Implants

Shape memory" & "Pseudo-elasticity" properties of Nitinol alloy is considered for the manufacturing of urologic stents



Residual Life Assessment:

- Residual Life of materials is the time period during which it shall retain the Fitness for service characteristics. External & internal inspection beside to routine operation have to be undertaken to monitor the extent of in-service life of material.
- This inspection is useful in power plant components, Aircraft components, & other Machineries which are susceptible to Fatigue & Creep

NonDestructive Testing or NDT is a wide group of analysis techniques used in science and technology industry to evaluate the properties of a material, component or system without causing damage, NDT does not permanently alter the sample being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research.

NDT Methods

1. Visual Inspection
2. Liquid penetrant method
3. Ultrasonic Inspection
4. Radiography methods
   - X-ray radiography & fluoroscopy
   - γ- ray radiography
5. Eddy current testing
6. Magnetic particle testing
7. Thermography

LIQUID PENETRANT METHOD

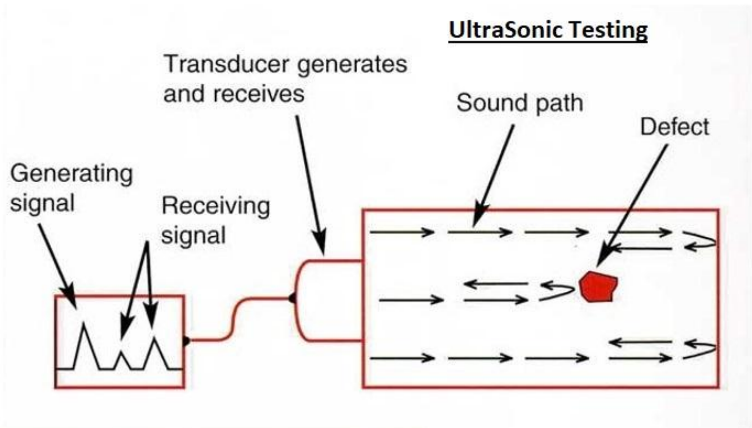
Principle

A liquid penetrant is applied at the surface of the specimen. The penetrant is drawn by the surface flaws due to capillary action and this is subsequently revealed by a developer, in addition with visual inspection.

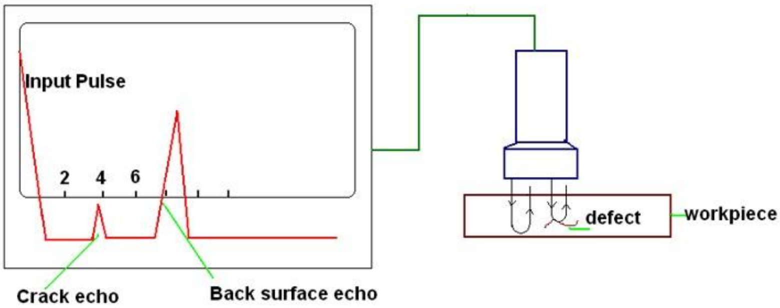
Procedure

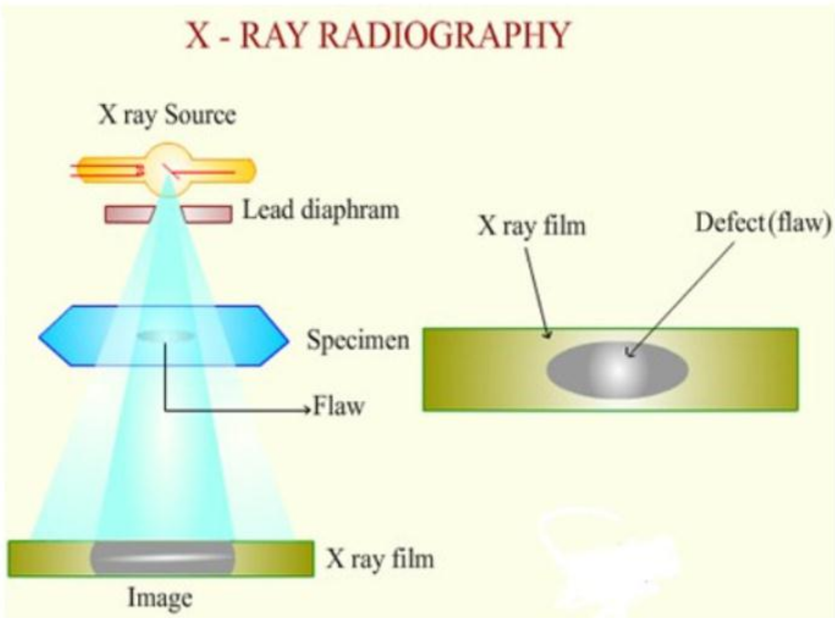
i. Cleaning the surface
ii. Application of the penetrant
iii. Removal of excess penetrant
iv. Developing
v. Inspection

UltraSonic Testing:



- High frequency sound waves are introduced into a material and they are reflected back from surfaces or flaws.
- Reflected sound energy is displayed versus time, and inspector can visualize a cross section of the specimen showing the depth of features that reflect sound.





X Ray are passed through the specimen under inspection & it is absorbed Differentially by the Specimen.

X-ray are received by the phtographic film & the Film is developed .

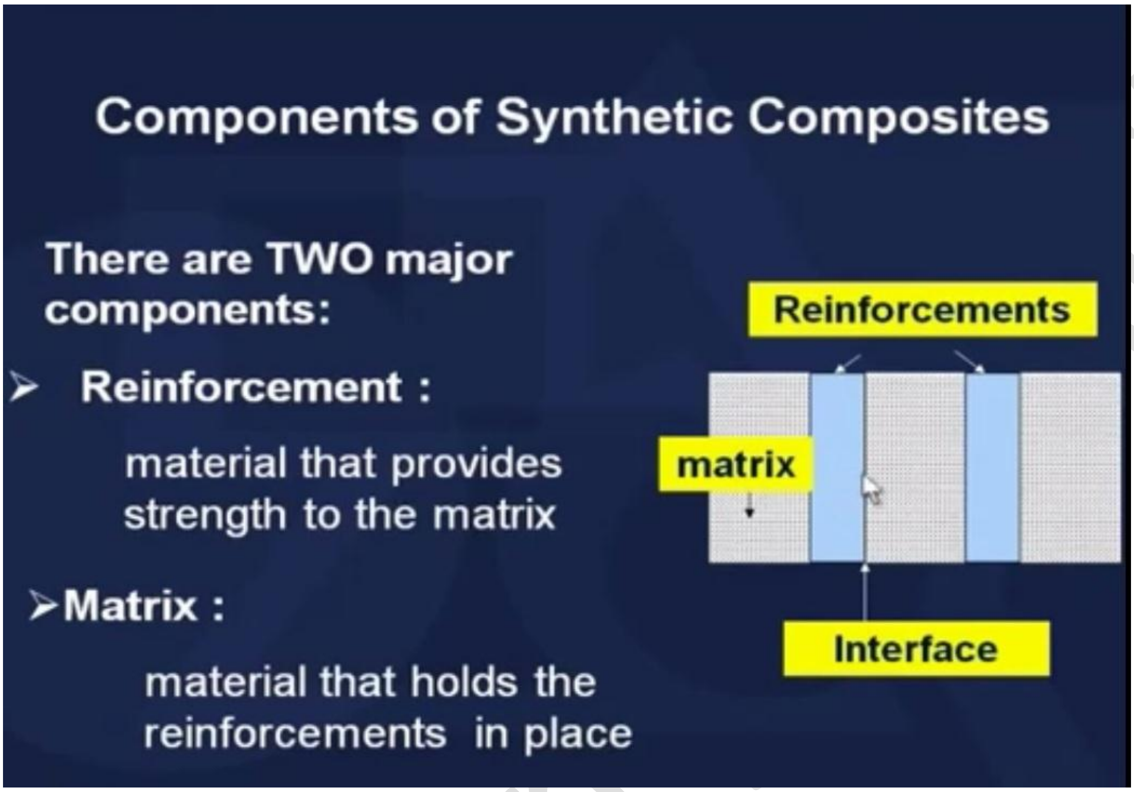
Dark & Light Shadow reveals the presence of Defect.

Composite Materials:

it is the Combination of 2 or more Constituent materials with different Physical & Chemical properties, Remain separate & distinct within the Finished structure is called Composite materials

Most Composites are made of 2 materials

- Matrix
- Reinforcement



Examples of naturally occurring Composites

- Wood: Cellulose fibers bound by Lignin matrix
- Granite: Granular composite of Quartz, Feldspar & Mica

Examples of Man-made Composites

- Concrete: Particulate composite of Aggregates(limestone or granite), sand, cement and water
- Plywood: Several layers of wood veneer glued together
- Fiberglass: Plastic matrix reinforced by glass Fibers

2. Role of Constituents in a Composite

1) Role of Matrix:

- It helps to Holds the fiber together.
- Protects the fibres from environment.
- Distributes the loads evenly b/w Fibres so that all fibres are subjected to the same amount of strain.
- Enhances Transverse properties of a Laminate.
- Improves impact and fracture resistance of a component.
- Helps to avoid propagation of crack growth through the fibres by providing alternate failure path along the interface between the fibres and the matrix.
- Carry interlaminar shear.

2) Role of Reinforcement:

- Carry the load, Provide Strength & Stiffness to the Composite
- it helps to deflect the Crack front in Matrix there by Lowering Crack growth
- Heat Resistance or Conduction in some composites

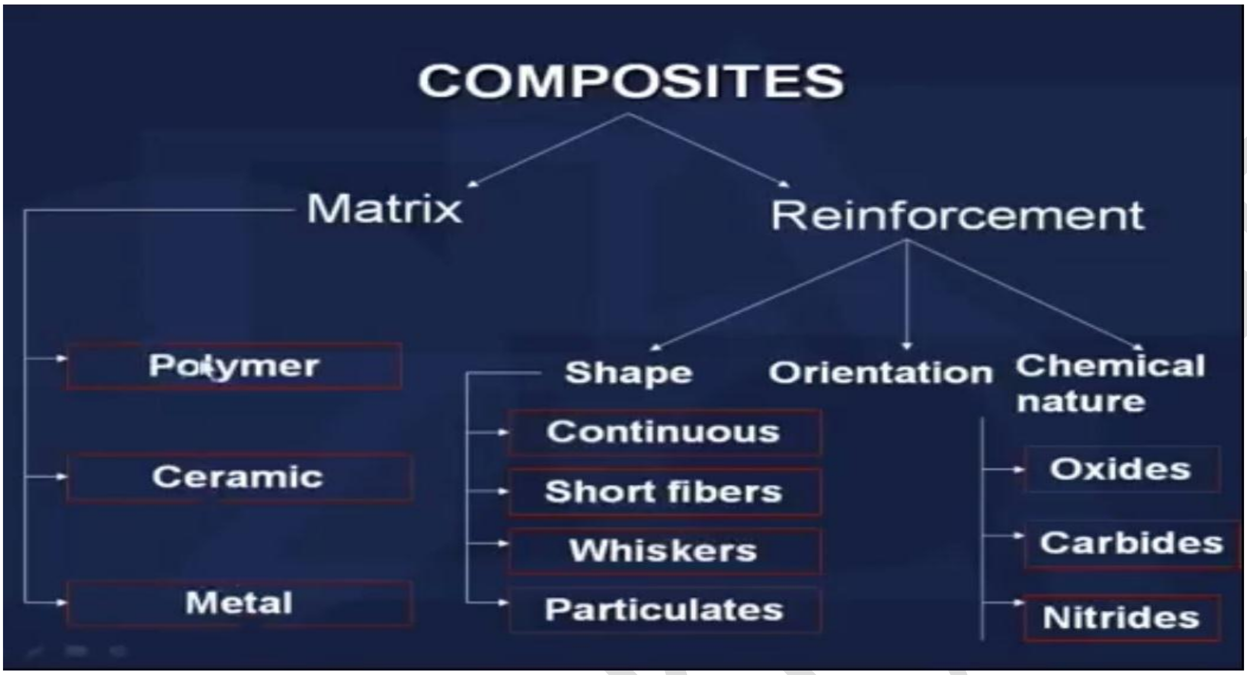
3) Role of interface:

- Interface is the segmental line which distinguishes Matrix & Reinforcement
- Matrix transfers the load via interface
- Creep, fracture Resistance also affected by the characteristics of interface

Advantage of Composites Vs Conventional Materials

- High Strength
- Corrosion Resistance
- Design Flexibility
- Design Stability
- Durability
- Low Investment
- Conductive/ Non Conductive

3. Classification of Composites Materials



1) Polymer Matrix: Matrix is made of Polymer Resin material , Reinforcement is usually Fibers, made from Graphite, boron Etc..

Two kinds of polymers are used : ThermoPlastic & ThermoSets

Applications: AeroSpace Structure, Boats, Canoes, Armors

2) Metal Matrix:

Matrix is made of metals or Alloys, Reinforcement is usually in the form of Fibers or Particulates

Ti, Al, Mg are the Popular Matrix agents because of its Low Density

Applications include: Pistons, Connecting Rod, Brake Component, Shafts

2) Ceramic Matrix:

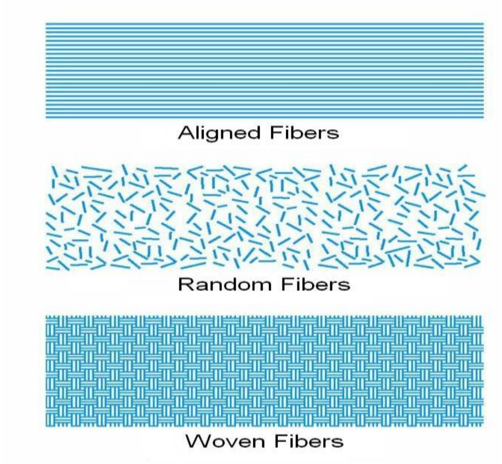
Matrix is made of Ceramics like SiCarbide, AlOxide, Zirconium Ozide.

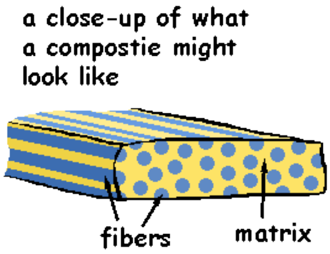
Reinforcement is usually in the form of Fibers which may also could be made of same ceramic materials

Applications include: Cutting Tools, Turbine components

Classification w.r.t Reinforced Constituent

A) Fibre Reinforced Composite





B) Particulate Composite

PARTICLE REINFORCED COMPOSITE

These are the cheapest and used.

They fall in two categories (size)

1. **Large-Particle Composites**

   -Consist of a high volume fraction of large sized hard particles embedded in a relatively soft matrix.

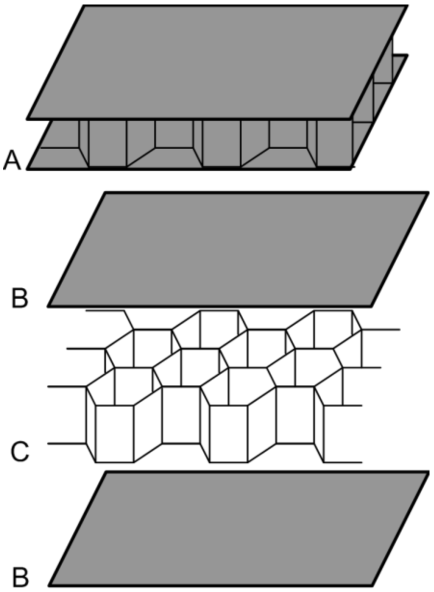
2. **Dispersion-Strengthened Composites**

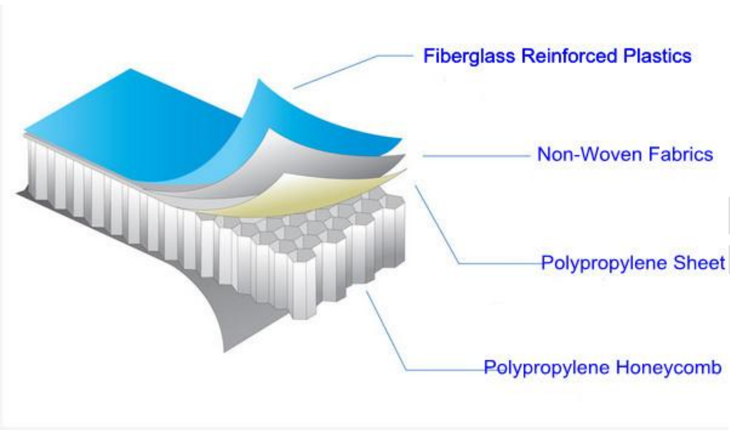
   -Contains extremely small sized particles dispersed

   -At low concentration which increases the matrix attractions

   -At the atomic level there by enhancing the strength

C) Laminated Composite





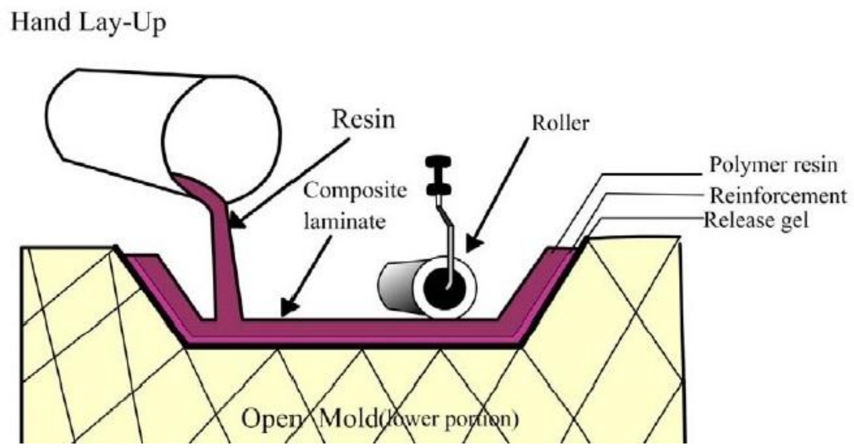
Advantages of Composites:

- **Composites possess high strength to weight ratio**
- **High resistance to Fatigue & corrosion degradation**
- **Durable – Long life**
- **Excellent structural damping feature**
- **Reliable, Dimensionally stable, Low thermal conductivity**
- **Directional Tailoring Capability is High**
- **Torsional Stiffness is High**
- **Easy Manufacturing**
- **High resistance to Wear & Friction**

Limitations of Composites:

- **Transverse Properties are Low**
- **Reuse & Disposal is difficult**
- **Repairing often introduce new problems**
- **It does not have good combination of Strength & Fracture toughness**
- **Required Sophisticated machines & Skilled labour to produce Composites**

1) **Hand Lay-Up Process:**



Matrix Used: Epoxy, PolyEster, PolyVinyl Ester, Penolic resin

Reinforcement used: Glass Fiber, Carbon fiber, Aramid Fiber & Hemp

Hand lay-up is the process that starts with the application of gel coating onto a completely polished and waxed mould.

A coat of laminating Resin with catalyst or hardener, is then being applied by roller.

The laminating resin is then applied to the reinforcement (the fiberglass) so that all trap air can be force out using roller.

Continue doing this for your next layer of fiberglass, until desired thickness is achieved.

Once finished, allow the resin to cure & finally, remove your product from the mould (De Mould)

2) Spray Lay-Up Process

Matrix Used: Epoxy, PolyEster, PolyVinyl Ester, Penolic resin
Reinforcement used: Glass Fiber, Carbon fiber, Aramid Fiber & Hemp

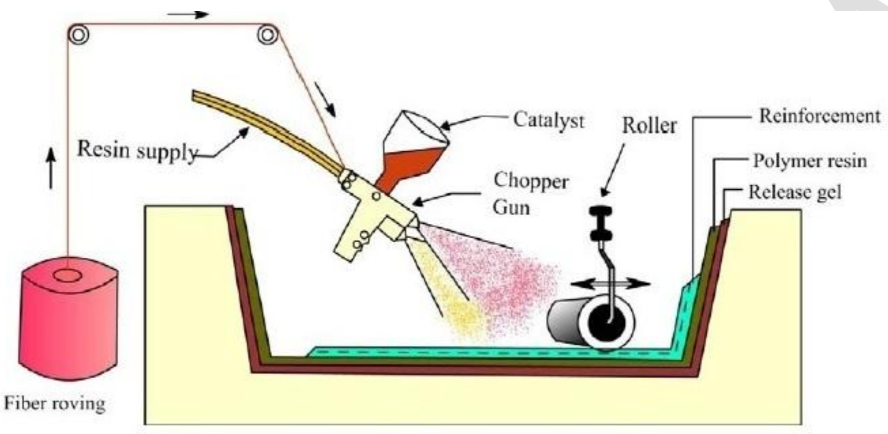


Figure 2 Spray lay-up method.

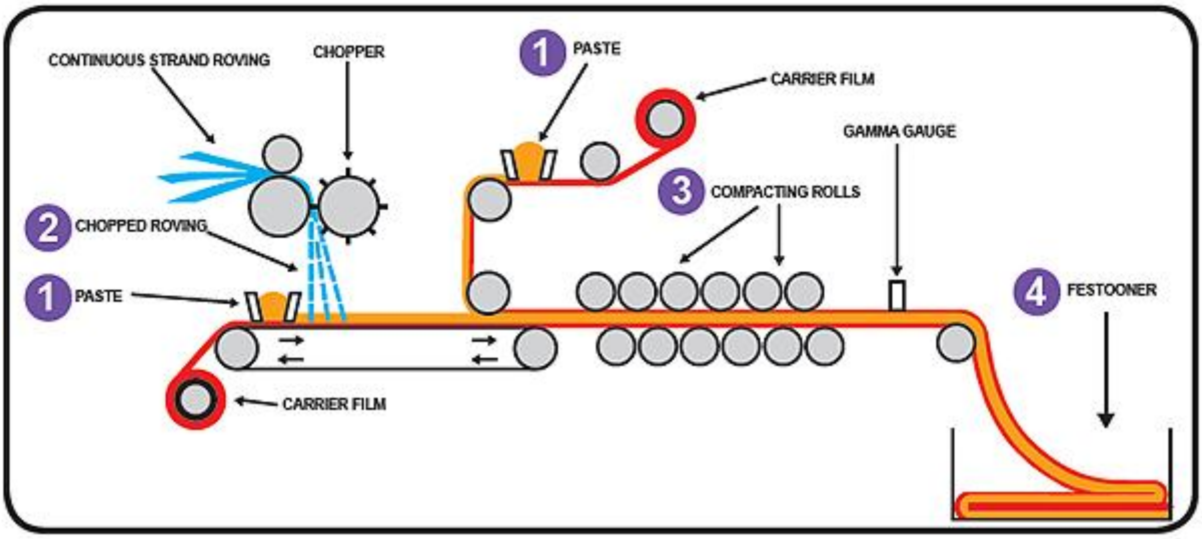
Spray Lay-Up process starts with the application of Gel coating onto a completely polished and waxed mould.

In this method, you will need a chopper gun that will chip away the glass roving. In this method, only glass roving can be used. While the resin mainly is Polyester.

Gun can have Separate Feeder pipe to Feed, Premixed Risen + Catalyst + Accelerator to the Lay along with Chopped Glass

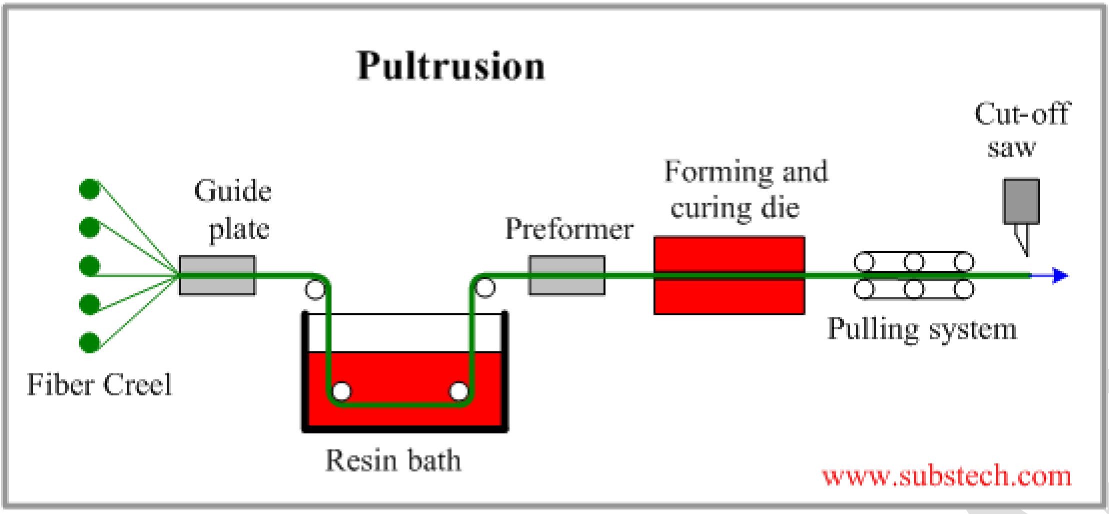
In this process chopping the fiber in a hand-held gun is done and fed into a spray of catalysed resin directed at the mould. And then the deposited materials are left to cure under standard atmospheric conditions.

3) Sheet Moulding Compound Process



- Sheet Moulding Compound is a combination of chopped glass strands & Polyester resin, in the form of a sheet. Processing of SMC is done by compression moulding
- Prepreg is made from glass strands, sandwiched between two layers of film, onto which the resin paste has already been applied. The Prepreg passes through a compaction system that ensures complete strand impregnation
- The film is stripped off and the material is cut into suitable pieces. These are collated into piles of material, which are called the charge.
- Heated moulds are used and a compression pressure is applied. The base resin being a thermosetting material cures and Hardens. Then the part is ejected.

Pultrusion Process:

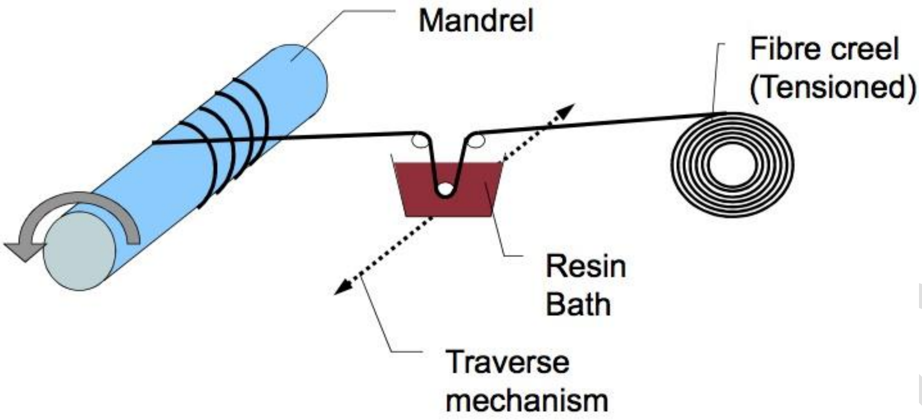


- Reinforcing fibers are pulled from the Roving.
- Guide plates collects the fibers into a bundle and direct it to the resin bath.
- Fibers enter the Resin bath where they are wetted and impregnated with liquid resin. Liquid resin contains thermosetting polymer, pigment, fillers, catalyst and other additives.
- The wet fibers exit the bath and enter performer where the excessive resin is squeezed out from fibers and the material is shaped.
- The preformed fibers pass through the heated die where the final cross-section dimensions are determined and the resin curing occurs.
- The cured product is cut on the desired length by the cut-off saw.

Advantages: Homogeneous distribution and high concentration of the reinforcing fibers in the material is achieved, excellent mechanical properties can be achieved due to the use of continuous fibers

Applications: Fabrication of Cross sectional profiles like I-Beams, Channels, Tubes Pipe, Poles Etc

Filament Winding Process:



Fibers: Aramide, Borons, E-Glass & S-Glass

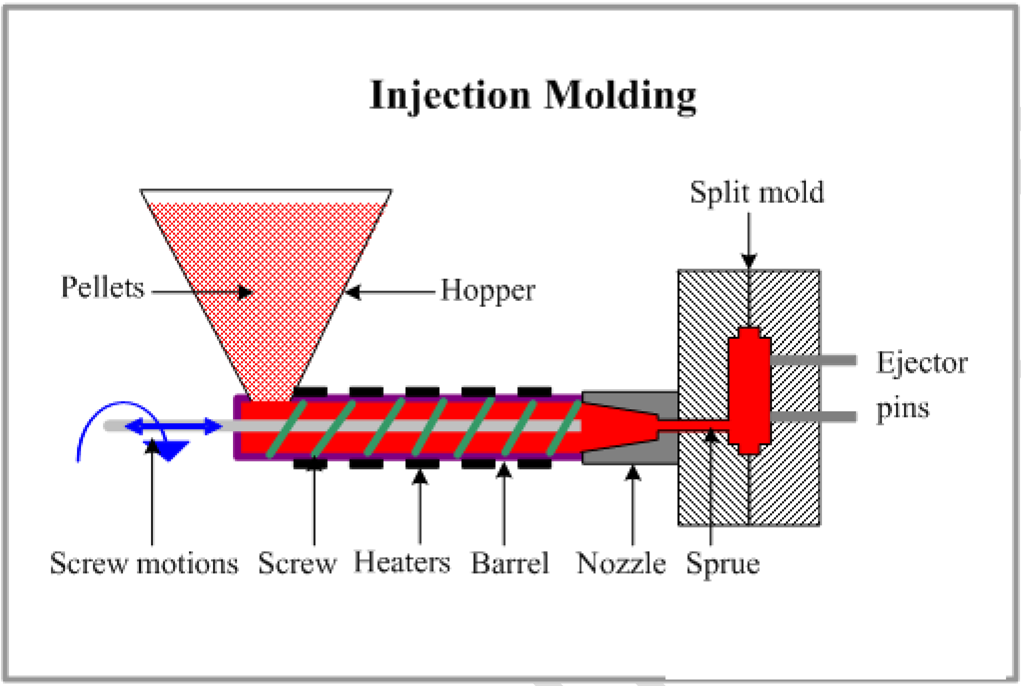
Resins: Epoxies, PolyEster, PolyAmides

Filament winding is the process of winding fiber material & resin around the shape of Manderal, it is typically used to create Circular comosites with a Hollow core

Process:

- Manderal rotates at a predetermined speed while the Carriage carrying the Resin bath moves Transversely
- Required Pressure is achieved through tensioning the fibers
- Once the mandrel is completely occupied with fibers it is now fed to Oven to solidify the resin.
- Final product is Hollow mesh of composite

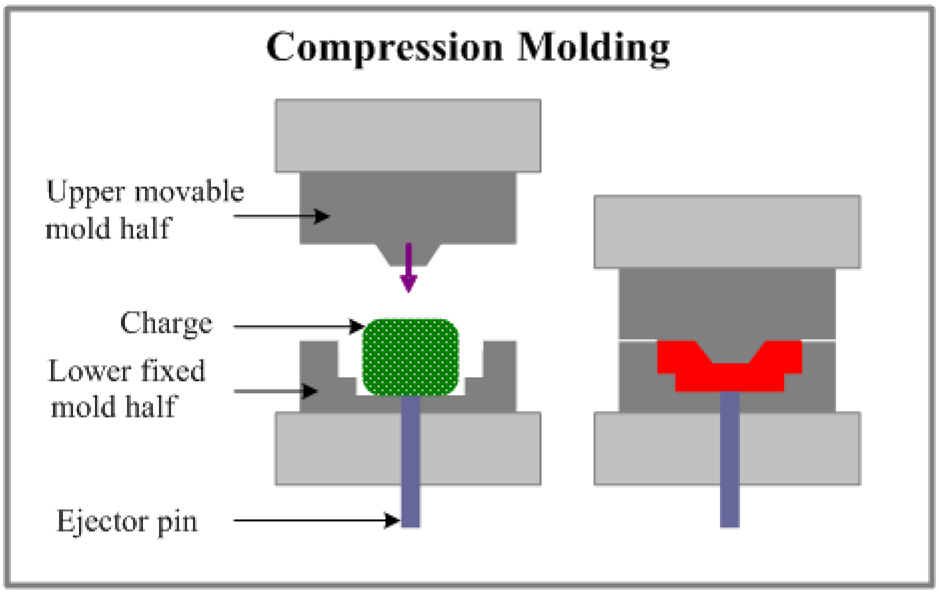
Injection moulding:



Injection Moulding is a Closed Mould process in which Molten Polymer (commonly Thermoplastic) mixed with very short reinforcing fibers is forced under high pressure into a mould cavity through an opening called Sprue

- Polymer Pellets are fed into an Injection Moulding machine through a Hopper. The material is then conveyed forward by a feeding screw and forced into a split mould, filling its cavity through a feeding system with Sprue gate and runners.
- Reciprocating screw rotates & also carries heated softened polymers Forward, Screw also acts as a Ram in the filling step wherein the molten polymer-fibers mixture is injected into the mould with high pressure and then it retracts backward in the moulding step.
- The polymer is held in the mould until solidification and then the mould opens and the part is removed from the mould by ejector pins.

Compression Moulding:



Compression Moulding is a Closed Mould process in which a moulding material is squeezed into a PreHeated mould taking a shape of the mould cavity and performing Curing due to Heat & Pressure applied to the material.

The method uses a split mould Hydraulic press

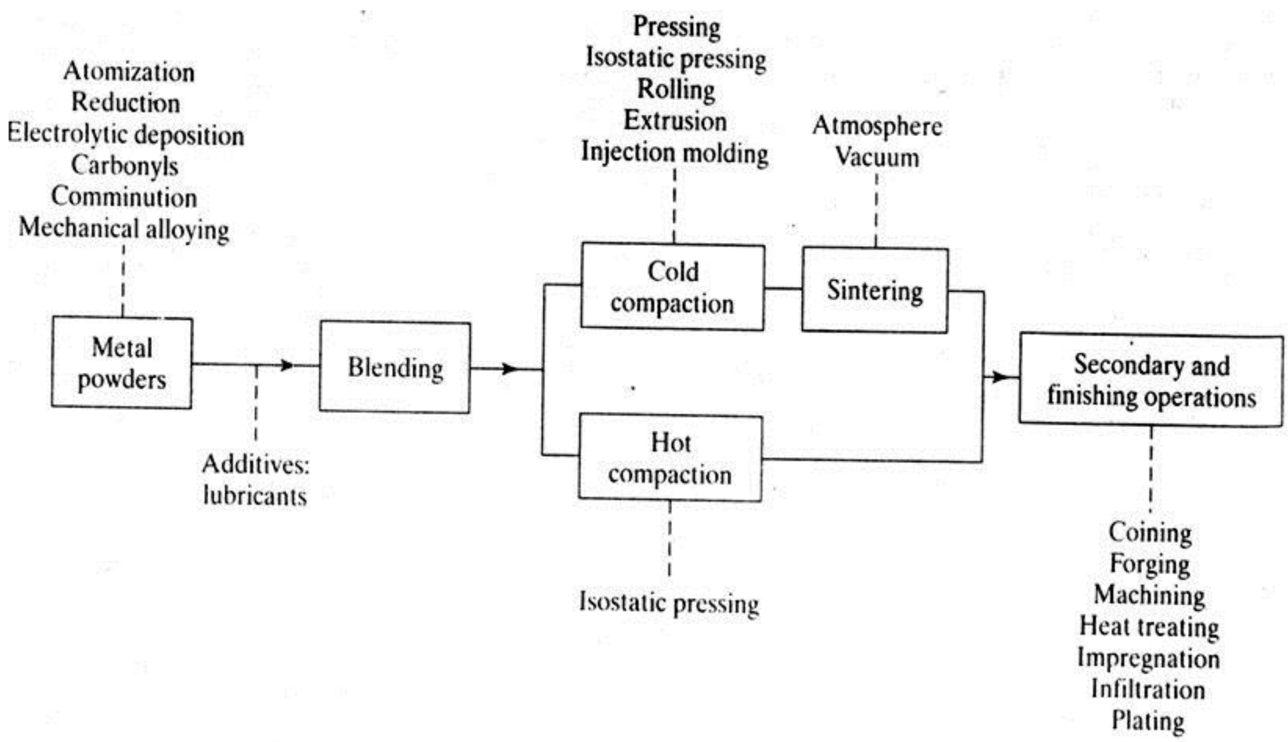
Compression Moulding process involves the following steps:

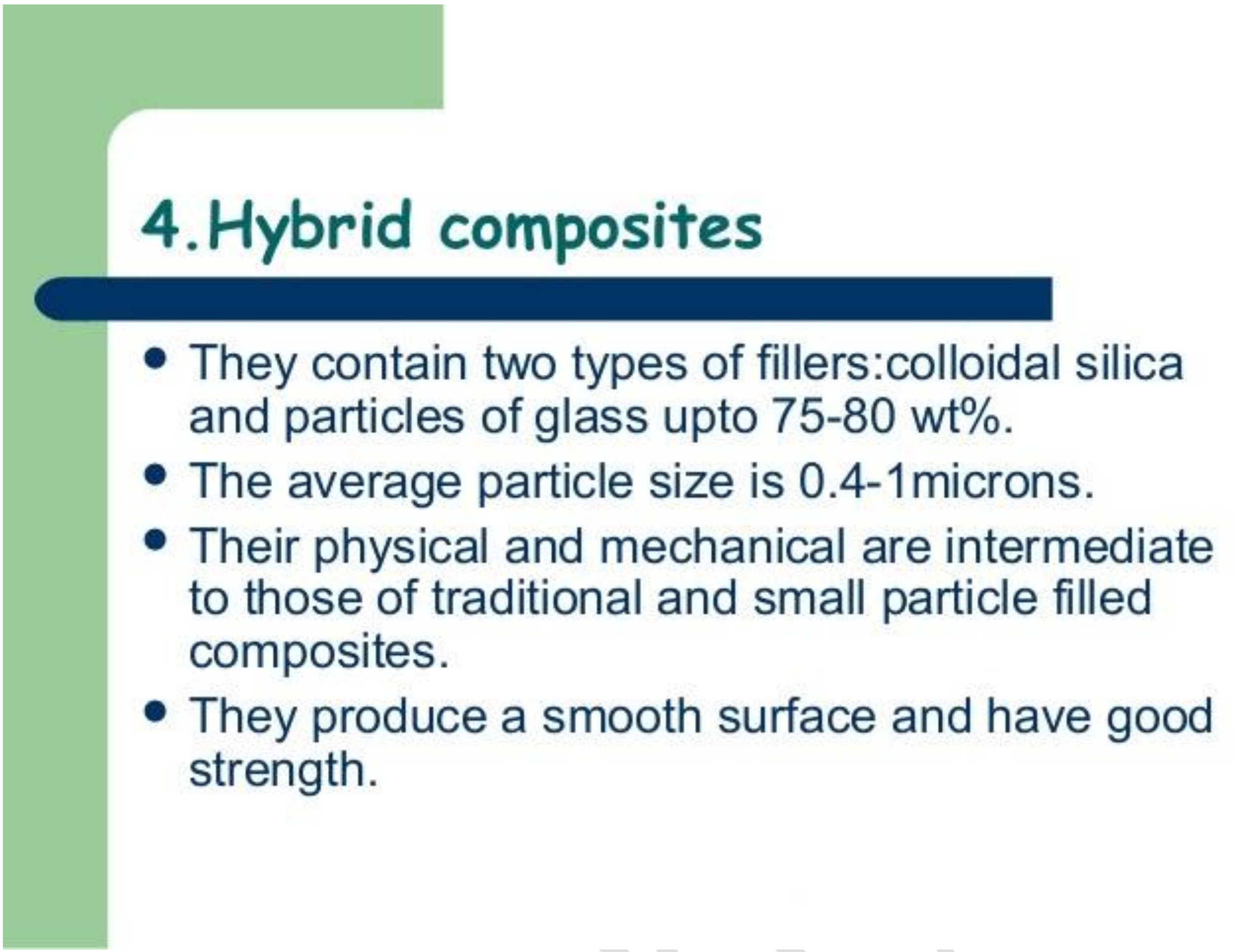
- Polymer (Thermosetting resin) mixed with chopped reinforcing fibers, hardening agent, anti-adhesive agent is placed into the lower half of the mould.
- The charge is usually Preheated prior to placement into the mould. Preheated polymer becomes softer resulting in shortening the moulding cycle time.

- The upper half of the mould moves downwards, pressing on the charge and forcing it to fill the mould cavity.
- The mould, equipped with a heating system, provides Curing (cross-linking) of the polymer matrix
- The mould is opened and the Part is now removed using Ejector pin.

Powder Metallurgy Technique

Powder Metallurgy Process





Applications of Hybrid Composites:

- Dental filling
- Due to its low density & high strength it is finding application in variety of fields such as Proton conducting membranes used in fuel cells.
- Fire retardant materials for construction industry.
- Super Capacitors
- Fire retardant materials