# UNIT 1: An overview of engineer materials having potential for tribological application

**Weightage**

Assignment: 10 Marks

Mid Term: 10 Marks

End Term: 20 Marks


*Lecture by*

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## Plan of Talk

- Tribology, its Historical Development
- Applications
- Tribological processes and tribological relevant properties of material

# Tribology
## *(from the Greek word 'tribos' meaning rubbing)*

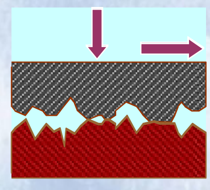
**The term *'tribology'* was coined in 1966 and it is defined as *"the science and technology of interacting surfaces in relative motion".***

**It encompasses the study of:**

***Friction***

***Wear***

***Lubrication***





# A Concise History of tribology

| 1880 BC | 1400 – 1800 A.D | 1800 – 1950 A.D | 20th Century and beyond |
|---|---|---|---|

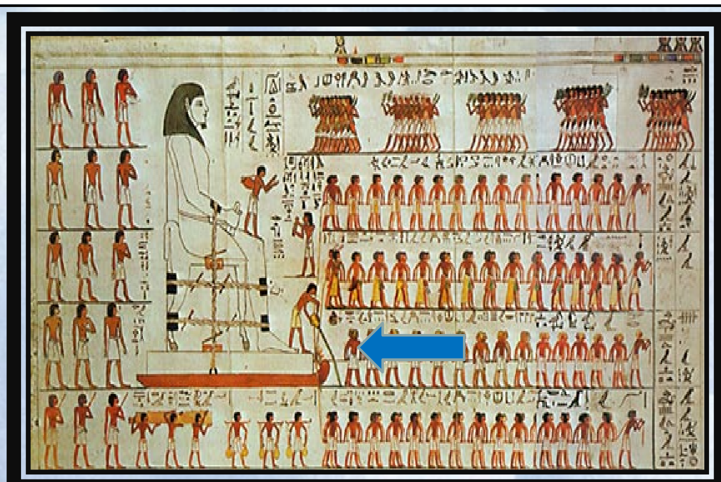
**Basic knowledge of frictional phenomena** → **Studies and rules governing friction developed.** → **Scientific studies of friction and wear and advancement of other Sciences** → **Tribology** (**1966**) → **Macro-tribology** / **Nano-tribology**

| | | | |
|---|---|---|---|
| Archeological findings from the Ancient **Roman** and **Egyptian** Empires<br>-water lubricated sleds | **Da Vinci** –1500 A.D<br>-Coefficient of friction<br>Guillaume **Amontons**<br>-Friction force of resistance<br>**Coulomb** 1785 A.D<br>-Static and kinetic friction | **Industrial revolution** 1850 AD<br>**Beauchamp Tower** 1886<br>-Hydrodynamic lubr. (Bearings)<br>**Ragar Holm** 1946<br>-Study of wear | **1969 - 2014**<br>Emerging of proximal probes (microscopes and the surface force apparatus), and computational techniques for simulating tip – surface interactions and interfacial properties. |

In ancient times, on the order of about 500,000 B.C., early humans learned that by rubbing sticks together with great force they could create fire.

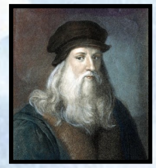
Around 3500 B.C. we learned that rolling motion required less effort than sliding, and the wheel was invented.



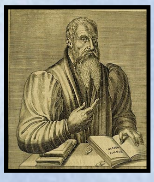


An Egyptian painting dating back to 1880 B.C. depicts workers dragging a sled containing a heavy statue.
One worker pours a liquid on the ground just before the runners to make the going easier.

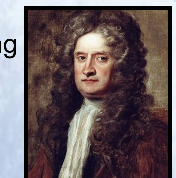
## 1495-1950: Laws of friction are developed



- In 1495 **Leonardo** formulated the two basic laws of friction: Friction is independent of contact area, and friction is proportional to load. For years, he never got credit for his work, as he did not formally publish his observations.



- Some 200 years later, in 1699, **Guillaume Amontons** (1663-1705) rediscovered these two basic laws. He reasoned that friction was primarily the result of work done to lift one surface over the roughness of the other, resulting in deformation and wear of the surfaces.



- **Sir Isaac Newton** (1642-1727), in studying and creating the basic laws of motion, added that moving friction was not dependent on speed or velocity, thus formul--ating the third law of friction. All these observations were made in the macro scale.



•In 1950, **Phillip Bowden** and **David Tabor** gave a physical explanation for the observed laws of friction. They determined that the true area of contact, which is formed by the asperities on the surface of a material, is a very small percentage of the apparent area. As the normal force increases, more asperities come into contact and the average area of each asperity contact grows.

•As our ability to analyze surface contacts at the monomolecular level has developed, we are learning that the “macro” laws don’t necessarily hold and that the processes of interaction are quite complex.

•“*Amontons Laws of Friction are the first quantitative description of a tribological process. Attempts (theories, mechanisms, models) to explain these laws have been central to the development of tribology*.” —**Bill Needelman**, Filtration Science Solutions.

## 1883-1905: Principles of hydrodynamic lubrication are elaborated

•In 1883, the elucidation of hydro-dynamic lubrication began in England, with testing done by **Beauchamp Tower**. He used a specially constructed test rig for journal bearings, simulating the conditions found in railway axle boxes.

•In the final phase of his research, Tower decided to drill an oil feed hole in the bearing. The oil was found to rise upwards in the feed hole and leak over the top of the bearing cap. He then installed a pressure gauge and found it to be inadequate for measuring the high pressure levels. This result proved the existence of a fluid film that could carry significant loads.

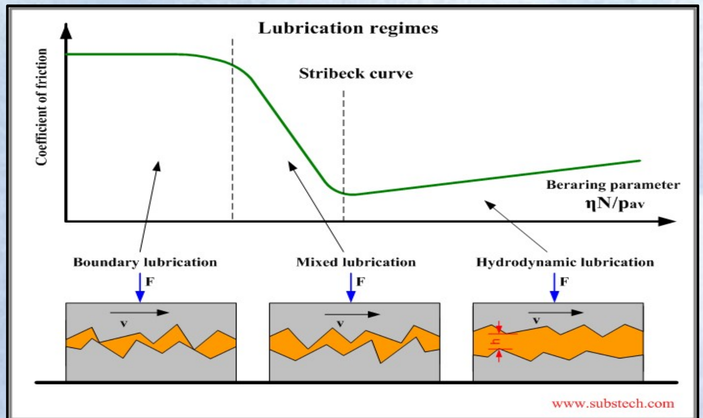


•In 1886 **Osborne Reynolds** published a differential equation describing this pressure buildup of the oil in the narrow converging gap between journal bearing surfaces. This equation, a variation of the Navier-Stokes equations resulting in a second-order differential equation, was so complex that many years passed before it was solved for journal bearings.

•In 1902 **Richard Stribeck**, published the Stribeck curve, a plot of friction as it relates to viscosity, speed and load.

•After the work of Tower and Reynolds, **Arnold Sommerfeld** refined the work into a formal theory of hydrodynamic lubrication in about 1905.

•A surface have tiny asperities that will contact if two plates are placed together. If one of the plates were to slide over the other, then friction would increase, the asperities would break and the surfaces would wear. In hydrodynamic lubrication, a fluid film separates the surfaces, prevents wear and reduces friction.



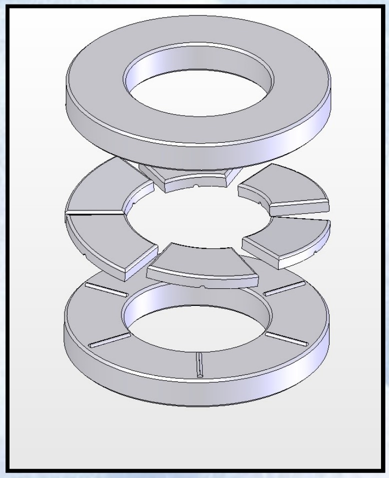



•The hydrodynamic film is formed when the geometry, surface motion and fluid viscosity combine to increase the fluid pressure enough to support the load. The increased pressure forces the surfaces apart and prevents surface contact. This is called hydrodynamic lift. Hydrodynamic bearings get load support by hydrodynamic lift.

•The most recognizable hydrodynamic bearings are slider bearings and journal bearings, both used extensively in machinery and vehicles—thanks to the development of hydrodynamic lubrication theory.

•"*The experiments of Beauchamp Tower formed the basis of modern-day hydrodynamic lubrication and inspired Osborne Reynolds to develop the Reynolds equation, which has remained at the center of fluid film lubrication to this day*." —**Martin Webster**, ExxonMobil R&E

•In 1905 fluid-film thrust bearings patented by Australian engineer **George Michell**. Michell bearings contain a number of sector-shaped pads, arranged in a circle around the shaft, and which are free to pivot. Michell's invention was notably applied to the thrust block of propellor driven ships. Their small size (one-tenth the size of old bearing designs), low friction and long life enabled the development of more powerful engines and propellers.



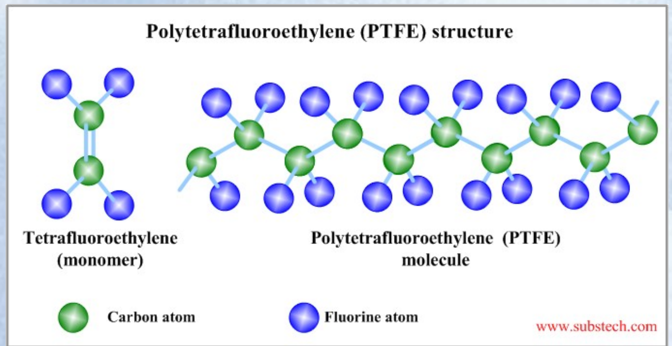


•In 1912 Dr. Albert Kingsbury invented the **hydrodynamic thrust bearing**.

•In 1922 understanding of **Boundary lubrication refined** by W.B. Hardy and I. Doubleday.

•1930s to 1940s The first **zinc dialkyldithiophosphates (ZDDPs)** began to be developed as anticorrosion agents and oxidation inhibitors. The antiwear activity of these molecules was recognized only later, in the 950s, at which point they became an integral part of many oil chemistries. To this day ZDDPs remain the backbone of antiwear additive technology.

•**PTFE**, the most famous of the self-lubricating coating materials, was discovered fortuitously during a project looking at tetrafluoroethylene as a refrigerant.




•In 1942 **Lithium grease** invented & rapidly became widely used multi-purpose grease



•In 1950 **Synthetic oils** introduced for usage in aviation.

•In 1950s **Fire Resistant Hydraulic Fluids** developed.

•In 1962 **Aluminium Complex grease** invented for high temperature applications.

•In 1960s **Multi-grade motor oils** introduced.

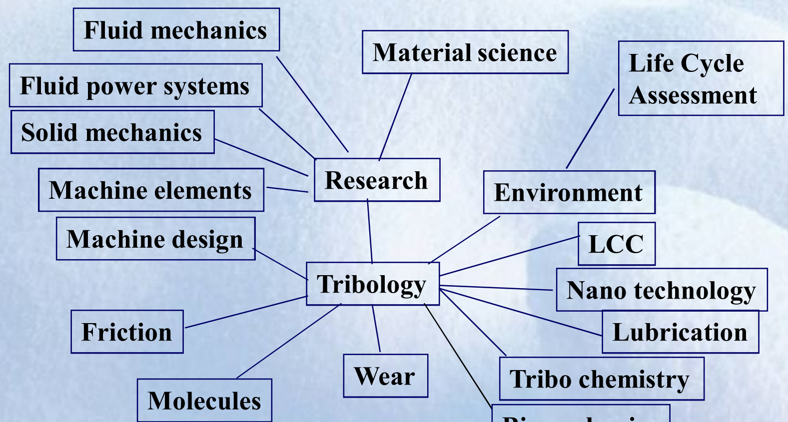
•In 1960s **Synthetic oils** used for motor oils.

•In 1986 the development of the **Atomic Force Microscope** enabled scientists to study & understand friction at the atomic scale.

•1980 onwards **Biolubricants** developments begin.

•1990 onwards **Nanotribolgy, Biotribology** developments begin.

## Tribology is a Multi-Disciplinary Subject






## Tribology is Everywere- Few Examples

- Tyre-road (high friction required)
- Bearings (low friction and wear required)
- Screw joints (low friction in threading, no wear in contact)
- Ski-snow (low friction for gliding but high in the grip zone)
- Shoe-floor (medium friction for easy walking and dancing)
- Brake-disc (controlled, stable friction, not too low or too high)
- Cam-follower (no wear, low friction)
- Piston ring-cylinder (no wear, low friction)
- Chalk-board (controlled wear process)
- Pen-paper (controlled wear process)
- Artificial joints and
- Many more

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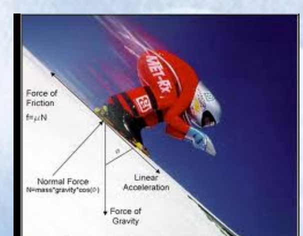

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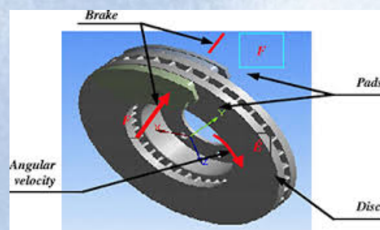




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- Piston ring-cylinder (no wear, low friction)

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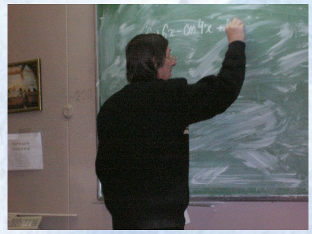
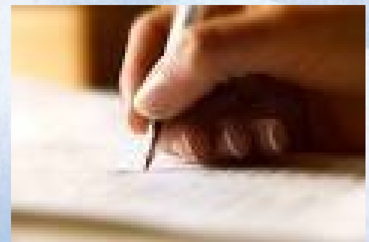


- Pen-paper (controlled wear process)



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## Tribology is Everywere- Few Examples

- Artificial joints


- **And Many more....**

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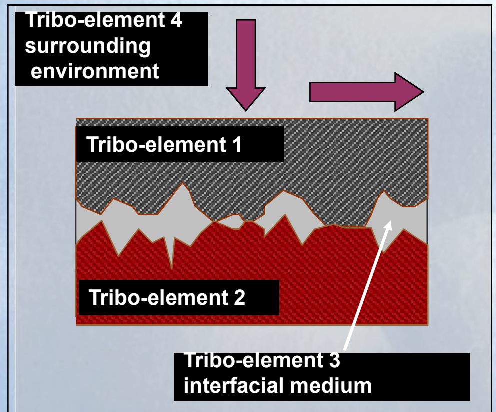
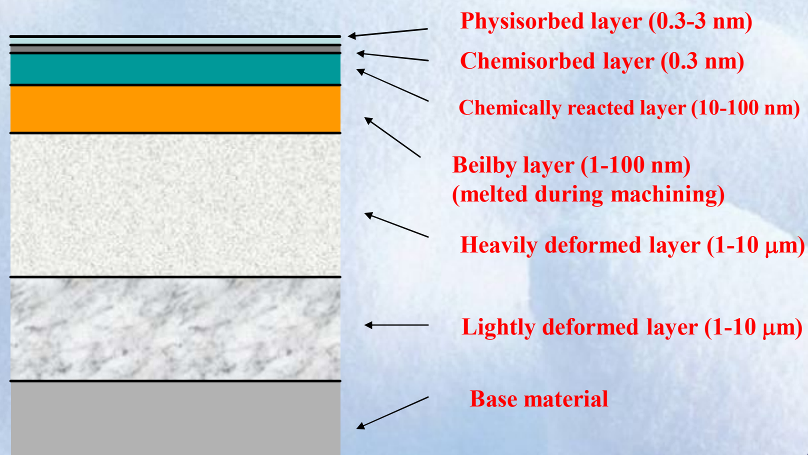
## Tribo-system

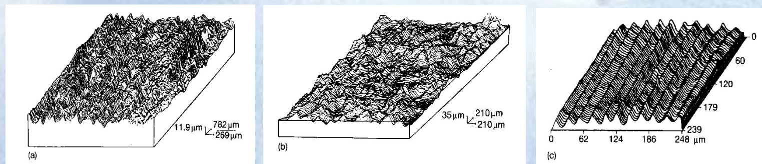




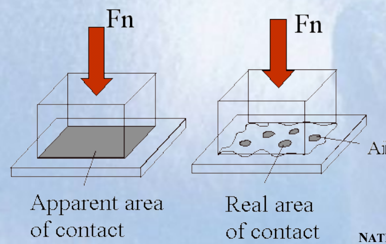

## The Nature of Solid Surfaces



## Contact of Rough Surfaces




*Ground steel surface* | *Shot-blasted steel surface* | *Diamond turned surface*






## General Remarks

***Considering the complexity of the tribological system, it may be pertinent to point out that friction and wear characteristics of materials are not their intrinsic or inherent properties but are highly system dependent.***

## Types of Engineering Materials

Broadly Engineering Materials are classified as:

Engineering Materials

- Metals &Alloys
- Polymers
  - Thermoplastic Polymers
  - Thermosetting Polymer
  - Elastomers
- Composites
- Ceramics

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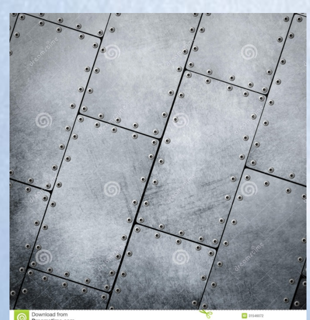
## METAL

- A solid material which is typically hard, shiny, malleable, fusible, and ductile, with good electrical and thermal conductivity
- (e.g. iron, gold, silver, and aluminum, and alloys such as steel)



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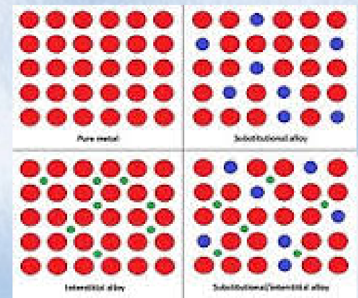
## ALLOY

- An **alloy** is a material composed of two or more metals or a metal and a nonmetal.



## Types of Engineering Materials

### Metals & Alloys are futher classified as:

**Metals & Alloys**

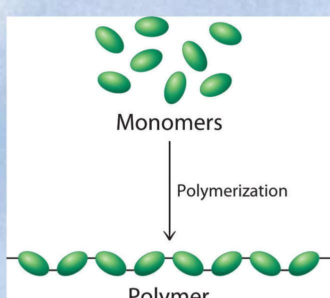
- Ferrous
  - Steels
    - Plain Carbon Steels
    - Alloy Steels
  - Cast Irons
    - White Cast Iron
    - Malleable Cast Iron
    - Grey Cast Iron
    - S.G. Cast Iron
    - Chilled Cast Iron
- Non-ferrous
  - Cu-Alloys
  - Ni-Alloys
  - Al-Alloys

- Ferrous: iron as main constitute
- Non ferrous: other than iron as main constitute.
- Steel: carbon less than 2 %.
- Cast iron: carbon more than 2%.
- Cu alloy: cu as main content.
- Al alloy: Al as main content.
- Ni alloy: Ni as main content.



## POLYMER

- The word polymer means
- Poly means many and meros means units, parts.
- Polymer means many parts or many units



## THERMOPLASTIC POLYMER

- A **thermoplastic**, or **thermosoftening plastic**, is a plastic material, polymer, that becomes pliable or moldable above a specific temp and solidifies upon cooling.
- thermoplastics may be reshaped by heating Temperature and solidifies upon cooling.



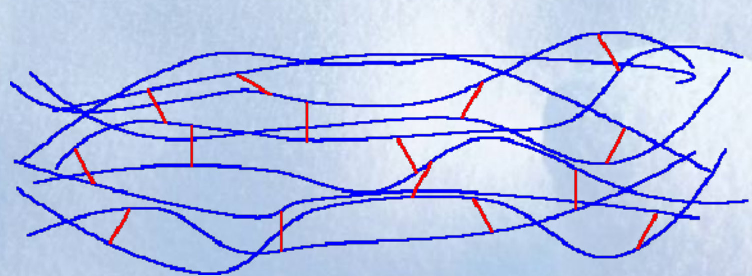


## Thermosetting polymers

- Thermosetting polymers have their chains cross linked by covalent bonds.
- The starting materials are placed into a mould to form the desired shape.
- The polymer is then heated (or initiated with uv light) and chemical reactions occur to form the cross links between the chains.
- The resulting three dimensional solid structure cannot then be changed.
- Further heating will not cause the polymer to soften, melt or change shape (unlike thermosoftening polymers).

## Thermosetting polymers

- The picture below shows a typical structure for a thermosetting polymer. The red lines represent the cross links between the chains.



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## Examples

- Epoxy resins - used as coating materials, caulks, manufacture of insulating materials, etc ...
- Phenolic resins - tool handles, billiard balls, sprockets, insulation, etc ...
- Unsaturated polyester resins - manufacture of plastics reinforced fiberglass commonly known as polyester, fillers, etc ...

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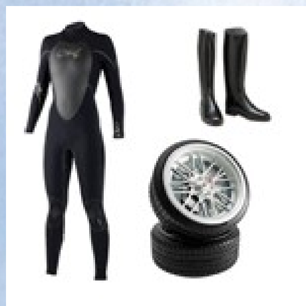
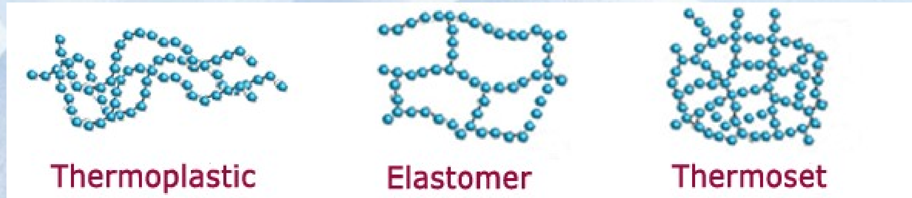
## Elastomers

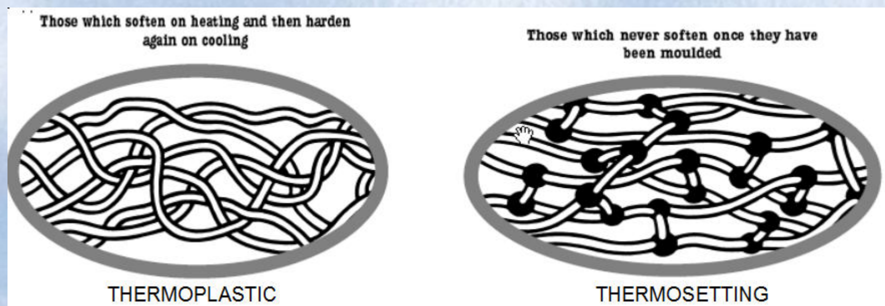
- **Elastomer** materials are those materials that are made of polymers that are joined by chemical bonds, acquiring a final slightly crosslinked structure.





- Natural rubber - material used in the manufacture of gaskets, shoe heels...
- Polyurethanes - Polyurethanes are used in the textile industry for the manufacture of elastic clothing such as lycra, also used as foam, wheels, etc ...
- Polybutadiene - elastomer material used on the wheels or tires of vehicles, given the extraordinary wear resistance.
- Neoprene - Material used primarily in the manufacture of wetsuits is also used as wire insulation, industrial belts, etc ...
- Silicone - Material used in a wide range of materials and areas due their excellent thermal and chemical resistance, silicones are used in the manufacture of pacifiers, medical prostheses, lubricants, mold, etc ...

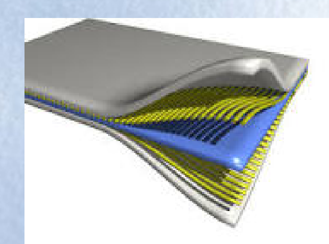


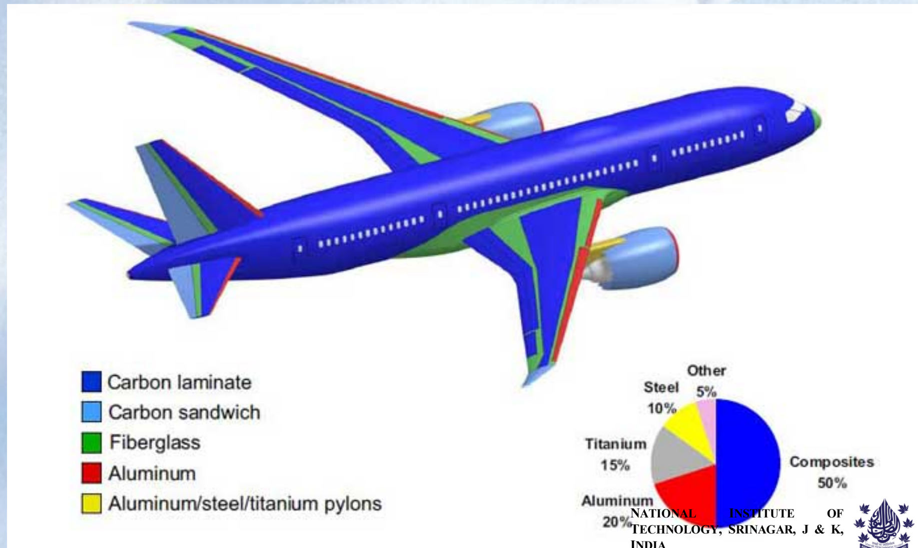



## Composite

- **Composite** materials (also called composition materials or shortened to **composites**) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.



## Material used in the Boeing 787






## Types of Engineering Materials

### Composites are futher classified as:

Composites

- Laminar
- Particle Reinforced
- Fibre Reinforced

# Types of Engineering Materials

## Ceramics are futher classified as:

Ceramics

- Metal Oxides
  - Alumina
  - Beryllia
  - Zirconia
  - Glass
  - Glass Ceramics
- Nitrides
- Carbides

Ceramic is defined as any inorganic (inorganic substances do not contain carbon or its compounds)non metallic material.

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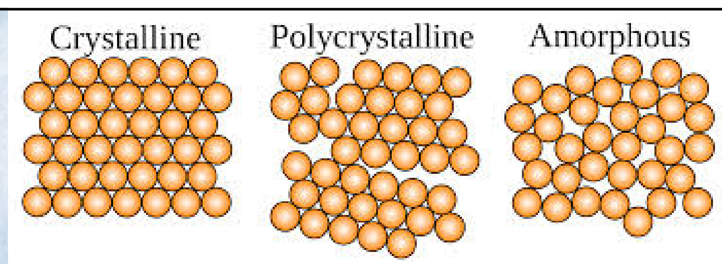
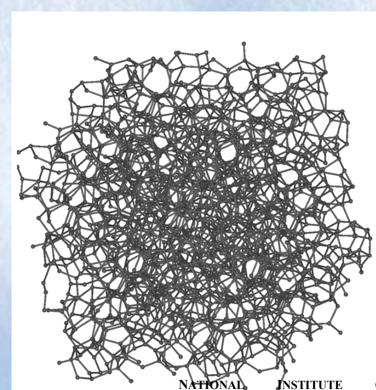
## Amorphous material

- The material have no regular arrangement of their molecules.
- Material like glass and paraffin are example of amorphous material.
- These material have properties of solids.
- They have definite volume and shape and diffuse slowly.



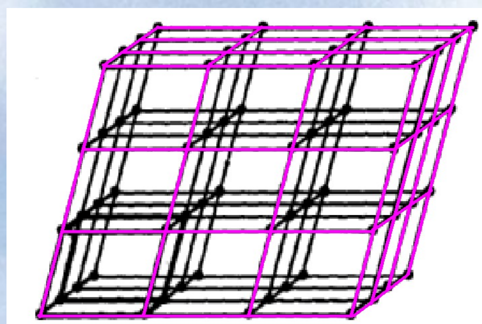


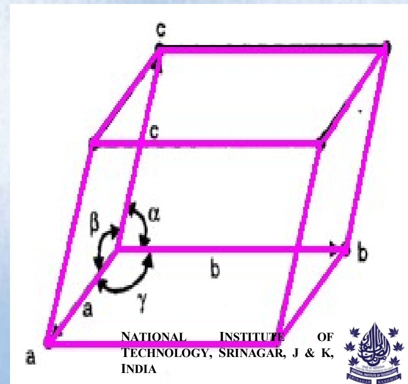

- Amorphous carbon



## Crystalline material

- In a crystalline structure , the atoms are arranged in three dimensional array called a lattice.
- The lattice has a regular repeating configuration in all direction.



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## polymorphism

- A crystal is defined as an orderly array of atoms in space.
- Normally metals are made up of number of crystals and each crystal consist of large number of atoms.
- Crystal structure is atomic arrangement in solids.
- Polymorphism is the ability of solid material to exist in more than one form or crystal structure.

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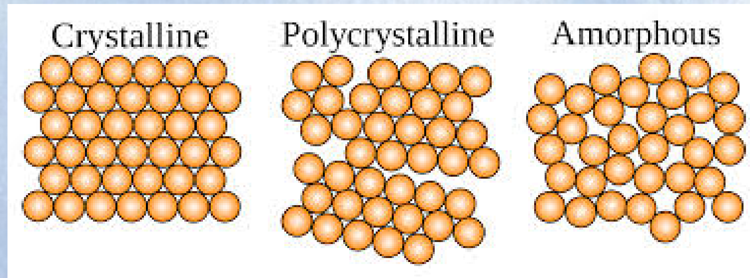




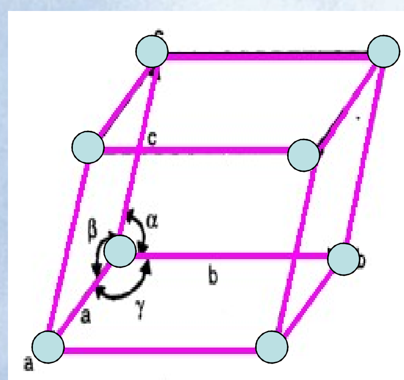


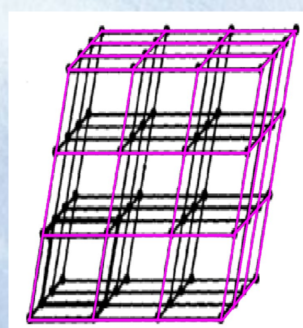

**Single atom**

**Unit Cell**

**lattice**

## Crystal Structure in Metals

**Majority of Metals falls in either of the following crystal structure**

- **BCC (Body Centered Cubic)**
- **FCC (Face Centered Cubic)**
- **HCP (Hexagonal Close Packed)**

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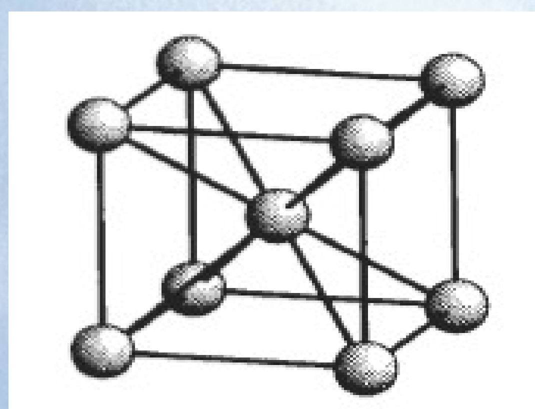
## Crystal Structure in Metals

**BCC (Body Centered Cubic)**



**Examples: α-iron, Mo, W, V, Ta, Cr, Na, K**

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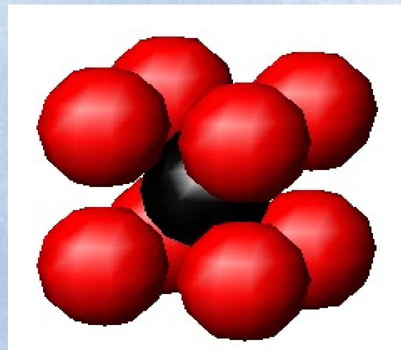
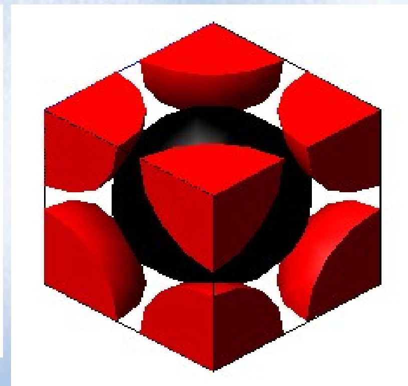
## Crystal Structure in Metals

### BCC (Body Centered Cubic)







### BCC (Body Centered Cubic)

In these structure, there are 8 corner atoms and one atom at in the interior i.e. in the centre of the unit cell with no atom on face.

Therefore,

Nav = average no. of atoms per unit cell.

Nc= total no. of corner atom in unit cell.

Nf= total no. of face atom in unit cell.

Ni = center or interior atom

Nc = 8, Nf=0, Ni=1

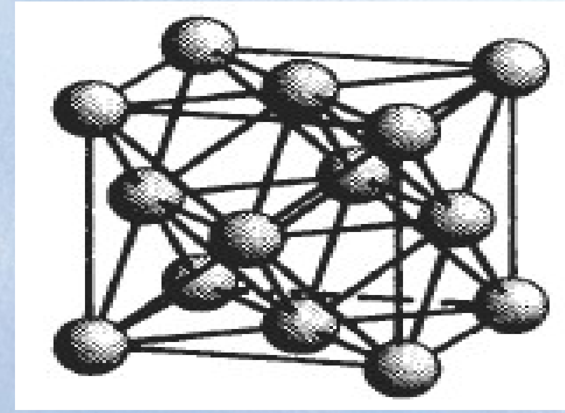
Nav= (Nc/8)+(Nf/2)+(Ni/1)

=(8/8)+(0/2)+(1/1)

=2

## Crystal Structure in Metals

- FCC (Face Centered Cubic)

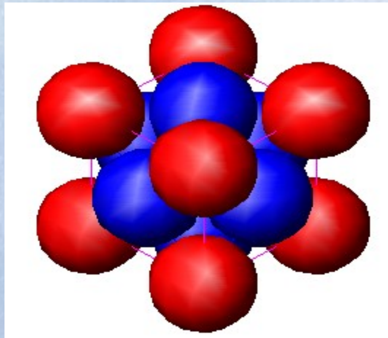


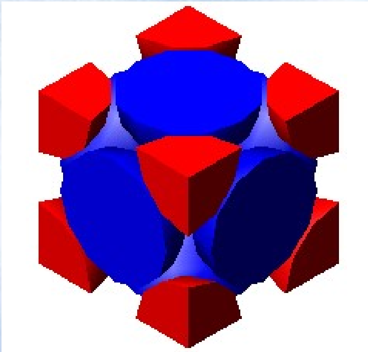
**Examples:γ-iron, Cu,Au,Ag,Al,Pb, Ni, Pt**



## Crystal Structure in Metals

- FCC (Face Centered Cubic)





## FCC (Face Centered Cubic)

In these structure, there are 8 corner atoms and 6 atoms at centre of the face and interior atom

Therefore,

Nav = average no. of atoms per unit cell.

Nc= total no. of corner atom in unit cell.

Nf= total no. of face atom in unit cell.

Ni = center or interior atom

Nc = 8, Nf=6, Ni=0

Nav= (Nc/8)+(Nf/2)+(Ni/1)

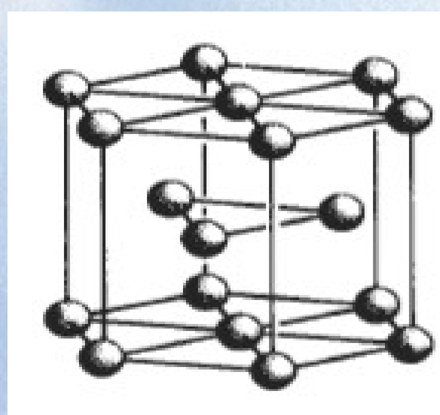
=(8/8)+(6/2)+(0/1)

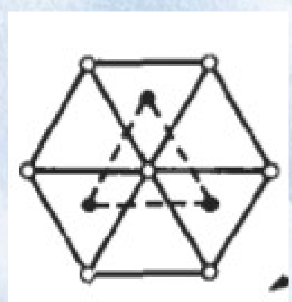
=4



## Crystal Structure in Metals

- **HCP (Hexagonal Close Packed)**





**Examples: Mg,Zn,Be,Cd,Co,Zr,Ti**

## HCP (Hexagonal Close Packed)

- For hexagonal structure, the corner atoms are shared by 6 cells (3 from below and 3 from above), face atoms are shared by adjacent 2 cells, and atoms in the interior are shared by only one cell.
- Nav= (Nc/6)+(Nf/2)+(Ni/1)
- For HCP structure , there are 12 corner atoms, 2 atoms at the centers of the above two faces and 3 atoms in the interior of the unit cell.

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## HCP (Hexagonal Close Packed)

- Nc = 12, Nf=2, Ni=3
- Nav= (Nc/8)+(Nf/2)+(Ni/1)
- =(12/6)+(2/2)+(3/1)
- =6

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## Physical properties

- Density
- Density of a substance is its mass per unit volume.
- The symbol most often used for density is ***ρ*** (the lower case Greek letter rho).
- Mathematically, density is defined as mass divided by volume.

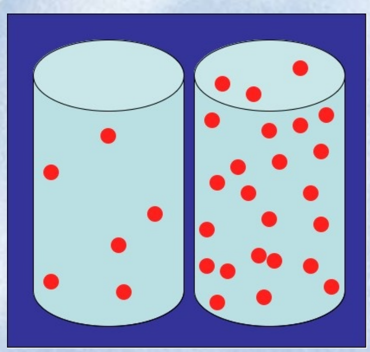
$$\rho = \frac{m}{V},$$

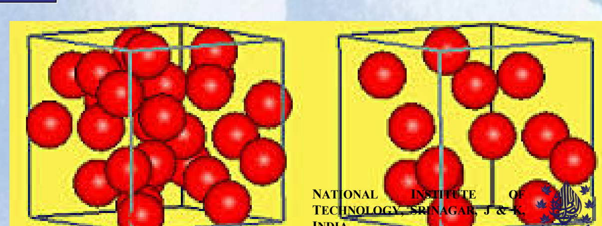
- where $\rho$ is the density, $m$ is the mass, and $V$ is the volume.





## Density





## Melting point

- The **melting point** of a solid is the temperature at which it changes state from solid to liquid at atmospheric pressure.
- The melting point of a substance depends (usually slightly) on pressure and is usually specified at standard pressure.
- The melting point of ice at 1 atmosphere of pressure is very close to 0 °C (32 °F, 273.15 K).

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## Specific heat

- Energy required to change the temperature of an object by 1degree c.
- The SI unit of heat capacity is joule per kelvin.
- Metals have lower specific heat capacity than plastics.
- Therefore they require less heat to reach a particular temperature than plastics.

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## Thermal expansion

- **Thermal expansion** is the tendency of matter to change in volume in response to a change in temperature, through heat transfer.
- The degree of expansion divided by the change in temperature is called the material's **coefficient of thermal expansion** and generally varies with temperature.
- (lf-l0) / l0 = 1 (Tf-To)
- Where, lf and lo are initial and final length.
- Tf and T0 are initial and final temperature.
- 1 is coefficient of thermal expansion.
- Unit is reciprocal temperature i.e. 1/c°

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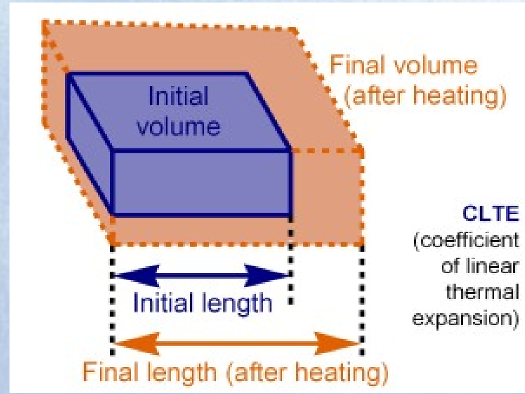


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## Thermal conductivity

- It is the property of a material to conduct heat.
- often denoted *k*, *λ*, or *κ*.
- In SI units, thermal conductivity is measured in watts per meter kelvin (W/(m·K))
- High energy generation rates within electronics or turbines require the use of materials with high thermal conductivity such as copper *(see: Copper in heat exchangers)*, aluminium, and silver.
- On the other hand, materials with low thermal conductance, such as polystyrene and alumina, are use in building construction or in furnaces in an effort to slow the flow of heat, i.e. for insulation purposes

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## Mechanical properties

- Strain
- Change in dimension per unit original dimension is nothing but strain.
- Stress
- Applied force per unit area is nothing but stress.
- $\sigma = F/A$.
- N/mm2.

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- Strength
- Ability of a material to resist the externally applied force without breaking or yielding.
- Stiffness
- It is ability of material to resist deformation under stress.
- Elasticity
- It is property of material to regain its original shape after deformation when the external force are removed.
- Steel is more elastic than rubber.
- Plasticity
- It is property of a material which retains the deformation produced under load permanently.



- Ductility
- It is ability of a material enabling it to be drawn in to wire with the application of a tensile force.
- Steel copper aluminium nickel zinc lead tin
- Brittleness
- It is property of a material opposite to ductility.
- It is the property of breaking of material with little permanent distortion.
- Cast iron is a brittle material
- Malleability
- It is special case of ductility which permits materials to be rolled or hammered in to thin sheets.
- Lead soft steel wrought iron copper aluminium.

- Toughness
- It is property of material to resist fracture due to high impact load like hammer blow.
- Machinability
- It is property of a material which refers to relative case with which a material can cut.
- Resilience
- It is property of a material to absorb energy and resist shock and impact load.
- Creep
- When a part is subjected to a constant stress at high temperature for long period of time, it will under go slow and permanent deformation called creep.



- Fatigue
- When a material is subjected to a repeated stresses, it fails at a stresses below the yield point stresses. Such type of failure of material is called fatigue.
- Hardness
- Resistance to wear, scratching, deformation and machinability.
- It also mean ability of material to cut another metal.

## Packing efficiency

- The packing efficiency is the fraction of crystal occupied by the atoms.
- It must be always less than 100%. Because it is impossible to pack spheres without empty space between them.
- Packing efficiency is the percentage of total space filled by the particles.
- It is also called as atomic packing factor.
- (Volume occupied by atoms in unit cell/ total volume of unit cell ) x100



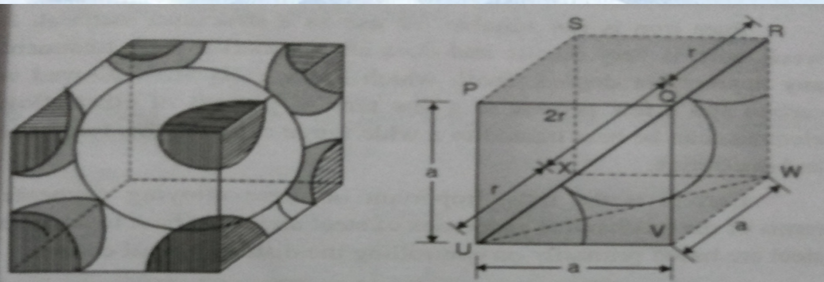


Fig. 1.1.10: BCC (Arrangement of atoms)

From Fig. 1.1.10

Volume of unit cell $= a^3$

Volume of an atom $= 4/3\ \pi r^3$

but, $UW^2 = UV^2 + VW^2$

and $UR^2 = UW^2 + WR^2$

$$4r^2 = (2a^2) + a^2 \quad (\because UW^2 = a^2 + a^2)$$

$$\therefore \quad r = \frac{a\sqrt{3}}{4}$$

$$\text{Atomic packing factor} = \frac{\text{Volume occupied}}{\text{Total volume}}$$

$$= \frac{2 \times 4/3\, \pi \left( \frac{a\sqrt{3}}{4} \right)^3}{a^3} \quad \left( \because r = \frac{a\sqrt{3}}{4} \right)$$

$$= 0.68 = 68\%$$



Thank You