Dr. Vishwanath Karad MIT WORLD PEACE UNIVERSITY | PUNE

TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

MATERIAL SCIENCE (MEE102B)

Module: 3

Application of polymers, ceramics, composites and metals

Application of polymer, ceramics, composite and metals

Polymers, types of polymers, polymerization techniques, applications of polymers, special purpose plastics. Introduction to composite, classification and application of composite materials, manufacturing process of composite, iso-stress-iso-strain condition of composite, numerical on iso-stress iso-strain conditions. Introduction to ceramics, types and applications. Introduction to nonferrous metals, common non-ferrous metals - Aluminium, Copper & its alloys like Hindalium, LM-6, LM-12, Brass, Bronze, Babbitt, aerospace material, soldering & brazing materials, recent developments in non-ferrous alloys, lever Rule, numerical on lever rule.

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Polymers Introduction

- Polymers means many units (poly means many, mer means units) is composed of a large number of repetitive called monomers (mono means one) or simple molecules.
- Thus a polymer is made up of thousands of monomers joined chemically together to form a large molecule.
- It has been observed that each molecule of polymer is either a long chain or a network of repetitive units or monomers.

Introduction….

- Polymers are natural or synthetic resins or their compound which can be molded, extended, cast or used as films or coatings.

- Naturally occurring polymers – those derived from plants and animals – are in use for many centuries; these materials include wood, rubber, cotton, wool, leather, and silk.

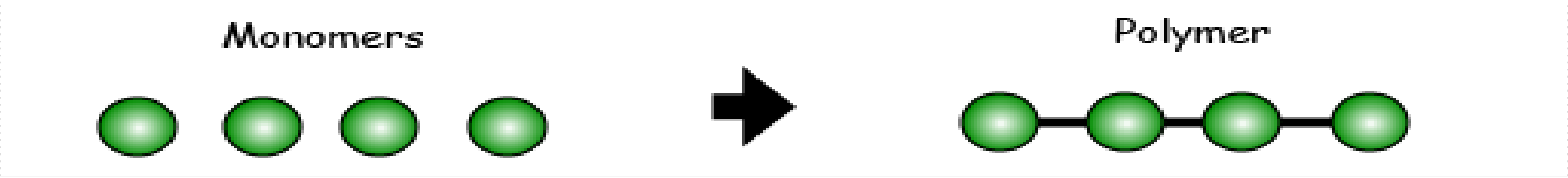
- Modern scientific research tools facilitated the determination of the molecular structures of this group of materials, and the development of numerous polymers, which could be synthesized from small organic molecules.

- The synthetics can be produced inexpensively, and their properties may be managed to the degree that many are superior to their natural counterparts.

How Plastic are made?

Plastics are produced using a process know as polymerization. Polymerization occurs when monomers join together to form long chains of molecules called polymers.

Polymerization comes from the word 'POLY' which means 'MANY' and 'MER' which means 'PART'. So Polystyrene means 'POLY' many single monomers of 'STYRENE', joined together to form a long chain.



PLASTICS ARE MADE FROM THE FOLLOWING MATERIALS:

Plasticizers:- They improve the softening, decrease brittleness and workability of plastics. They are organic substances such as diisononyl phthalate (DINP), diisodecyl phthalate (DIDP)

Stabilizers:- They prevent chemical degradation of plastics. By nature they are antioxidants. Hindered amine light stabilizer. Polyamides, polycarbonate.

Reinforcing:- They increase its mechanical strength. Example is glass fiber.

Pigments : They are used to impart a particular color to the plastic.

Classification of Polymers

- Polymers are classified into two main groups as below :

(1)Thermoplastic polymers.

(2)Thermosetting polymers.

Thermoplastic Polymers :

- Thermoplastic polymers are the polymers which become soft and deformable when heated, which is characteristic of linear polymeric molecules.

Thermoplastic:-(Recycled Plastic)

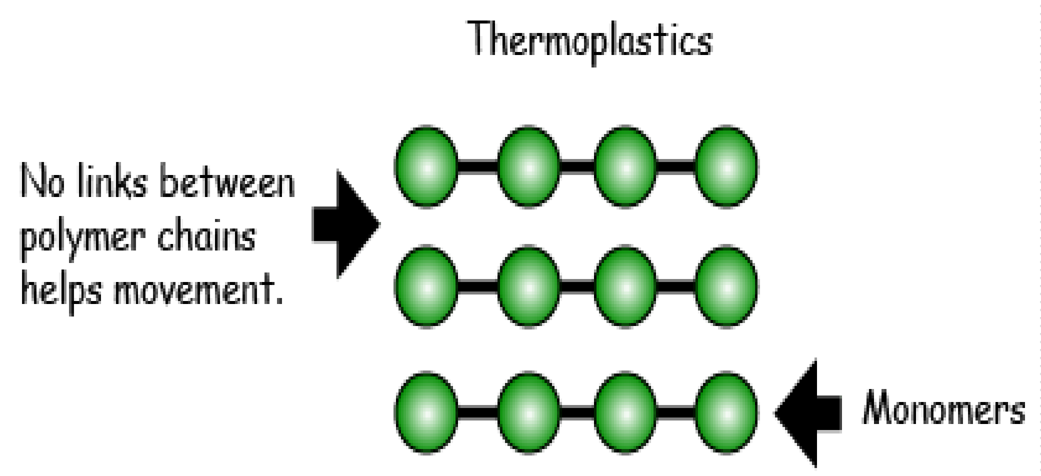
Thermoplastics pellets soften when heated and become more fluid as additional heat is applied. The curing process is completely reversible as no chemical bonding takes place. Eg. Nylon, acrylic, LDPE, HDPE

Pros

Highly recyclable.
Aesthetically-superior finishes.
High-impact resistance.
Remolding/reshaping capabilities.
Chemical resistant.
Eco-friendly manufacturing.

Cons.

Generally more expensive than thermos
Can melt if heated.



Thermoplastic Polymers

- However, metallic bonding generally restricts creep deformation to temperatures closer to 1000°C in typical alloys.
- Although polymers can not, in general, be expected to duplicate fully the mechanical behavior of traditional metal alloys
- A major effort is made to produce some polymers with sufficient strength and stiffness to be serious candidates for structural applications once dominated by metals
- These polymers are noted in engineering polymers, which retain good strength and stiffness up to 150 - 175°C.

Thermosetting plastic:-(Heat-Setting Plastic)

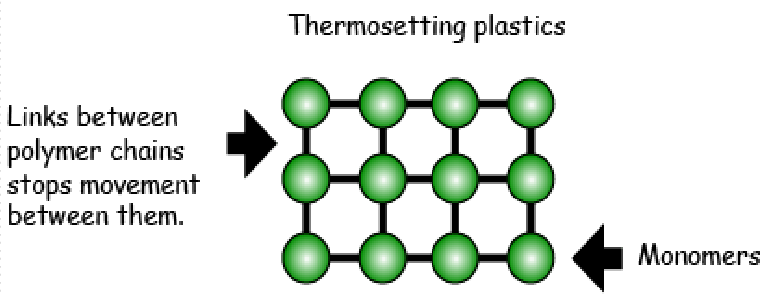
Thermosetting plastics can only be heated and shaped once. Separate polymers are joined in order to form a huge polymer. The main thermosetting plastics are **epoxy resin, melamine formaldehyde, polyester resin and urea formaldehyde.**

Pros

- More resistant to high temperatures than thermoplastics
- Highly flexible design
- Thick to thin wall capabilities
- Excellent aesthetic appearance
- High levels of dimensional stability
- Cost-effective

Cons

- Cannot be recycled
- Cannot be remolded or reshaped



Thermosetting Polymers

- Thermosetting products can be removed from the mold at the fabrication temperature 200°C to 300°C.
- By contrast, thermoplastics must be cooled in the mold to prevent distortion.
- Significant strength and stiffness so as to be common Metal substitutes.

Characteristics of Polymers

The followings are the characteristics of polymers :

1. Poor tensile strength
2. Poor temperature resistance
3. Low mechanical properties.
4. Economical
5. Polymers can be produced transparent or in different colours
6. Excellent surface finish can be obtained
7. Polymers can be produced with close dimensional tolerances
8. Good mouldability
9. Low coefficient of friction
10. Good corrosion resistance
11. Low density

DIFFERENCE BETWEEN THERMOPLASTICS AND THERMOSETTING PLASTICS:

....

Thermoplastics

1. Formed by addition polymerization
2. Linear molecular arrangement
3. Soft ,weak and less brittle
4. Soluble in organic solvent

Thermosetting plastics

1. Formed by condensation polymerization
2. Cross-linked molecular arrangement
3. Hard strong and more brittle
4. Insoluble in organic solvent

Applications of Engineering Polymers

- The rear quarter panel on the sports car was a pioneering application of an Engineering polymer in a traditional structural metal application.
- In automotive industry Engineering polymers are used.
- Consumer and industrial products made of polymers include food and beverage containers. Packing, housewares, textiles, medical devices foam, safety shields and toys.

Applications of Engineering Polymers

Ceramics

keramikos - burnt stuff in Greek - desirable properties of ceramics are normally achieved through a high temperature heat treatment process (firing).

- Usually a compound between metallic and nonmetallic elements
- Always composed of more than one element (e.g., Al2O3, NaCl, SiC, SiO2)
- Bonds are partially or totally ionic, and can have combination of ionic and covalent bonding
- Generally hard and brittle
- Generally electrical and thermal insulators
- Can be optically opaque, semi-transparent, or transparent
- Traditional ceramics – based on clay (china, bricks, tiles, porcelain), glasses.

Comparison metals v ceramics

Metals	Ceramics
Crystal structure	Crystal structure
Large number of free electrons	Captive electrons
Metallic bond	Ionic/covalent bonds
Good electrical conductivity	Poor conductivity
Opaque	Transparent (in thin sections)
Uniform atoms	Different-size atoms
High tensile strength	Poor tensile strength[a]
Low shear strength	High shear strength
Good ductility	Poor ductility (brittle)
Plastic flow	None
Impact strength	Poor impact strength
Relatively high weight	Lower weight
Moderate hardness	Extreme hardness

Classification of Ceramics

Ceramic Materials

- **Glasses** (Amorphous, silica based)
  - **Glass Ceramics** (polycrystalline, eg. Pyroceram)
- **Clay Products**
- **Refractories**
  - Alumina, Silica
  - high purity oxides
  - Graphite
- **Abrasives**
  - Diamond
  - SiC
  - Silica Sand
  - Alumina
- **Cements**
  - Calcium
  - Silicon
- **Advanced Ceramics**
  - Si_3N_4
  - SiC, BC, WC
  - ZrO_2
  - **Ceramic-Matrix Composites** (fibre and whisker reinfored)

Types of Ceramics

1.Whitewares

2.Refractories

3.Glasses

4.Abrasives

5.Cements

6. Advance Ceramics

1.Whitewares

- Raw Material: Clay, Flint and Feldspar
- Clay is the plastic component, giving shaping abilities to the unfired product .
- Flint (the common name used in the industry for all forms of silica) serves as a filler, lending strength to the shaped body before and during firing.
- Feldspar serves as a fluxing agent, lowering the melting temperatures of the mixture.

Uses

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

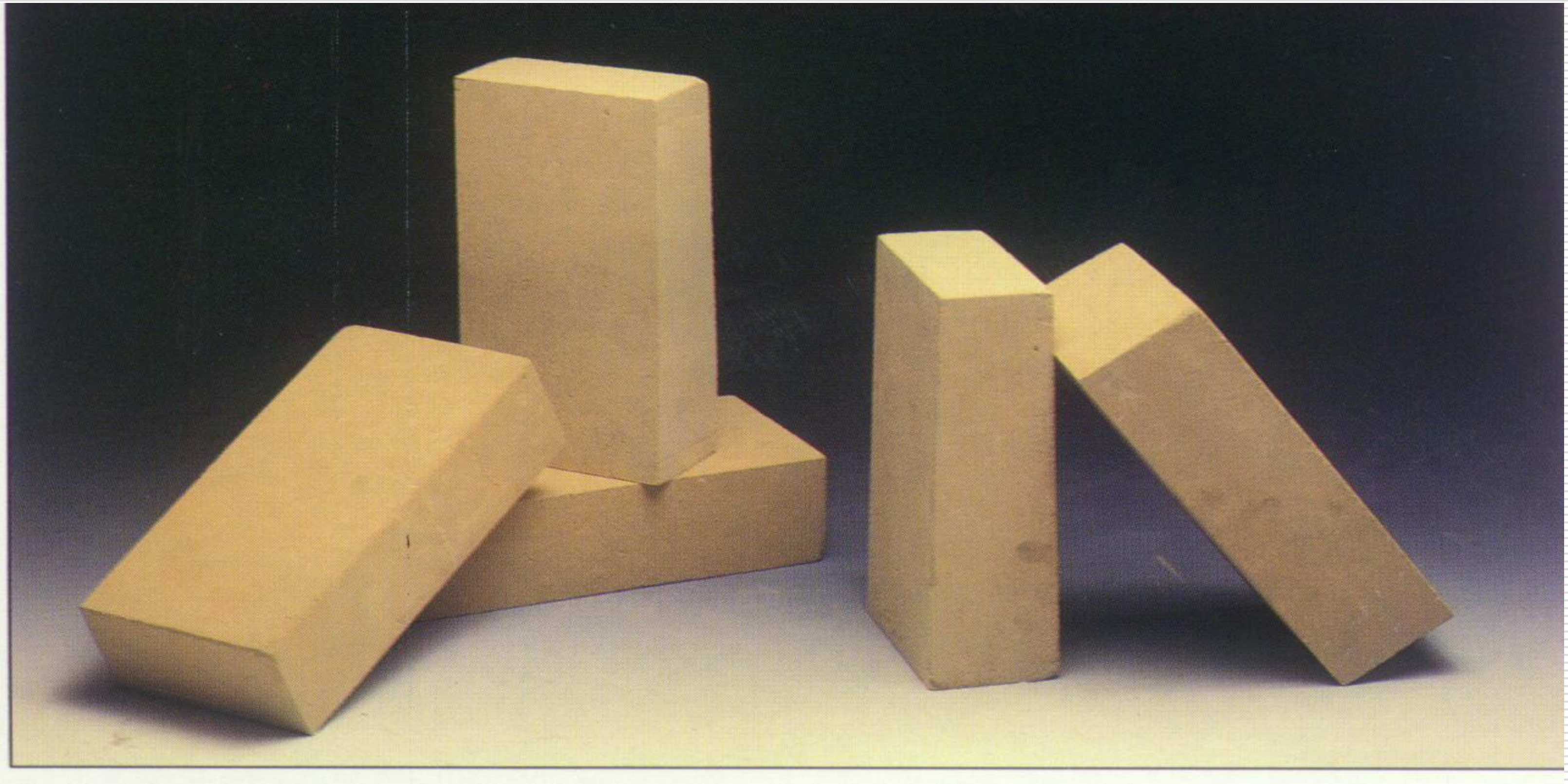
Whitewares

Electrical porcelain

2.Refractories

- Firebricks for furnaces and ovens. Have high Silicon or Aluminium oxide content.
- Brick products are used in the manufacturing plant for iron and steel, non-ferrous metals, glass, cements, ceramics, energy conversion, petroleum, and chemical industries.
- Used to provide thermal protection to other materials in very high temperature applications, such as steel making (T_m=1500°C), metal foundry operations, etc.
- They are usually composed of alumina (T_m=2050°C) and silica along with other oxides: MgO (T_m=2850°C), Fe_2O_3, TiO_2, etc.

Refractory Brick



3.Amorphous Ceramics (Glasses)

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

Glasses

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

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Glass Containers

5.Abrasives

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

Crystalline Ceramics

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

6.Advanced Ceramics

- Advanced ceramic materials have been developed over the past half century
- Applied as thermal barrier coatings to protect metal structures, wearing surfaces, or as integral components by themselves.
- Engine applications are very common for this class of material which includes silicon nitride (Si_3N_4), silicon carbide (SiC), Zirconia (ZrO_2).
- Heat resistance and other desirable properties have lead to the development of methods to toughen the material by reinforcement with fibers opening up more applications for ceramics.

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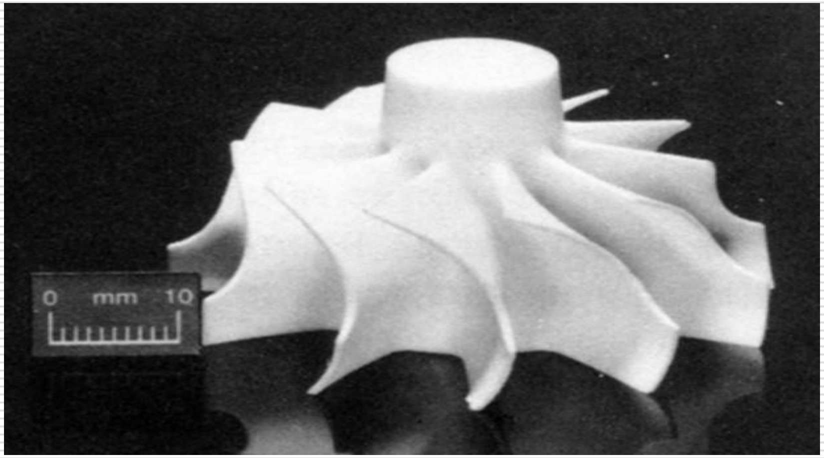
Advanced Ceramics

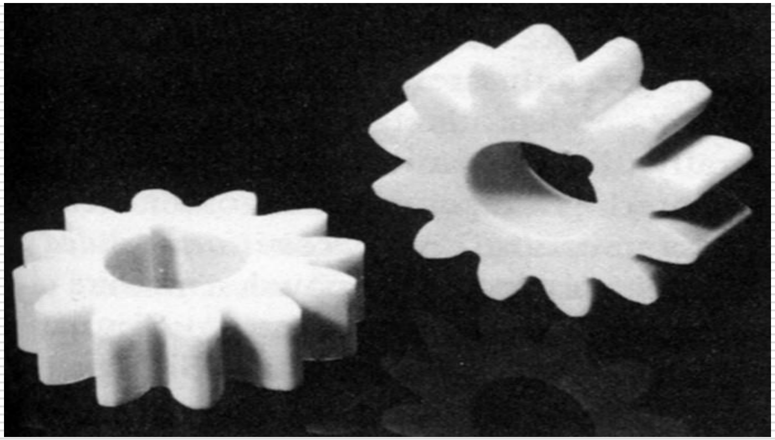
- *Structural:* Wear parts, bioceramics, cutting tools, engine components, armour.
- *Electrical:* Capacitors, insulators, piezoelectrics, magnets and superconductors
- *Coatings:* Engine components, cutting tools, and industrial wear parts

Bioceramics

Engine Components



Rotor (Alumina)



Gears (Alumina)

Ceramic Brake Discs

Aluminium metal matrix composites (AMMC) with SiC reinforcement

Composite Material

- A combination of two or more materials to form a new material system with enhanced material properties
- Reinforcement + Matrix = Composite
- **Composites:** A combination of two or more materials (reinforcement, resin, filler, etc.), differing in form or composition on a macro scale.
- The constituents retain their identities, i.e.., they do not dissolve or merge into each other, although they act in concert.
- **Composites:** Artificially produced multiphase materials.
- **Composites:** Design materials with properties better than those of conventional materials (metals, ceramics, or polymers).

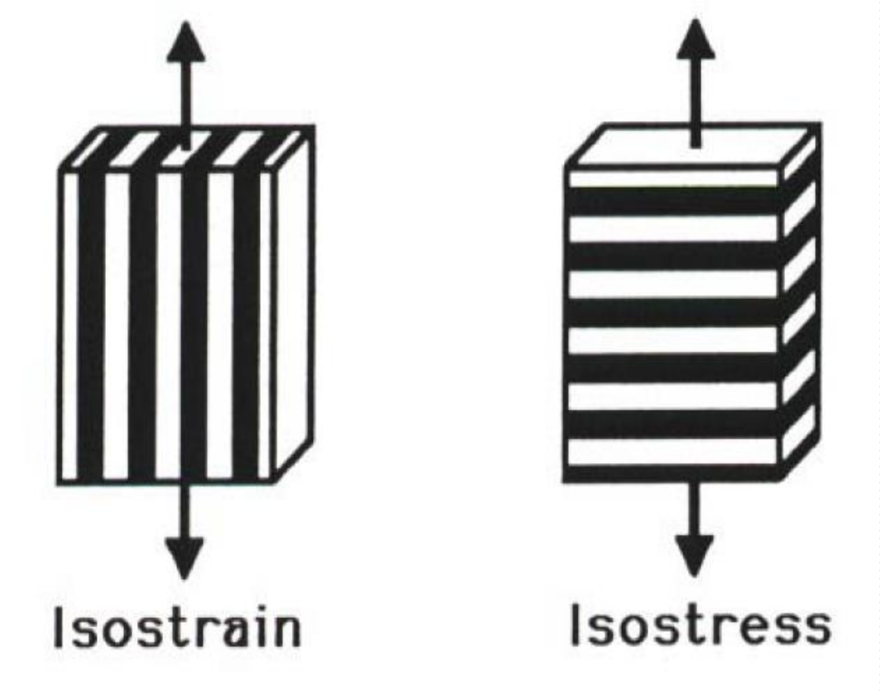
Composite

- The base material surrounding other materials is normally, present in higher percentage and is called matrix.
- Other material which reinforce the properties of base material are called reinforcements.
- Cohesion between the matrix and reinforcement is essential and may take place in any or combination of the following ways,

(i) Chemical reaction at the interfaces of the constituents.

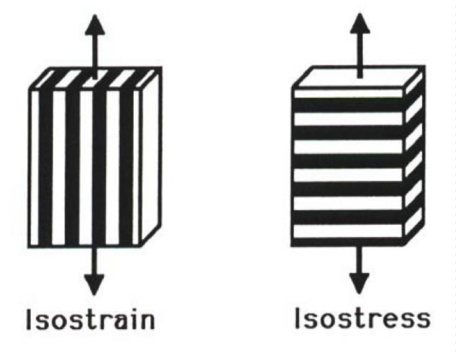
(ii) Mechanical keying between the matrix and the reinforcement.

(iii) Physical bonding between the matrix and the reinforcement by vander waals forces acting between the surface molecules of the various constituents.


Isostrain
Isostress

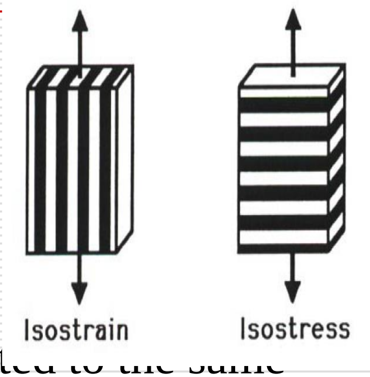
Functions of Reinforcement

- In continuous fiber reinforced Composites, the reinforcement is the principal load-bearing constituent.
- The metallic matrix serves to hold the reinforcing fibers together and transfer as well as distribute the load.
- Typically, the addition of reinforcement increases the strength, stiffness and temperature capability.
- The reinforcement also serves to reduce the density of the composite, thus enhancing properties such as specific strength.



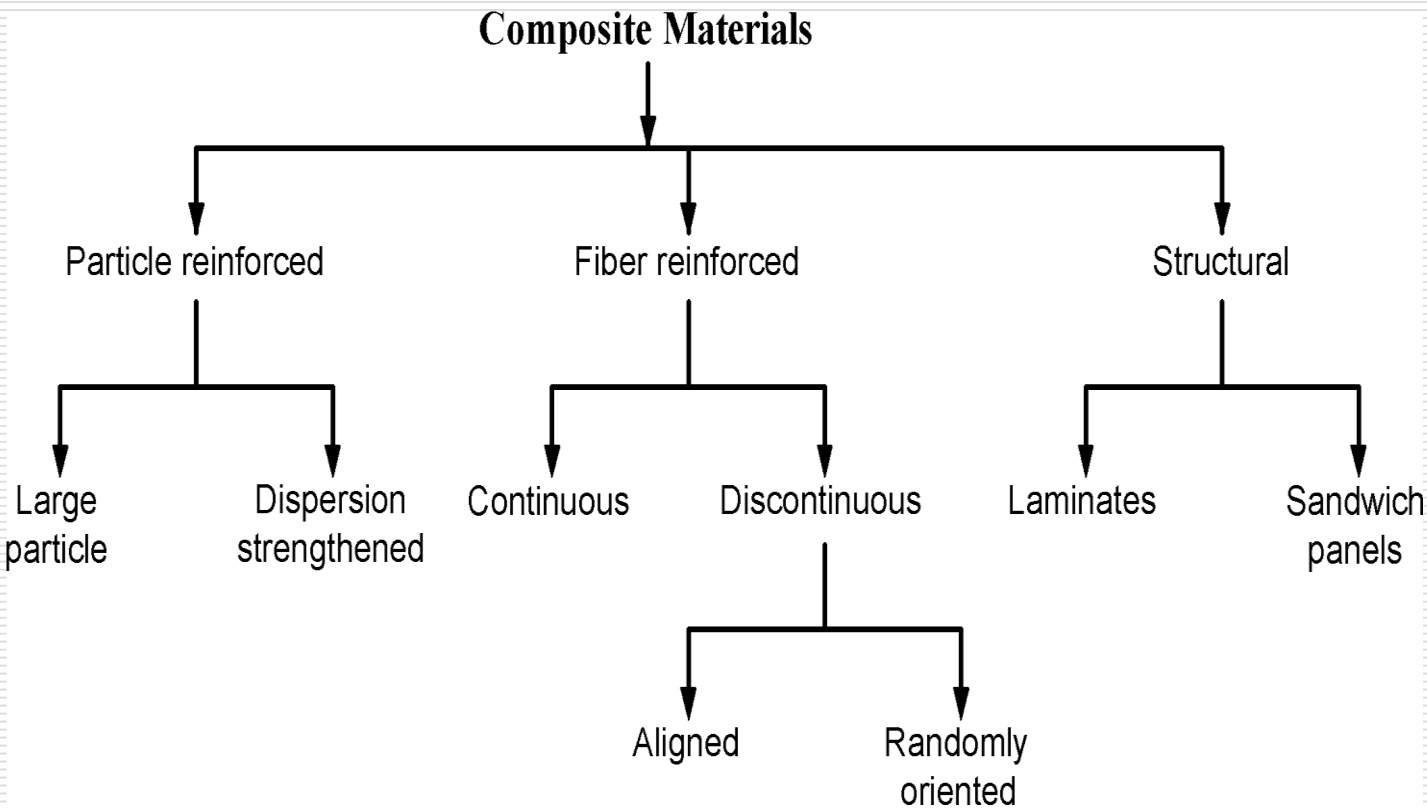
Functions of Matrix

In a composite material, the matrix material serves the following functions:



- Holds the fibres together.
- Protects the fibres from environment.
- Distributes the loads evenly between fibres so that all fibres are subjected to the same amount of strain.
- Improves impact 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.

Classification and Types of Composite Materials based on reinforcement :



Composites can be classified by their matrix material which include

-Metal matrix composites (MMC's)

-Ceramic matrix composites (CMC's)

-Polymer matrix composites (PMC's) or sometimes referred to as organic matrix composites (OMC's)

Polymer matrix composites or Fiber Reinforced Polymer (FRP)

- Fibers generally glass, carbon or kevlar
- Matrix can be:
  - Thermoplastics: PE, Nylon, PP, PVC
  - Thermosets: Epoxy, polyester, phenolics
- Have high strength and stiffness to weight ratio
- Used in Aerospace, sporting goods, marine applications.
- Examples: GFRP aka fiberglass (polyester or epoxy and glass), CFRP (polyester or epoxy and carbon), KFRP (polyester or epoxy and Kevlar)

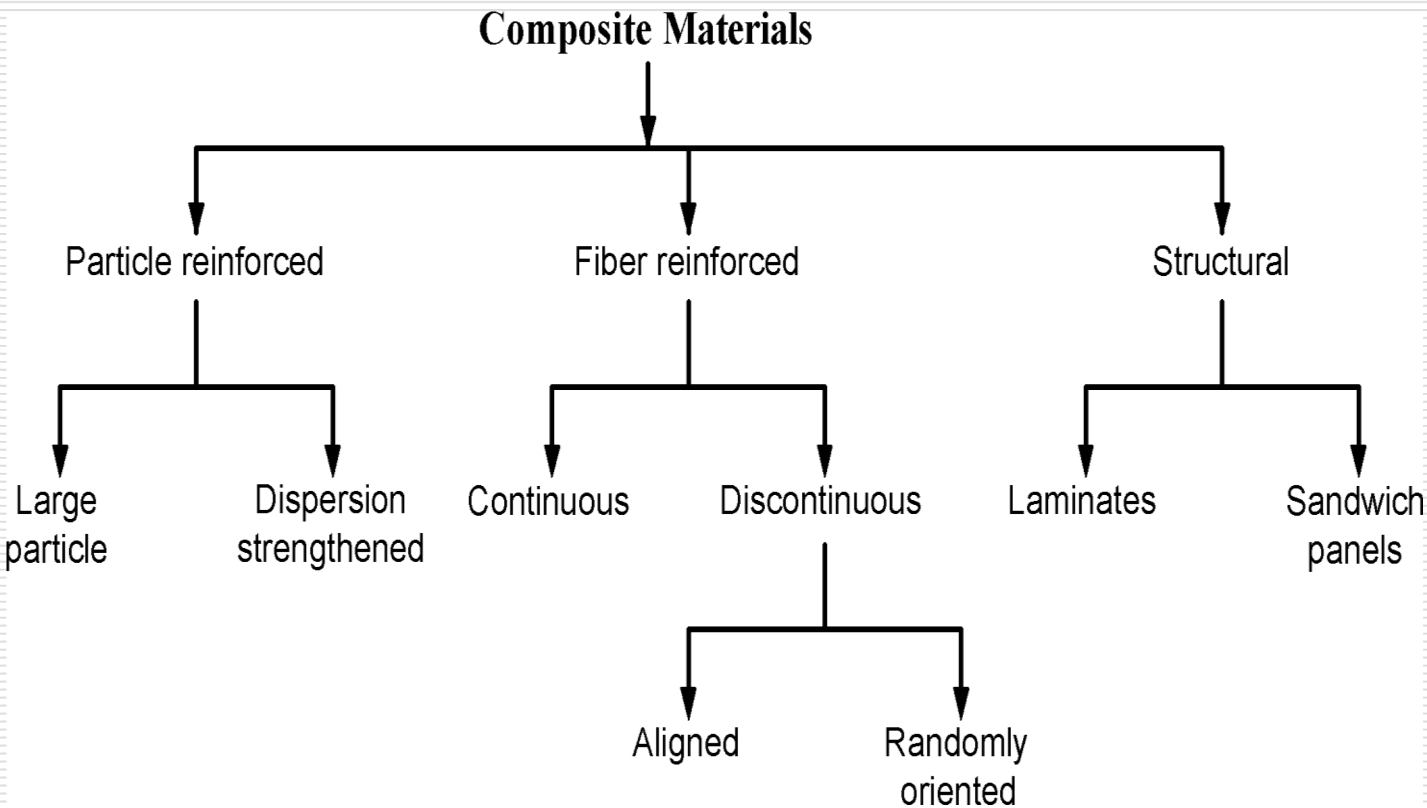
Metal matrix composites (MMC):

- Metal matrix: Al, Ti, Mg, Fe, Cu, Ni
- Example: Si -SiC (silicon carbide)
- Example: Al- Al_2O_3 (aluminum oxide)
- High strength, high stiffness, abrasion resistance, dimensional stability, high temperature and toughness.
- High performance tungsten carbide cutting tools are made from a tough cobalt matrix cementing the hard tungsten carbide particles.
- Some tank armors may be made from metal matrix composites, probably steel reinforced with boron nitride, which is a good reinforcement for steel because it is very stiff and it does not dissolve in molten steel.

Ceramic matrix composites (CMC):

- Silicon carbide-silicon carbide (SiC-SiC)
- Same material both matrix and filler BUT filler different form such as whickers, chopped fibers or strands to achieve preferred properties.

Classification and Types of Composite Materials based on reinforcement :



Particle Reinforced Composites:

- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix. Examples:

1. automobile tire which has carbon black particles in a matrix of elastomeric polymer.
2. spheroidized steel where cementite is transformed into a spherical shape which improves the machinability of the material.
3. concrete where the aggregates (sand and gravel) are the particles and cement is the matrix.

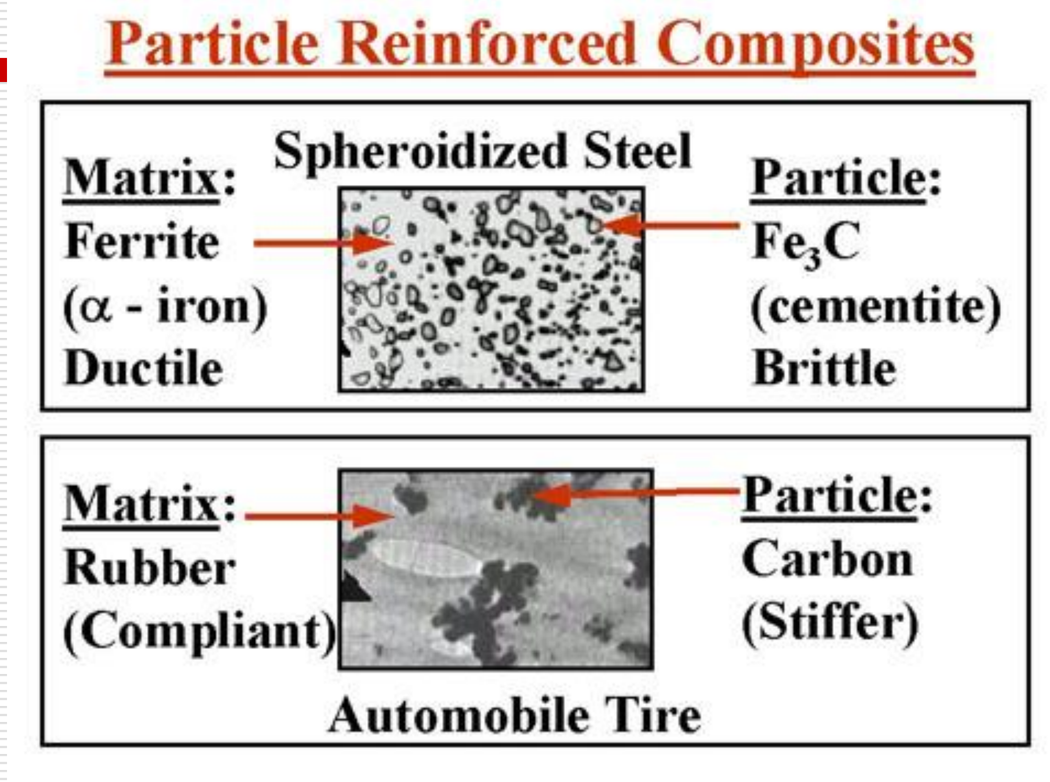
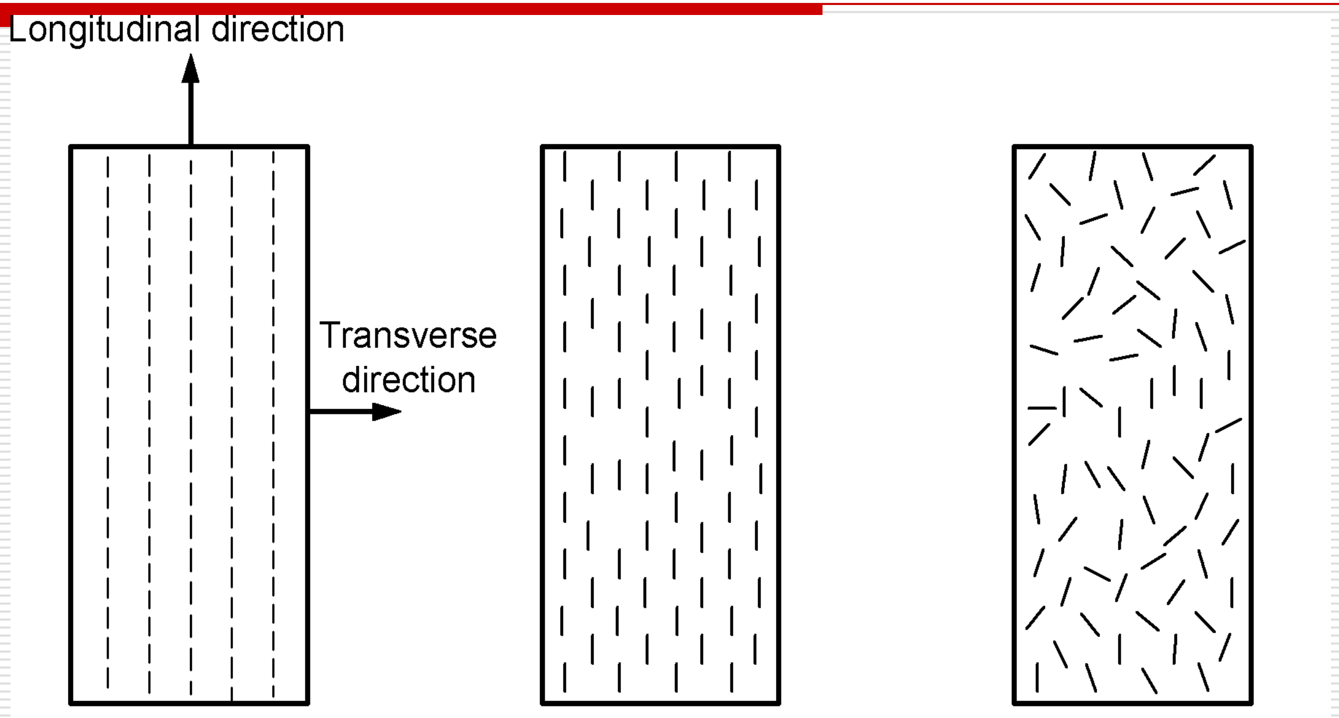


Figure. Examples for particle-reinforced composites. (Spheroidized steel and automobile tire)

Fiber-reinforced Composites:

- Reinforcing fibers can be made of metals, ceramics, glasses, or polymers.
- Fibers increase the modulus of the matrix material.
- The strong covalent bonds along the fiber's length gives them a very high modulus in this direction because to break or extend the fiber the bonds must also be broken or moved.
- Fibers are difficult to process into composites which makes fiber-reinforced composites relatively expensive.
- Fiber-reinforced composites are used in some of the most advanced, and therefore most expensive, sports equipment, such as a time-trial racing bicycle frame which consists of carbon fibers in a thermoset polymer matrix.
- Body parts of race cars and some automobiles are composites made of glass fibers (or fiberglass) in a thermoset matrix.

Fiber Reinforced Composites :



(a) Continuous and aligned

(b) Discontinuous and aligned

(c) Discontinuous and randomly oriented fiber reinforced composites.

Structural Composites:

Common structural composite types are:

1. Sandwich Panels:

- Consist of two strong outer sheets which are called face sheets and may be made of aluminum alloys, fiber reinforced plastics, titanium alloys, steel.
- Face sheets carry most of the loading and stresses.
- Core may be a honeycomb structure which has less density than the face sheets and resists perpendicular stresses and provides shear rigidity.
- Sandwich panels can be used in variety of applications which include roofs, floors, walls of buildings and in aircraft, for wings and tailplane skins.

Structural Composites

Common structural composite types are:

2. Laminar:

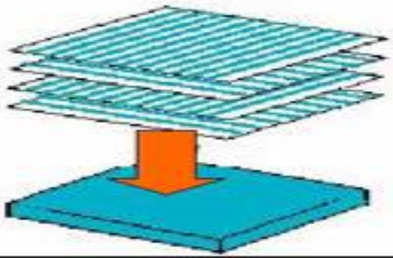
- Is composed of two-dimensional sheets or panels that have a preferred high strength direction such as is found in wood and continuous and aligned fiber-reinforced plastics.
- The layers are stacked and cemented together such that the orientation of the high-strength direction varies with each successive layer.
- One example of a relatively complex structure is modern ski and another example is plywood.

Structural Composites

Stacked and bonded fiber-reinforced sheets

-stacking sequence: e.g., 0/90

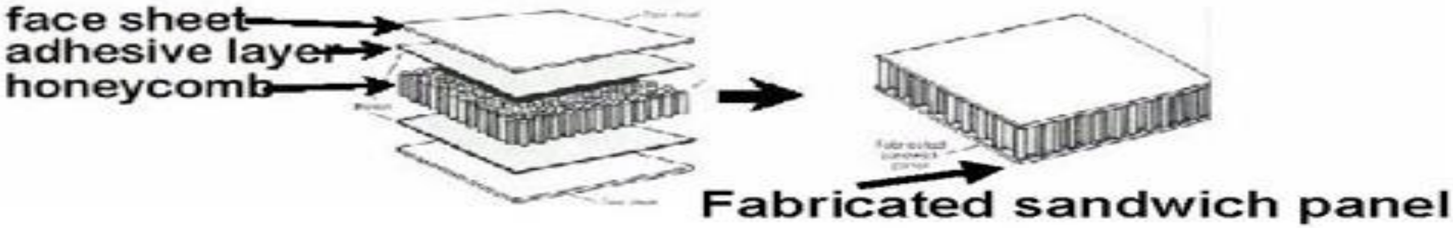
-benefit: balanced, in-plane stiffness



Sandwich panels

-low density honeycomb core

-benefit: small weight, large bend stiffness



Nature of Composites:

- Advantages:
  - High strength to weight ratio (low density high tensile strength) or high specific strength ratio!
  - High creep resistance
  - High tensile strength at elevated temperatures
  - High toughness
  - Generally perform better than steel or aluminum in applications where cyclic loads are encountered leading to potential fatigue failure (i.e. helicopter blades).
  - Corrosion resistance

Nature of Composites:

- Disadvantages (or limitations):
  - Material costs
  - Fabrication/ manufacturing difficulties
  - Repair can be difficult
  - Operating temperature can be an issue for polymeric matrix Less an issue for metal matrix.
  - Inspection and testing typically more complex.

Recent Materials

Carbon fibre reinforced carbon CFRC, reinforced carbon–carbon (RCC)

- It is a composite material consisting of carbon
- fiber reinforcement in a matrix of graphite.
- It was developed for the nose cones of intercontinental ballistic missiles, and is most widely known as the material for the nose cone and wing leading edges of the Space Shuttle orbiter.
- It has been used in the brake systems of Formula One racing cars since 1976; carbon–carbon brake discs and pads are a standard component of Formula One brake systems.

- **glass-reinforced plastic (GRP),glass-fiber reinforced plastic (GFRP)**
- The composite is also called "fiberglass reinforced plastic.“
- Fiberglass is an immensely versatile material due to its light weight, inherent strength, weather-resistant finish and variety of surface textures.
- Fiberglass is also used in the telecommunications industry for shrouding antennas, due to its RF permeability .

Composite Application

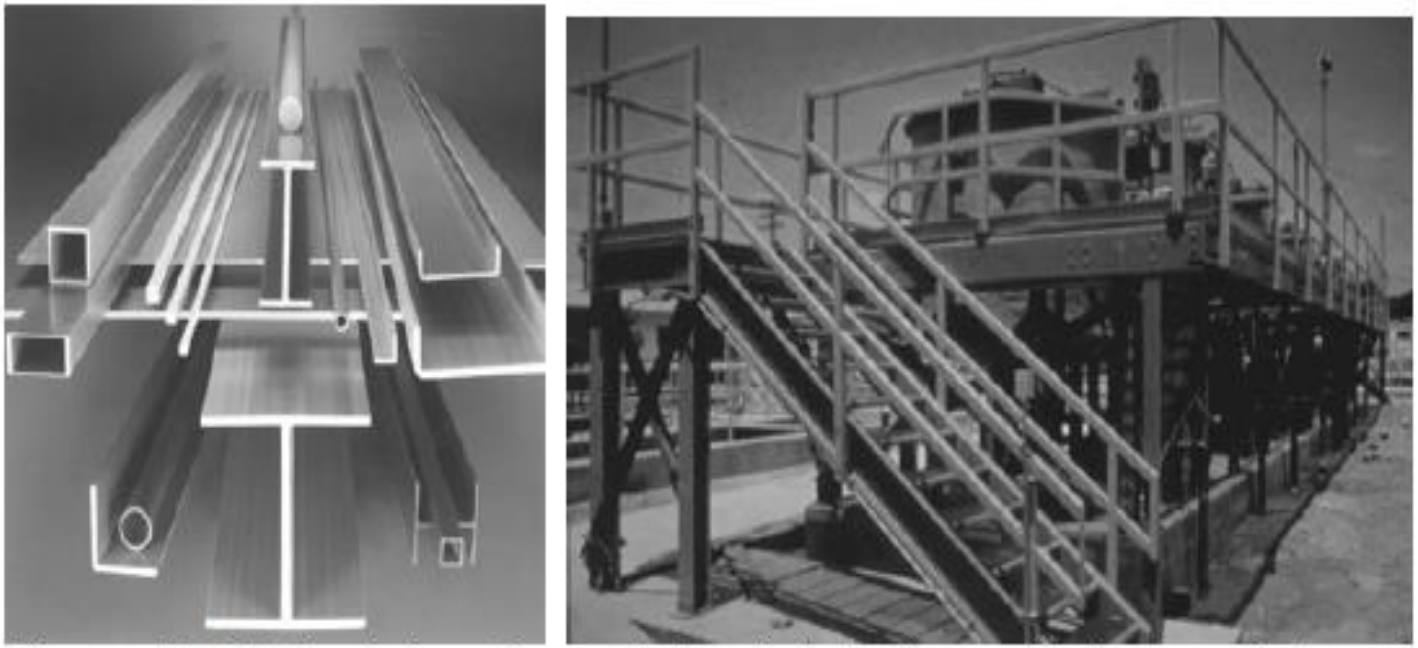


Fig. – FRP Pultruded sections and chemical platform with these products

Composite Application

a *b*

Fig. – FRP composite tanks: *a* – horizontal tanks [7]; *b* – vertical tanks

Composite Application

a *b*

Fig. – *a* – Blades made of glass fibre reinforced polymer (GFRP)
b – FRP composite components for an offshore platform

Where are composites used??????

CFRP – carbon fiber reinforced composite.

GFRP – glass fiber reinforced composite

Composites in industry

- Engineering applications
  - Aerospace
  - Automobile
  - Pressure vessel and pipes
- Any place where high performance materials are desired

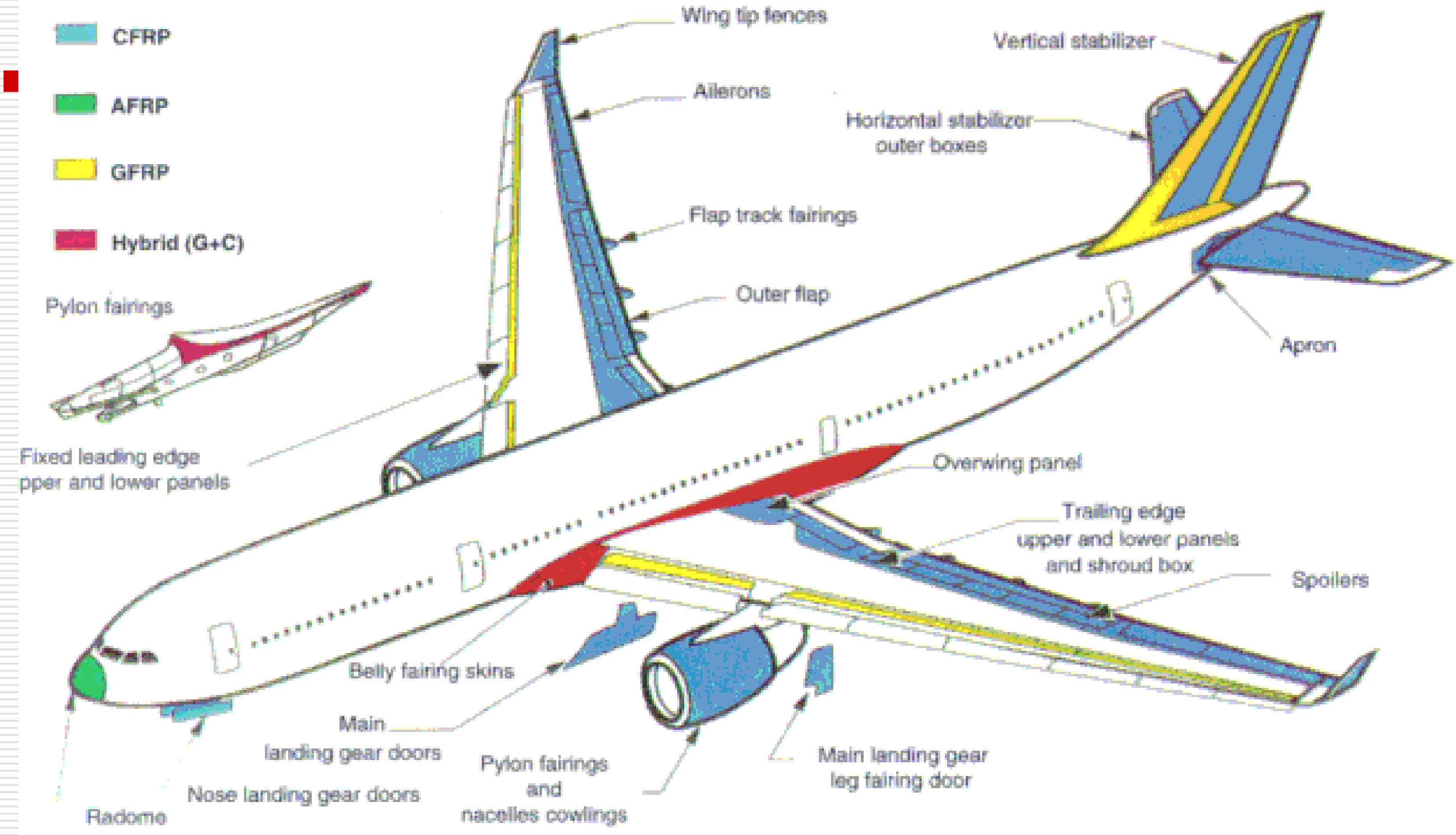
carbon-filament-reinforced-plastic (CFRP)

Turret Shield

Medical Table

Bullet proof shields

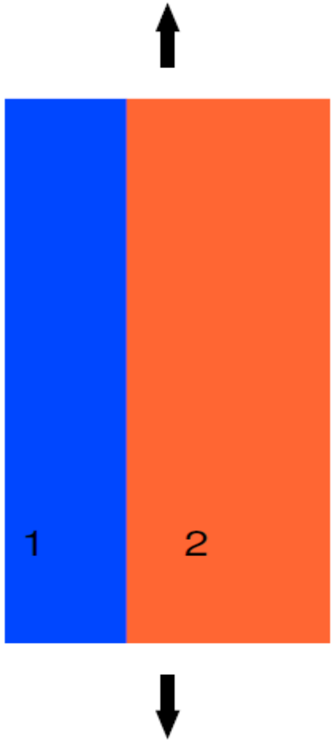
carbon fiber composite materials,



A330 composite materials application

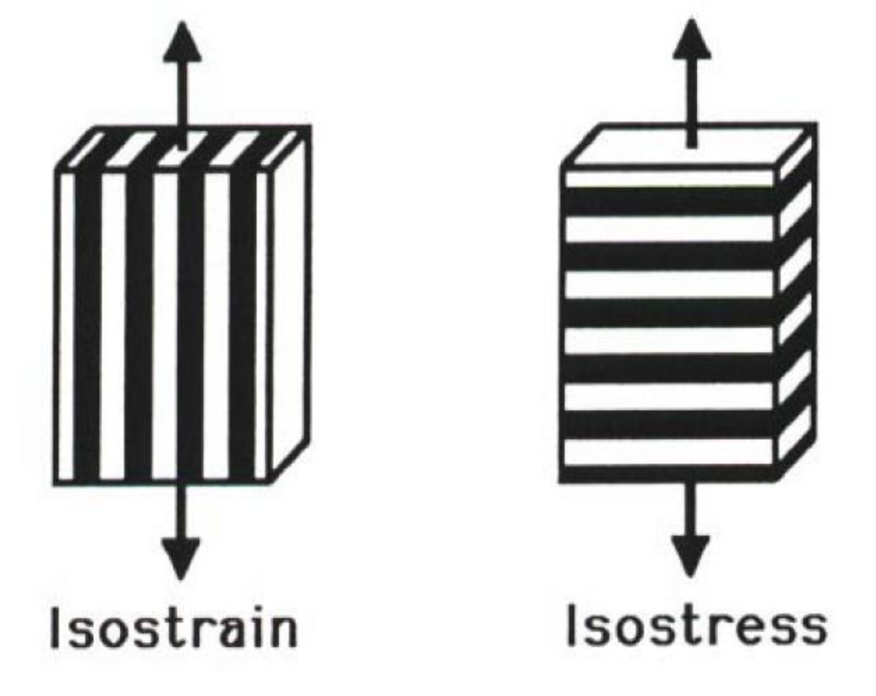
Iso-stress-Iso-strain condition of composite

Bounding Case - Isostrain



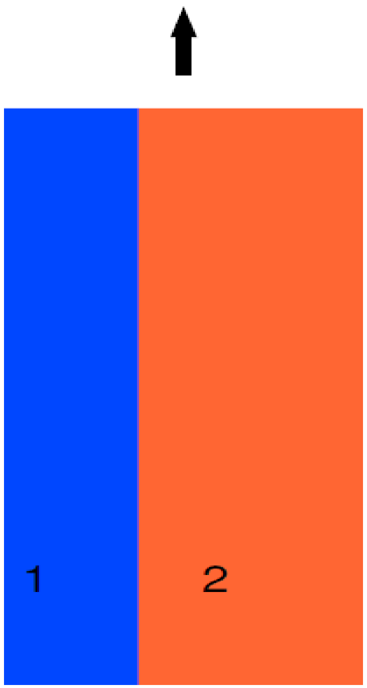
- Examine simplified cases to determine a range of possible outcomes
- Assume the following:
  - Two materials with different E and ν (or G and K)
  - Perfect bonding between zones 1 and 2
  - Constant cross-section
- Given these assumptions:
  - What is E for the composite?
  - How are loads shared between the two zones?

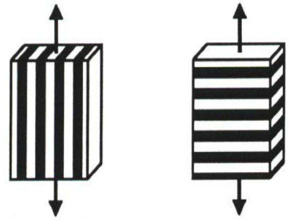
Iso-stress-Iso-strain condition of composite



Iso-strain Condition

Bounding Case - Isostrain





$$\epsilon_1 = \epsilon_2 = \epsilon_{tot}$$

$$\sigma_1 = E_1 \epsilon_1 = E_1 \epsilon_{tot} \quad ; \quad \sigma_2 = E_2 \epsilon_2 = E_2 \epsilon_{tot}$$

$$P_1 = A_1 \sigma_1 = A_1 E_1 \epsilon_{tot} \quad ; \quad P_2 = A_2 \sigma_2 = A_2 E_2 \epsilon_{tot}$$

$$P_{tot} = P_1 + P_2 = \epsilon_{tot} (A_1 E_1 + A_2 E_2)$$

$$\sigma_{tot} = \frac{P_{tot}}{A_1 + A_2} = \epsilon_{tot} \left(\frac{A_1}{A_1 + A_2} E_1 + \frac{A_2}{A_1 + A_2} E_2 \right)$$

$$\sigma_{tot} = (f_1 E_1 + f_2 E_2) \epsilon_{tot}$$

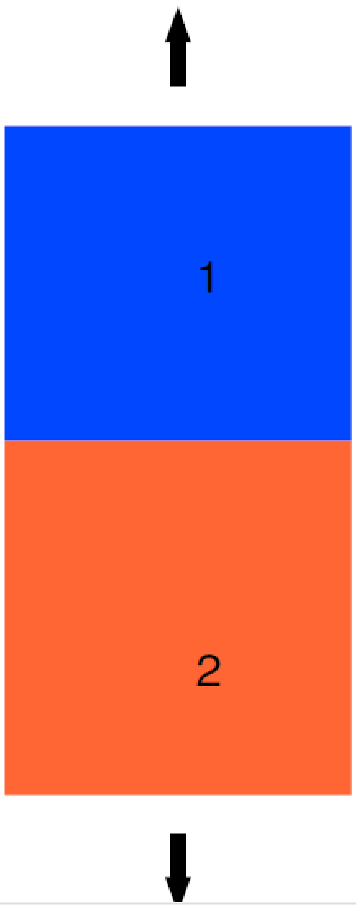
$$\boxed{E_{tot} = f_1 E_1 + f_2 E_2}$$

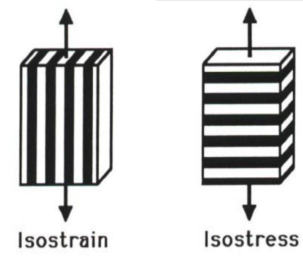
P_1, P_2 are the loads on 1 and 2.

f_1, f_2 are the volume fractions of 1 and 2.

Iso-stress Condition

Bounding Case - Isostress





$$\sigma_1 = \sigma_2 = \sigma_{tot}$$

$$\sigma_1 = E_1 \epsilon_1 \quad ; \quad \sigma_2 = E_2 \epsilon_2$$

$$\epsilon_{tot} = f_1 \epsilon_1 + f_2 \epsilon_2 = f_1 \frac{\sigma_{tot}}{E_1} + f_2 \frac{\sigma_{tot}}{E_2}$$

$$\boxed{E = \frac{\sigma_{tot}}{\epsilon_{tot}} = 1/(f_1/E_1 + f_2/E_2) = \frac{E_1 E_2}{f_1 E_2 + f_2 E_1}}$$

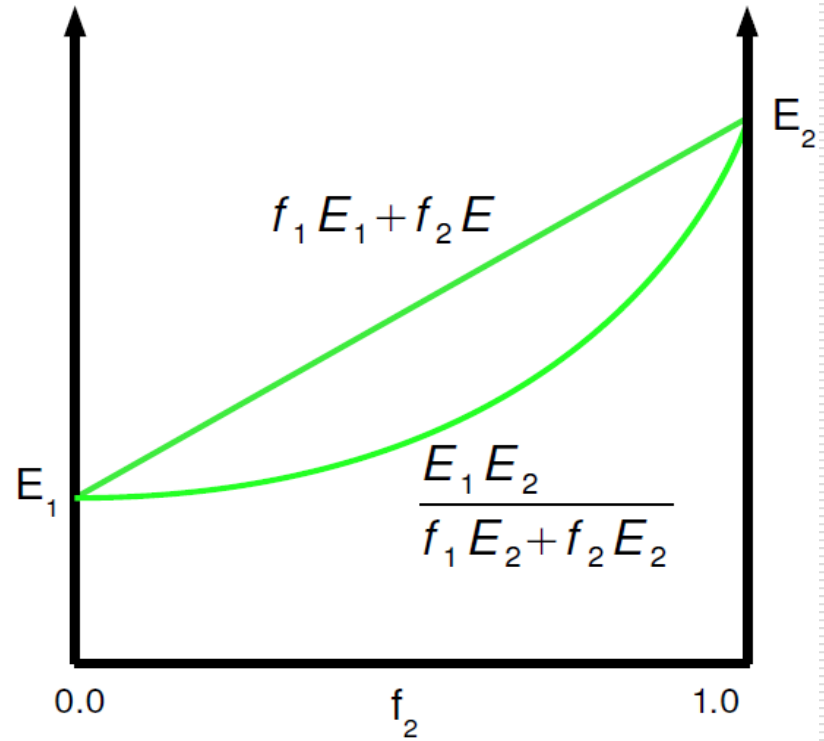
Modulus in Iso-stress-Iso-strain condition

Modulus Limits

Isostrain case: $E_{tot} = f_1 E_1 + f_2 E_2$

Isostress case: $E_{tot} = \dfrac{E_1 E_2}{f_1 E_2 + f_2 E_2}$

These two cases provide the bounds for more complicated microstructures.



Numerical on Iso-stress-Iso-strain condition

T2		Specification	E (GPa)	ν	σ_y (MPa)
Metals	Aluminum	BS 1490 (99% pure)	71	0.345	240
	Mild Steel	BS 070M20 >0.2 wt.% C	210	0.293	215
Ceramics and Glass	Aluminum Oxide (Al_2O_3)	-	~ 350 344.7-408.8	0.21-0.27	255-260.6 (Fracture)
	Glass (SiO_2)	-	~ 73 72.76-74.15	0.166-0.177	69.6-74.53 (Fracture)
Polymers	Polyester	General purpose grade	~ 4 1.03-4.48	0.33	51.5-55.1

Room temperature data

Numerical on iso-stress iso- strain condition

A composite is made from 40% parallel glass fiber in polymer matrix. Elastic modulus of glass and polymer are 72 GPa and 4 GPa respectively.

Find the Elastic modulus of polymer matrix composite in iso-stress and iso-strain condition.

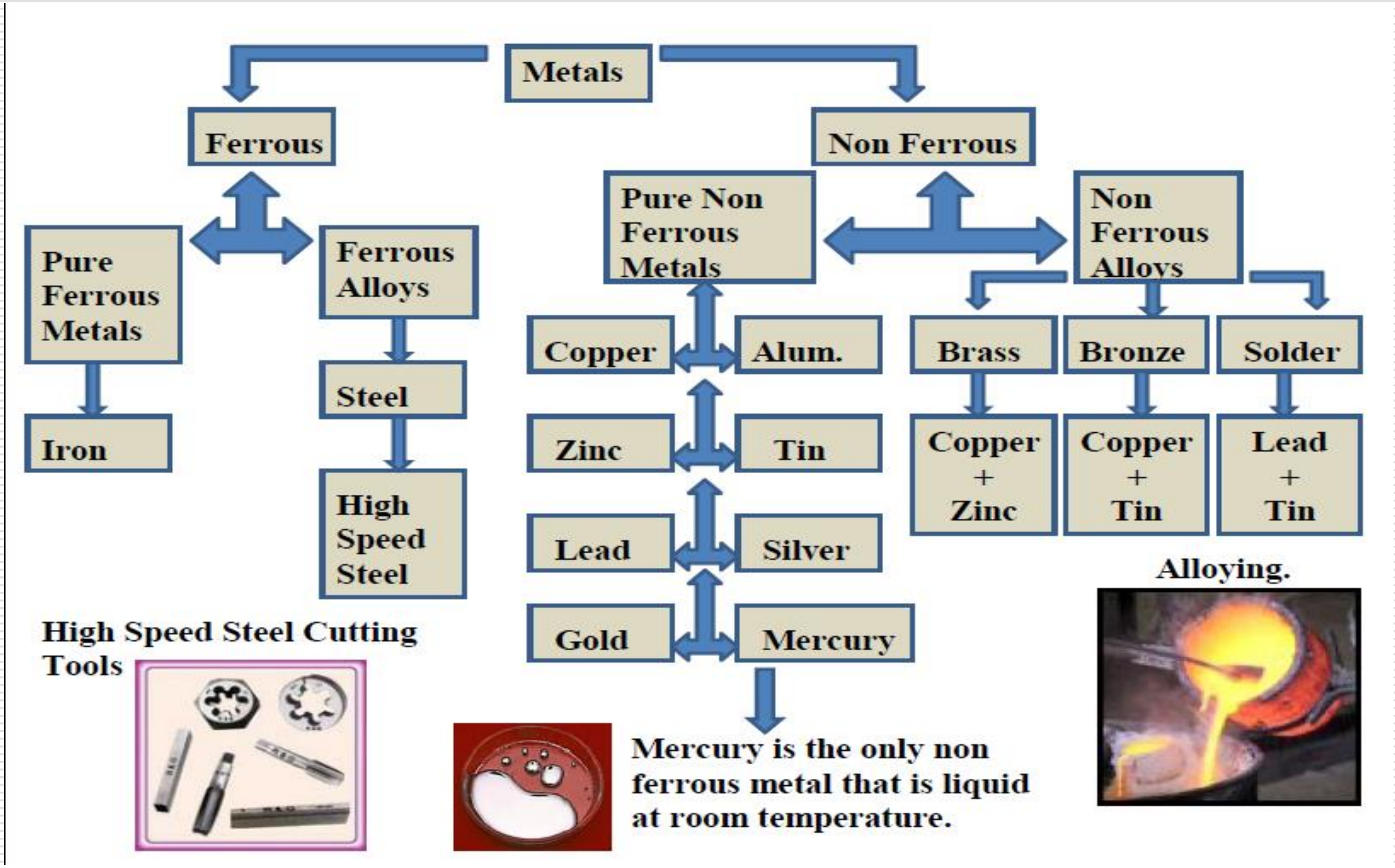
Numerical on iso-stress iso- strain condition

A composite is made from 35% longitudinal carbon fiber in Polyester. Elastic modulus of carbon fiber and Polyester are 225 GPa and 4.4 GPa respectively.

Find the Elastic modulus compsite

Introduction to nonferrous metals

- Metals
  - Ferrous
  - Non ferrous


Metals
Ferrous
Non Ferrous
Pure Ferrous Metals
Ferrous Alloys
Iron
Steel
High Speed Steel
High Speed Steel Cutting Tools
Pure Non Ferrous Metals
Non Ferrous Alloys
Copper
Alum.
Zinc
Tin
Lead
Silver
Gold
Mercury
Brass
Bronze
Solder
Copper + Zinc
Copper + Tin
Lead + Tin
Alloying.
Mercury is the only non ferrous metal that is liquid at room temperature.

What is Ferrous Metals?

- Ferrous is the adjective used to indicate the presence of iron.
- Typical ferrous metals include mild steel, cast iron and steel.
- ***Examples:***
- 1.Mild Steel.
- 2.Cast Iron.
- 3.High Carbon Steel.
- 4.High Speed Steel.
- 5.Stainless Steel.

Cast iron

Metal Type.

Cast Iron.
Is a very strong metal when it is in compression and is also very brittle. It consists of 93% iron and 4% carbon plus other elements.

Metal Uses.

Used as car Brake discs, car cylinders, metalwork vices, manhole covers, machinery bases eg: The pillar drill.

Melting Point.

1200°C

High Carbon steel

Metal Type.

High Carbon Steel .
It is a very strong and very hard steel that has a high resistance to abrasion. Properties – Up to 1.5% carbon content. Very tough.

Metal Uses.

Used for hand tools such as screwdrivers, hammers, chisels, saws, springs and garden tools.

Melting Point.

1300°C

Stainless steel

Metal Type.

Stainless Steel.
Stainless steel is very resistant to wear and water corrosion and rust.
Properties – It is an alloy of iron with a typical 18% chromium 8% nickel and 8% magnesium content.

Metal Uses.

Used for kitchen sinks, cutlery, teapots, cookware and surgical instruments.

Melting Point.

1400°C

Dr. Vishwanath Karad
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TECHNOLOGY, RESEARCH, SOCIAL INNOVATION & PARTNERSHIPS

Non – Ferrous Metal

- Non-ferrous metals are metals that do not have any iron in them.
- Non-ferrous metals are not attracted to a magnet and they also do not rust in the same way when exposed to moisture.
- Typical Non-ferrous metals include copper, aluminium, tin and zinc.

Non – Ferrous Metal

- **Examples:**
- **1.Aluminium.**
- **2.Copper.**
- **3.Zinc.**
- **4.Tin.**
- **5.Lead.**
- **6.Silver.**
- **7.Gold.**
- **8.Magnesium.**

Copper

Copper is an element and a mineral called *native copper*.

Native copper

- Found in Chile, Indonesia and USA.
- In India Hazaribagh (Jharkhand), Khetri, Udaipur (Rajasthan),Sundergarh (Odisha)
- Copper is an industrial metal and widely used in unalloyed and alloyed conditions. (second ranked from steel and aluminium).

Physical properties of copper and *copper alloys*

Metal	Relative electrical conductivity (copper = 100)	Relative thermal conductivity (copper = 100)
Silver	106	108
Copper	100	100
Gold	72	76
Aluminum	62	56
Magnesium	39	41
Zinc	29	29
Nickel	25	15
Cadmium	23	24
Cobalt	18	17
Iron	17	17
Steel	13–17	13–17
Platinum	16	18
Tin	15	17
Lead	8	9
Antimony	4.5	5

29 FCC
Cu
Copper
63.546

- High ductility, formability.
- High electrical and thermal conductivities.

Electrical and thermal conductivities of pure metals at RT

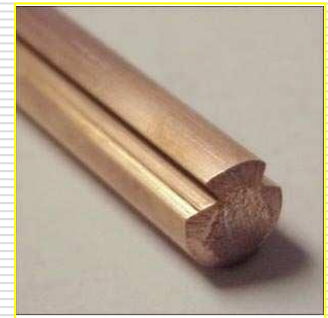
Properties and applications of copper

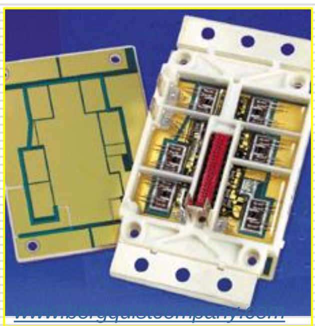
Properties:

- High electrical conductivity
- High thermal conductivity
- High corrosion resistance
- Good ductility and malleability
- Reasonable tensile strength

Applications:

Only second to silver for electrical conductance





Electronic products

Copper finish parts

Copper plating

Classification of copper and copper alloys

1) Unalloyed copper

2) Brass

Copper – Zinc alloys

brasses

Copper – Lead alloys with Tin and Aluminium additions

Alloy brasses

3) Bronze

Copper – Tin alloys
Copper – Aluminium alloys
Copper – Silicon alloys
Copper – Beryllium alloys

4) Cu-Ni based

Cupronickel (Cu-Ni)
Nickel silver (Cu-Ni-Zn)

Brass

Metal Type.

Brass.

Brass is a mixture of copper and zinc. Copper is the main component, and brass is usually classified as a copper alloy. The color of brass varies from a dark reddish brown to a light silvery yellow. Brass is stronger and harder than copper, but not as strong or hard as steel. It is easy to form into various shapes, a good conductor of heat, and generally resistant to corrosion from salt water.

Metal Uses.

Brass is used to make water fittings, screws, radiators, musical instruments, and cartridge casings for firearms.

Melting Point.

940°C

Mechanical properties of brasses

Low brasses (80-95%Cu, 20-5%Zn)

↑ *Zn content* ↑ *Strength Hardness*

•Can be hot worked in 730-900°C temperature range.

•Annealed low brass is extremely *ductile* (40-50% at *RT*) and *malleable*.

High brasses (60-80%Cu, 40-20%Zn)

•*Increased strength and hardness* due to increasing *Zn* content.

Alloy brasses

•Multiple additions of *Mn*, *Fe*, *Sn* increase strength (manganese bronze).

Types of Brasses

I-Alpha brasses

•The range of alloys, termed 'alpha brasses', or 'cold working brasses', contain a minimum 63% of copper.

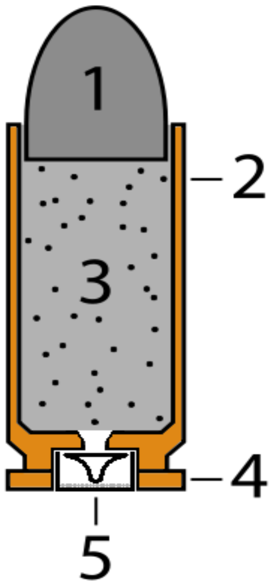
•They are characterised by their ductility at room temperature, and can be extensively deformed by rolling, drawing, bending, spinning, deep drawing, cold heading and thread rolling.

•The best known material in this group contains 30% zinc and is often known as '70/30' or 'cartridge' brass, CuZn30 - due to the ease with which the alloy can be deep drawn for the manufacture of cartridge cases.

Types of Brasses Alpha brasses

1. Cartridge Brass

- It contain about 30% zinc and has maximum ductility and malleability amongst all the brasses.
- It is used for forming by deep drawing, stretching , trimming, spinning, and press working operation.
- It is also called as 70-30 brass.
- It is used for cartridge cases, radiator fins, lamp fixture, rivets and springs.



Types of Brasses Alpha brasses

2.Admiralty Brass

- About 1% tin is added to cartridge brass to improve the corrosion resistance and such a brass is called as admiralty brass.
- It is used for condenser tubes and heat exchanger in steam power plants.

3.Gilding Metals:

- They contain zinc from 5 to 15 % and have different shades of colour from reddish to yellowish according to zinc content.
- They are used for condenser tubes, coin, needles, dress jewelry because of colour like gold.

Types of Brasses Alpha brasses

4.Cap Copper

- It contain zinc between 2 to 5%.
- Zinc is used as a deoxidizer for deoxidation of copper.
- If zinc is not added, copper oxide present in structure reduces ductility and malleability.
- Cap Copper are very ductile and is used for caps of detonators in ammunition factories.

Alpha-Beta brasses/Duplex brasses

II- Alpha-Beta brasses/Duplex brasses

- The ‘alpha-beta brasses’, ‘duplex brasses’ or ‘hot working brasses’ usually contain between 38% and 42% zinc.
- In contrast to the alloys of the first group, their ability to be deformed at room temperature is more limited.
- They are, however, significantly more workable than the alpha brasses at elevated temperatures and can be extruded into bars of complex section, either solid or hollow, and hot forged in closed dies to complex shapes.

Alpha-Beta brasses/Duplex brasses

1.Muntz Metal

- It contain about 40% zinc with balance copper.
- It can be readily hot worked, extruded or rolled in the temperature range of 600 to 800 C
- It is used for utensils, shafts, condenser tubes.

2.Naval Brass

- Addition of about 1% tin to Muntz metal increases corrosion resistance to marine environments and the brass is called naval brass.
- Brass with 39% zinc and 1% tin is used for marine hardware, piston rod, welding rods.

Alpha-Beta brasses/Duplex brasses

3. High tensile brasses

- Alloying element such as Al, Fe, Mn and Ni are frequently added to 60-40 brass to increase its tensile strength.
- Brasses containing one or more above elements are called high tensile brasses.
- It is used for marine engine pump, gears, valves bodies and other application requiring good strength and corrosion resistance.

Brasses

α-Brasses		
Material	Composition	Application
Cap Copper	2 to 5 % Zn	It is very ductile and used for cap of detonators in ammunition factories
Gilding Metals	5 to 15 % Zn	Used for condenser tube, coins, jewelry
Cartridge Brass	30% Zn	Used for cartridge cases ,radiator fins, spring
α-β Brasses		
Muntz Metal	40% Zn	It is used for utensils ,shaft, nuts & bolts, condenser tube
Naval Brass	39% Zn ,1%Tin	Used for marine hardware, propeller shaft, piston road

Copper alloy

Brass

copper and zinc

Alpha: Up to 36% Zn and rest copper for *cold working*.

Alpha-Beta: 36 to 45% Zn and remainder is copper for *hot working*.

Costume jewelry, cartridge casings, automotive radiators, musical instruments, electronic packaging, and coins.

Bronze

Copper and tin

- Phosphor bronze
- Gun metal
- Silicon bronze
- Bell metal
- Manganese Bronze
- Muntz Metal

hydraulic fittings, bearings, bushes, utensils, sheets, rods and many other stamped and drawn products.

Bronze

Metal Type.

Bronze.

Bronze is a metal alloy consisting primarily of copper, usually with tin as the main additive. It is a hard and brittle metal. It has a very high resistance to corrosion.

Metal Uses.

Used for ship propellers and underwater fittings. Also used for statues and medals.

Melting Point.

950°C

1. Phosphor bronze

- In bronze, phosphor is used to improve the deoxidizing property.
- Phosphor is a powerful deoxidizer and when it is used solely as deoxidizer.
- Higher amounts of phosphor than necessary for complete deoxidation serves as an alloying elements and improves the mechanical properties and castability by increasing the fluidity of melt
- Uses : springs, wire gauges, electrical contact, gears, bushing, valves

2. Silicon bronze

2. Silicon bronze

•Silicon bronze contains silicon along with copper. 1 - 3% of silicon is added to improve the cryogenic suitability and strength.

•They are used for wires, rod, tubes, pipes, bells etc.

3. Aluminium bronze

3. Aluminium bronze

•Aluminium bronze contain 5 -10% aluminium which improves the corrosion resistance with remarkable strength.

•These alloy are lustrous and their colour is the finest of all the copper alloys and hence they are frequently called as imitation gold.

• They are used for pump casting, spark plug bodies and electrical contact.

4. Gunmetal

4. Gunmetal

- Gunmetal, also known as red brass in the United States, is a type of bronze – an alloy of copper, tin, and zinc.
- Proportions vary by approximation but 88% copper, 8–10% tin, and 2–4% zinc is an approximation.
- Originally used chiefly for making guns, it has largely been replaced by steel. Gunmetal, which casts and machines well and is resistant to corrosion from steam and salt water.
- It is used to make steam and hydraulic castings, valves, gears, statues, and various small objects, such as buttons.

Cupronickels

Cupronickels

- Cupronickel is the combination of copper and nickel which are ranges as follows:

- 90 - 10, Cu - Ni
- 80 - 20, Cu - Ni
- 70 - 30, Cu - Ni

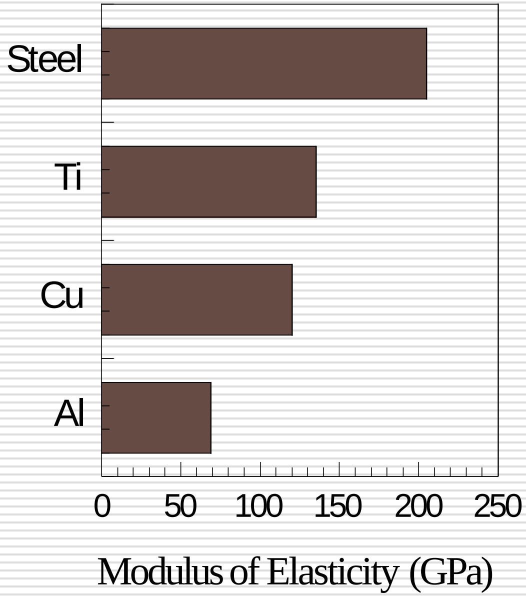
- Cupronickel have good resistance to seawater.
- The cupronickel has better temperature and corrosion resistance.
- The corrosion resistance increases with increase in the amount of nickel in these alloy.
- It is extensively used for thermocouple wires.

Al and its Alloys

- Low density (2700 Kg/m3) - ~1/3 of that of steel higher strength-to weight ratio
- High electrical conductivity - 60% of that of Cu
- Most recyclable metal
- It is alloyed to improve strength. Al is alloyed with any or combination of elements: Cu, Mn, Mg, Zn, Si
- In addition to alloying, Al alloys are also hardened by cold working
- Low elastic modulus: ~70 GPa Yield strength: 100~400MPa

Aluminium

- Low density (2.7g/cc)
- Modulus Al-70GPa and steel (210GPa)
- Corrosion resistance
- Recyclability
- Poorer formability than steel
- Less readily welded than steel



Aluminium

Metal Type.

Aluminium.
It tends to be light in colour although it can be polished to a mirror like appearance. It is very light in weight.

Metal Uses.

Used for saucepans, cooking foil, window frames, ladders, expensive bicycles.

Melting Point.

660°C

Important Aluminum Alloy

1. Duralumin

It is an important and interesting wrought alloy.

- Its composition is as follows:

Copper = 3.5 – 4.5%; Manganese = 0.4 – 0.7%; Magnesium = 0.4 – 0.7%, and the remainder is aluminium.

- This alloy possesses maximum tensile strength (upto 400 MPa) after heat treatment and hardening. After working, if the metal is allowed for 3 or 4 days, it will be hardened. This phenomenon is known as **age hardening.**
- It is widely used in wrought conditions for forging, stamping, bars, sheets, tubes and rivets.

Important Aluminum Alloy

2. Magnalium

- It is made by melting the aluminium with 2 to 10% magnesium in a vacuum and then cooling it in a vacuum.

- It also contains about 1.75% copper. Due to its light weight and good mechanical properties, it is mainly used for aircraft and automobile components.

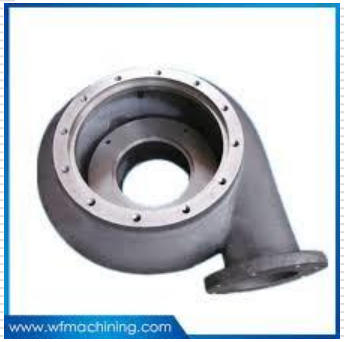
Important Aluminum Alloy

3. Hindalium

- It contain about 5% Cu and 1.5% Ni with small amounts of Mn, Ti, Co, Zr.
- It is superior at elevated temperature services particularly in respect of creep resistance.
- It is used in aero engine and other continuous elevated temperature service application up to 300 C.
- Mainly used in manufacturing of anodized utensils.

Aluminium Cast Alloy

1.LM6:



- Aluminium Alloy LM-6, which is called 12 percent Silicon-Aluminium alloy, has long been one of the best Aluminium Alloys for the die- casting of large and intricate parts and those having thin- walled sections.
- The molten metal has excellent fluidity and shows less shrinkage during solidification.
- Aluminium Alloy LM-6 is recommended for manufacturing gravity and pressure die cast components for use in various engineering applications.
- The alloy widely used for automobile casting such as water jacket, motor housing, pump parts.

Aluminium Cast Alloy

2.LM2:

- LM 2 (10% Si – 2.0% Cu) is the other popular alloys in which the silicon content is reduced and various amounts of copper are added.
- Reduction in silicon content reduces the fluidity.
- Copper increases the machinability but lowers the castability, corrosion resistance and ductility.

Aluminium Cast Alloy

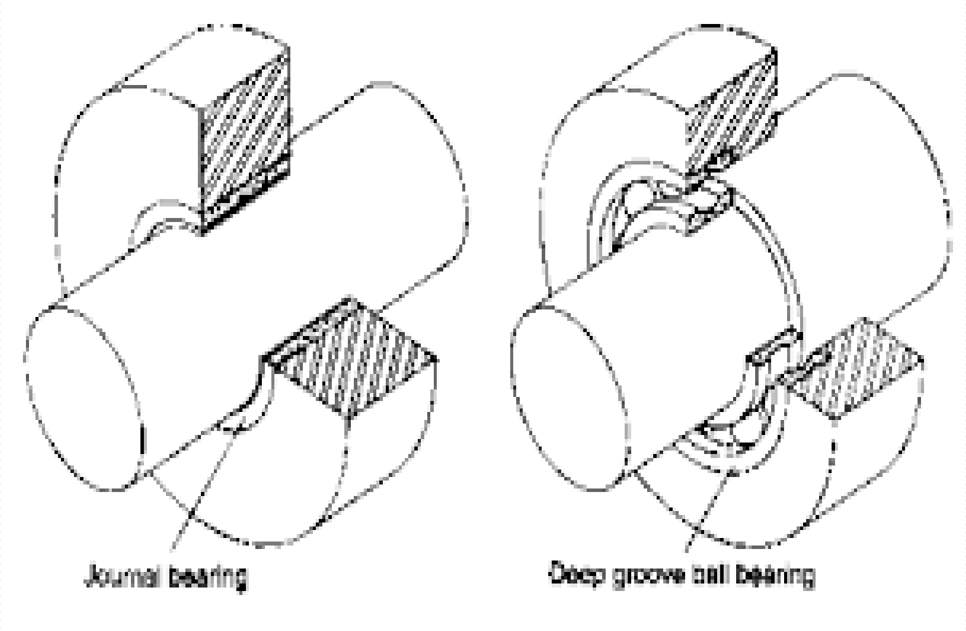
3.LM 13:

LM 13 (12% Si - 2.5% Ni – 0.9%Cu – 1.2% Mg) is used for elevated temperature application where a low coefficient of thermal expansion and good bearing properties are essentials e.g. Piston

Babbitt

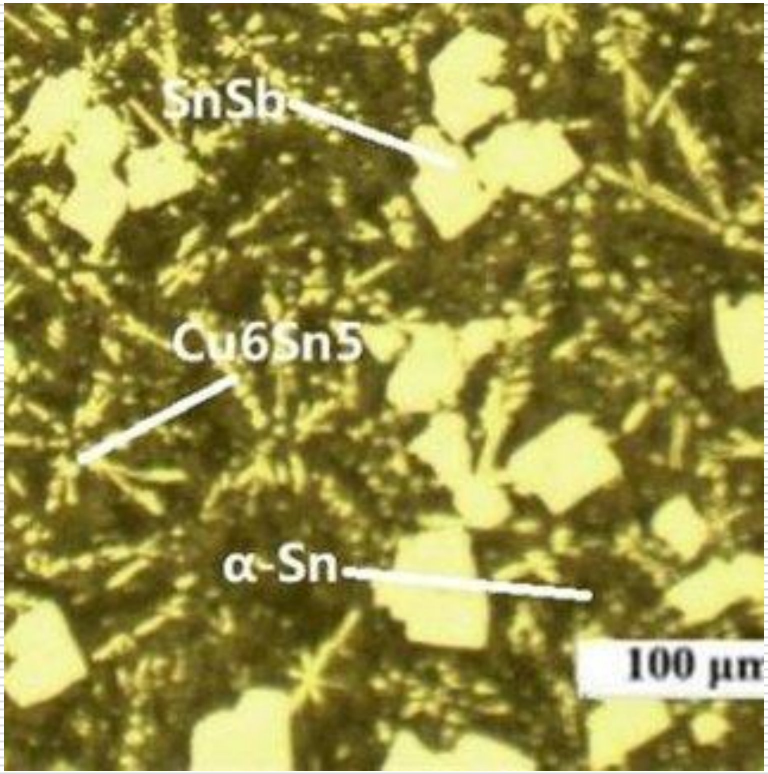
- In 1839, Isaac Babbitt received the first patent for a white metal alloy that showed excellent bearing properties. Since then, the name Babbitt has been used for other alloys involving similar ingredients.
- The original formula for Babbitt's bearing metal was 89.3% tin, 7.1% antimony and 3.6% copper
- Babbitt offer an almost unsurpassed combination of compatibility, conformability, and embeddability.
- They easily adapt their shapes to conform to the bearing shaft and will hold a lubricant film.

Babbitt



Babbitt

- Foreign matter not carried away by the lubrication is embedded below the surface and rendered harmless
- These characteristics are due to babbitt's hard/soft composition. High-tin babbitts, for example, consist of a relatively soft, solid matrix of tin in which are distributed in hard copper-tin needles and tin-antimony cuboids.
- Even under severe operating conditions, where high loads, fatigue problems, or high temperatures dictate the use of other stronger materials, babbitts are often employed as a thin surface coating to obtain the advantages of their good rubbing characteristics.



Soldering and Brazing Materials

Soldering

- Two parts made of similar or dissimilar metals are joined by a solder made of a fusible alloy.
- The solder is melted by the heat provided by the soldering iron and filled between the metal parts. The solder solidifies and joins the metal parts.
- Mechanism- wetting and surface alloying
- Temp < mp
- < 427°C
- Heat source– air acetylene flame, electric resistance.
- Filler rod - Tin and Lead- soft soldering
- Silver (40%)+ lead (30%)+ tin(30%)- hard soldering
- application -joining wires in radio ,TV , ckt board etc

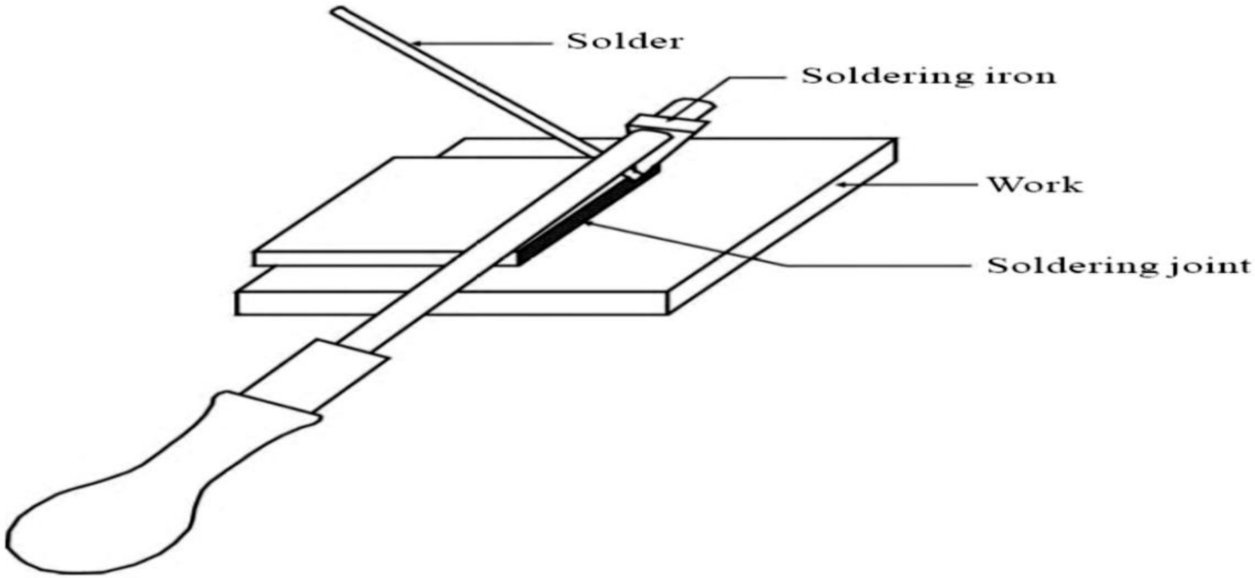
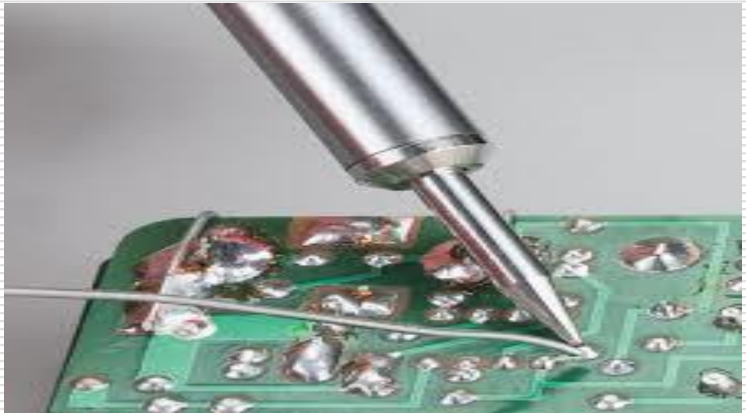


Fig. Soldering

Soldering Material

- Soldering is one of the oldest methods of joining metals. Because filler metals melt at low temperatures.
- Fluxes are used to deoxidised the soldering area.
- Fluxes are available as liquids, powders, pastes, solid and in flux-cored wires. Soldering fluxes may also be toxic and corrosive and require post-cleaning operations.
- Commonly Filler materials include combinations of tin-lead, tin-silver-lead.
- Again, as with brazing filler metals, solders are supplied as wires, foil, sheets, pastes, preforms, or as bars.

Soldering Material



- Alloys commonly used for electrical soldering are 60/40 Sn-Pb, which melts at 188 °C and 63/37 Sn-Pb used principally in electrical/electronic work. 63/37 is a alloy of these metals, which: has the lowest melting point (183 °C) of all the tin-lead alloys

Brazing

- In brazing, filler metal in molten state is filled between the metal parts of the joint.
- The parts to be joined are cleaned and the molten filler metal is applied between the parts to make the joint.
- Mechanism- wetting and surface alloying
- Temp- >427C and < MP
- Heat source – oxy-hydrogen flame, electric resistance
- Filler rod- Cu+Zn -high capillary action
- Application – kitchen appliances joining copper pipe in refrigeration system

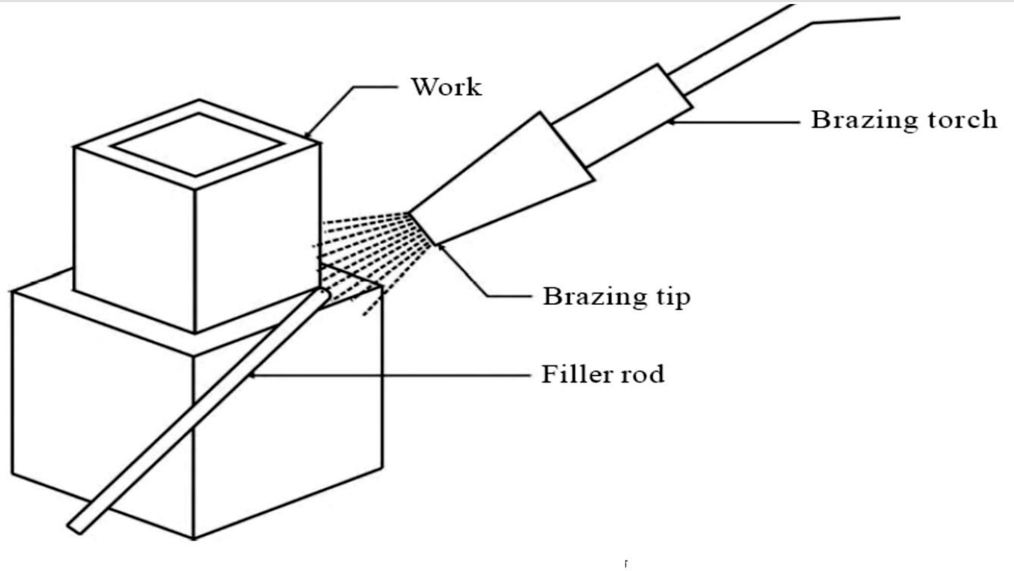


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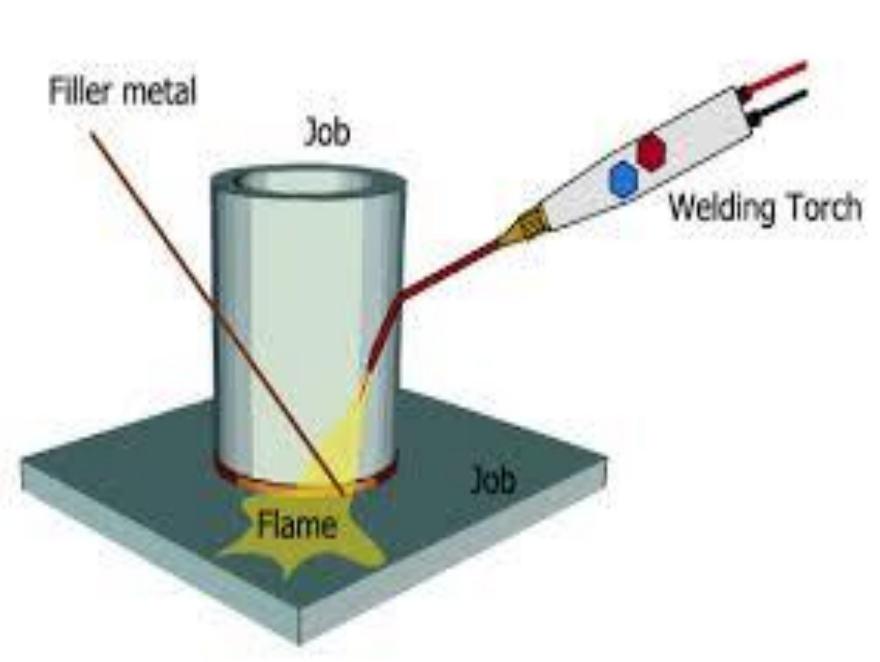
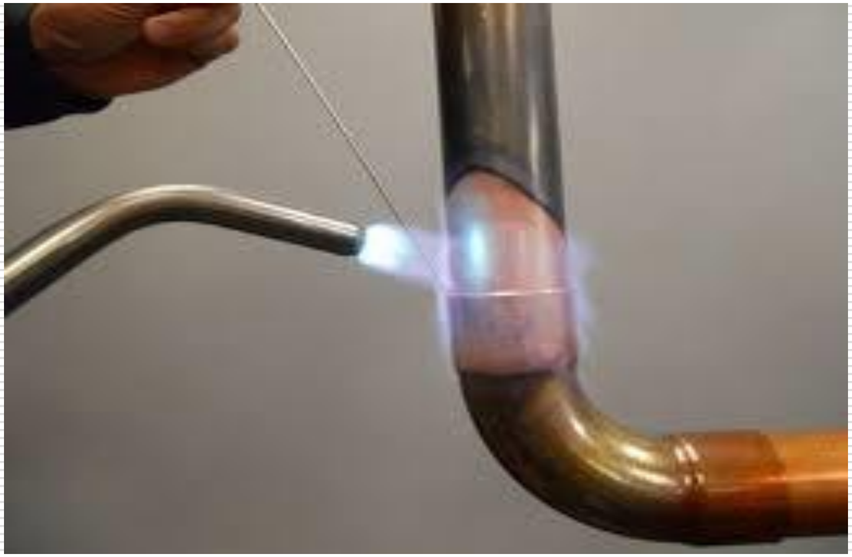
Fig. Brazing

Brazing Materials

- Brazing is a joining process wherein metals are bonded together using a filler metal with a melting (liquidus) temperature greater than 450 °C, but lower than the melting temperature of the base metal.
- Filler metals are generally alloys of silver (Ag), aluminum (Al), gold (Au), copper (Cu), cobalt (Co) or nickel (Ni).
- Most commonly used filler material is copper- zinc alloy because it has highest capillary action.


Filler metal
Job
Welding Torch
Job
Flame



Advantages of Soldering and Brazing

- Low temperature
- Permanent or Temporary Joining
- Dissimilar materials can be joined
- Speed
- Less chance of damage
- Slow rate of heating/cooling
- Parts of varying thickness can be joined

Lever Rule

The Lever Rule is used to calculate the weight % of the phase in any two-phase region of the Phase diagram (and only the two phase region!)

In general:

- Phase percent = $\dfrac{\text{opposite arm of lever}}{\text{total length of the tie line}} \times 100$

Lever Rule

Calculate the amount of α phase and *L* phase present in a Cu - 40% Ni alloy at 1250 C

In general:

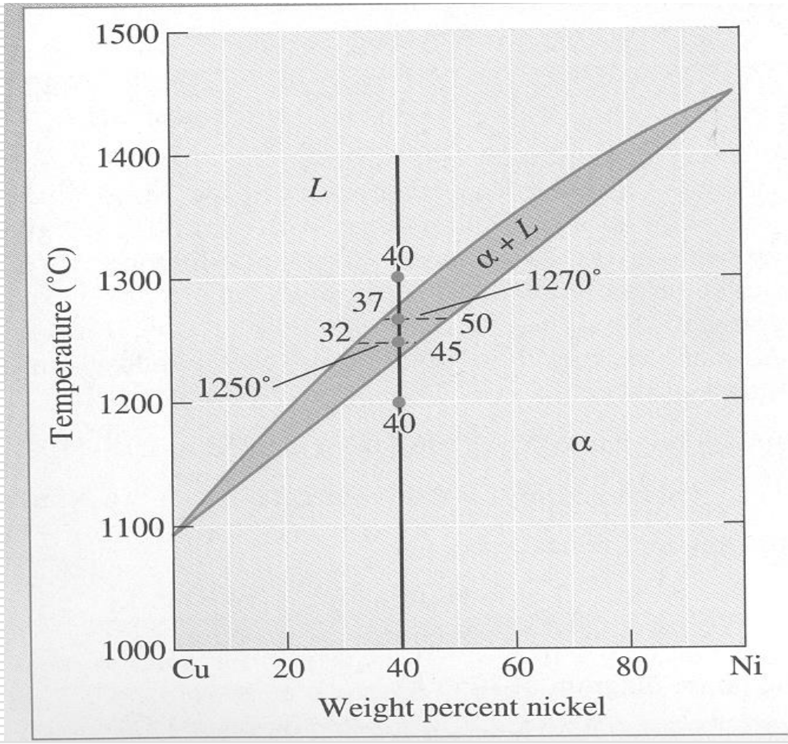
- **Percent α phase = ((% Ni in alloy) – (% Ni in L) / (% Ni in L - % Ni in α)) x 100**

$$\text{weight fraction}, \%X_s = \frac{40-32}{45-32} \text{ x } 100 = 62\,\%$$

(of solid α phase)

$$\text{weight fraction}, \%\,L = 38\,\%$$

(of liquid phase)



Lever Rule

- Examples:

C_o = 35wt%Ni

At T_A:

Only Liquid (L)

$C_L = C_o$ (= 35wt% Ni)

At T_D:

Only Solid (α)

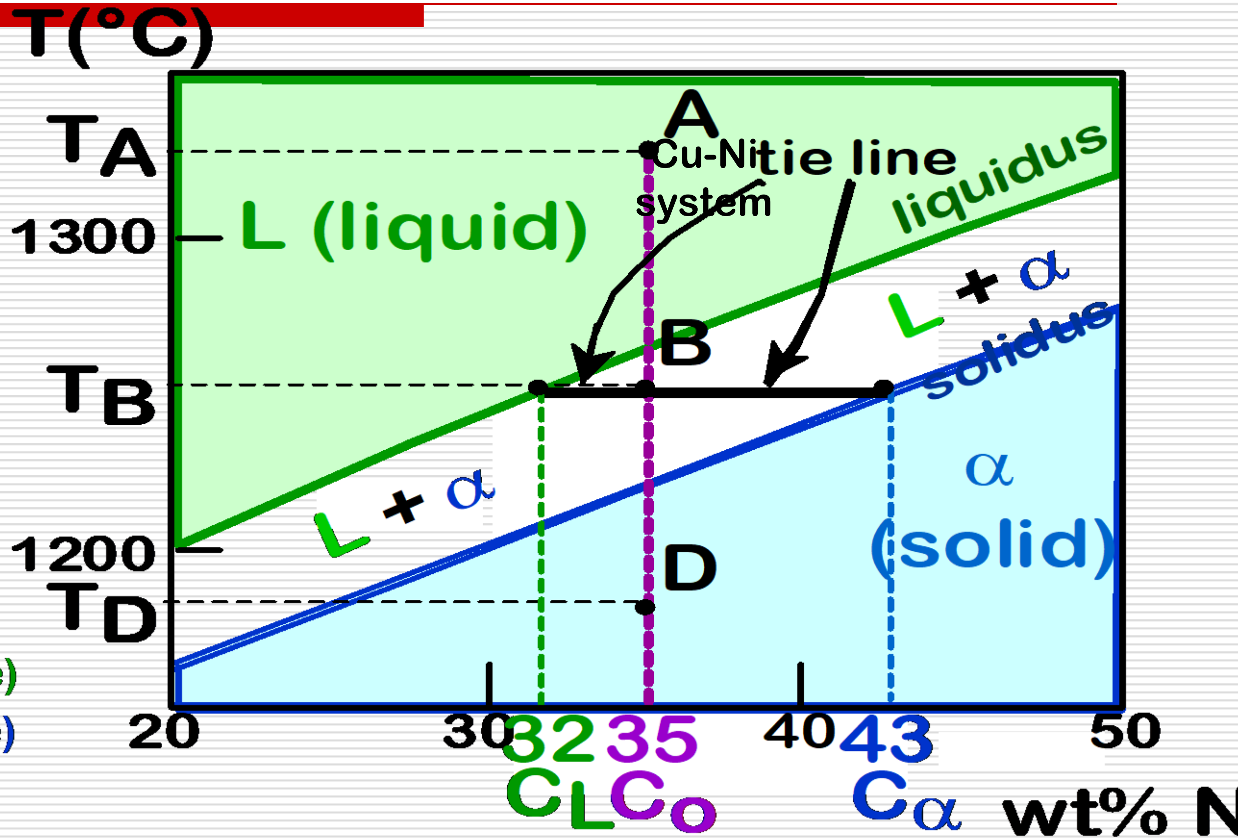
$C_\alpha = C_o$ (= 35wt% Ni)

At T_B:

Both α and L

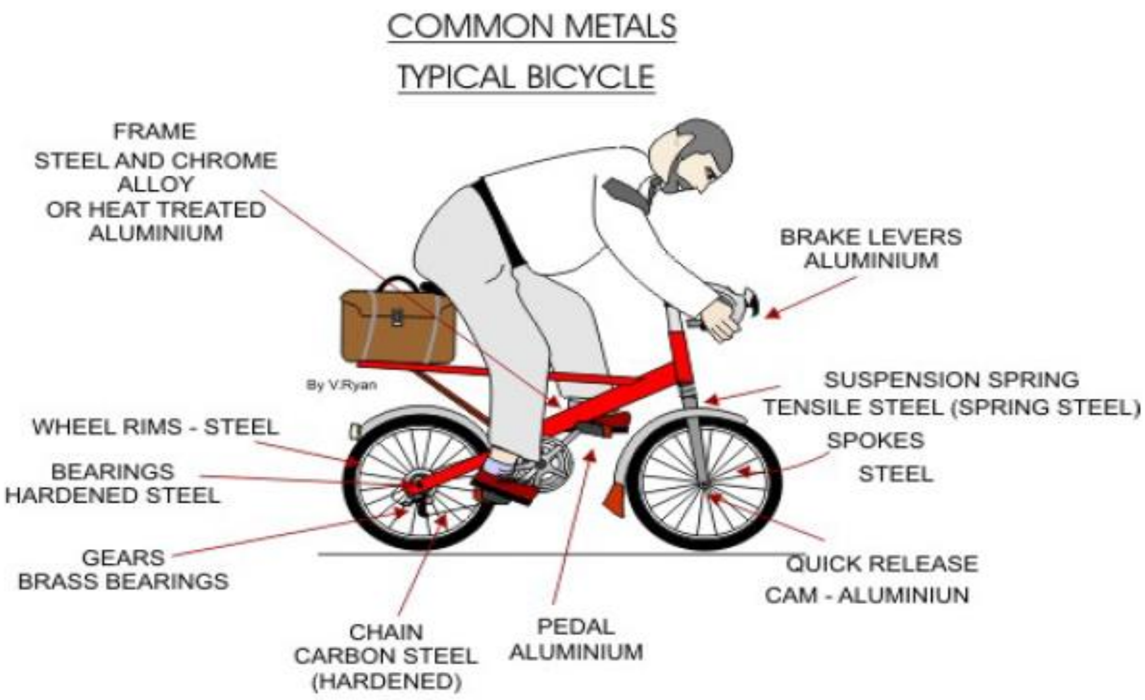
$C_L = C_{liquidus}$ (= 32wt% Ni here)

$C_\alpha = C_{solidus}$ (= 43wt% Ni here)



Metals in Everyday Use.

Below is a list of metals that would be used in the manufacturing of a bicycle.



Aerospace Materials

- Forty years ago, aluminium dominated the aerospace industry.
- As the new kid on the block, it was considered to be lightweight, inexpensive, and state-of-the-art. In fact, as much as 70% of an aircraft was once made of aluminum.
- Other new materials such as composites and alloys were also used, including titanium, graphite, and fiberglass, but only in very small quantities – 3% here and 7% there..
- Times have changed. A typical jet built today is as little as 20% pure aluminum.

Aerospace Materials

- Most of the non-critical structural material – paneling and aesthetic interiors – now consist of even lighter-weight carbon fiber reinforced polymers (CFRPs) and honeycomb materials.
- Composite materials also represent a growing piece of the aerospace material pie.
- They reduce weight and increase fuel efficiency while being easy to handle, design, shape.
- Once only considered for light structural pieces or cabin components, composites' aerospace application range now reaches into true functional components – wing and fuselage skins, engines, and landing gear.

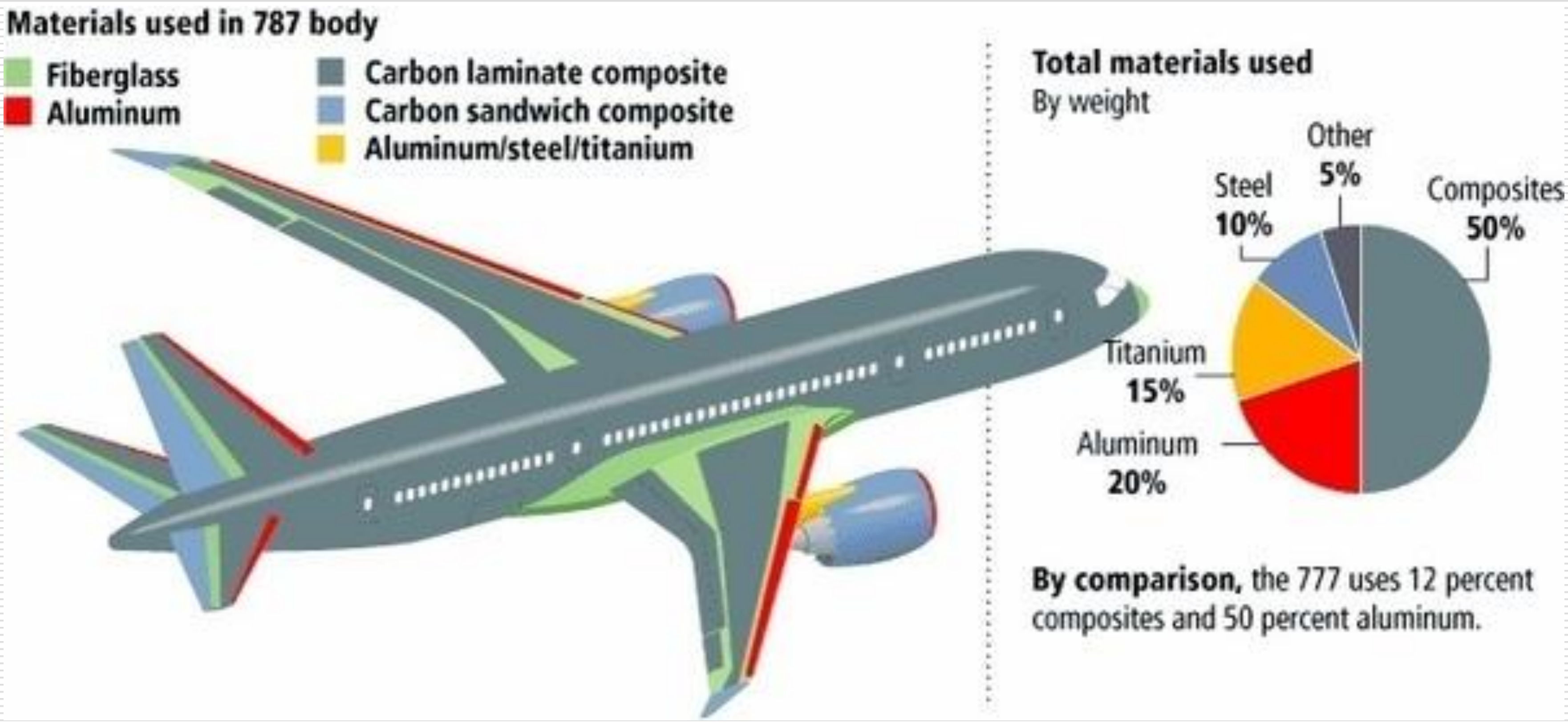
Aerospace Materials

- Also important, composite components can be formed into complex shapes that, for metallic parts, would require machining and create joints.
- Pre-formed composite components aren't just lightweight and strong, they reduce the number of heavy fasteners and joints – which are potential failure points – within the aircraft.
- In doing so, composite materials are helping to drive an industry-wide trend of fewer components in overall assemblies, using one-piece designs wherever possible.

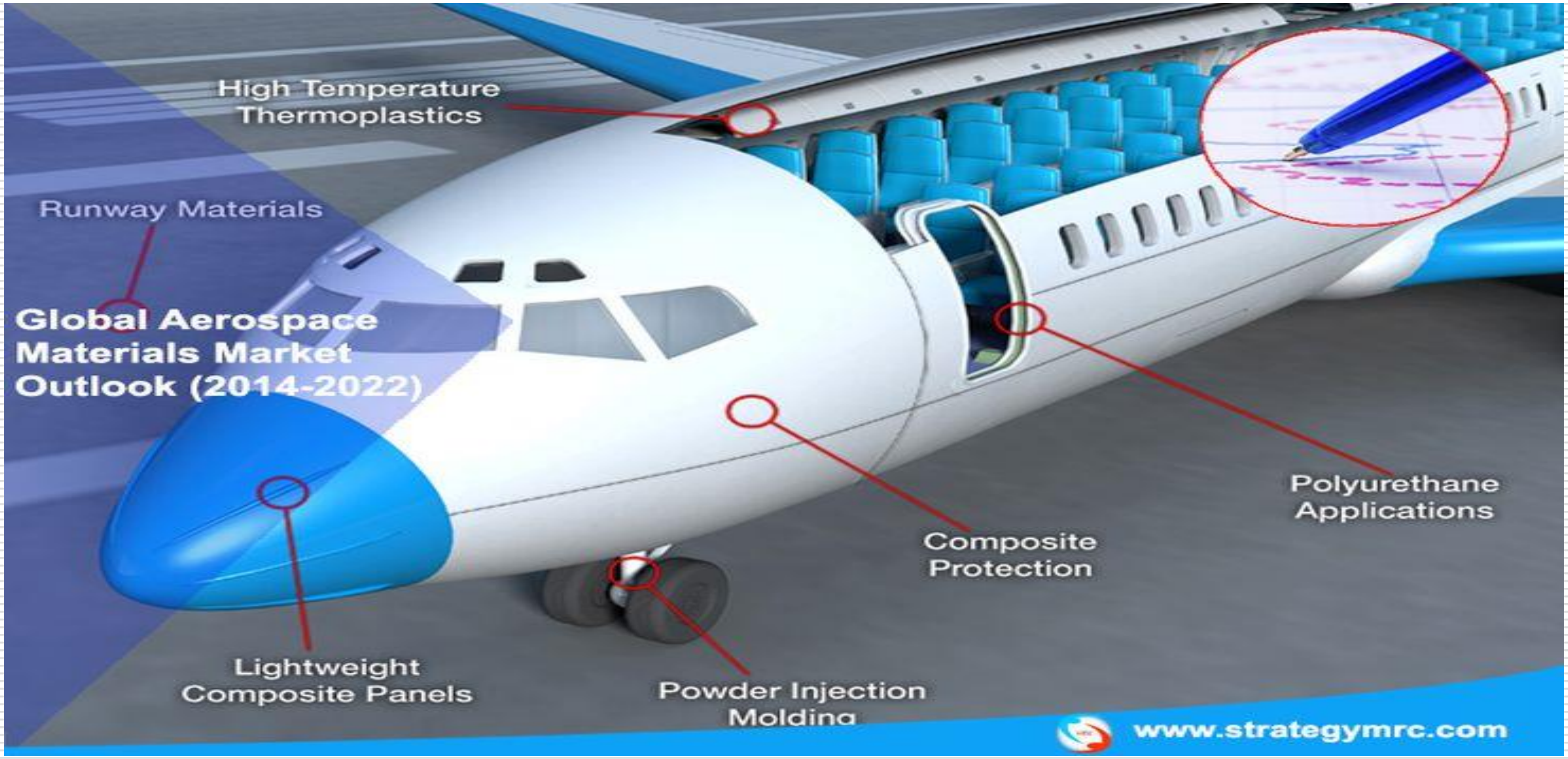
Aerospace Materials

- While CFRPs represent the lion's share of composite material in both cabin and functional components, and honeycomb materials provide effective and lightweight internal structural components, next-generation materials include ceramic-matrix composites (CMCs), which are emerging in practical use after decades of testing.
- CMCs are comprised of a ceramic matrix reinforced by a refractory fiber, such as silicon carbide (SiC) fiber.
- They offer low density/weight, high hardness, and most importantly, superior thermal and chemical resistance.

Aerospace Materials



Aerospace Materials



THANK YOU