POLYMERS

Polymers:

- Combination of many monomers is called polymers.
- Polymers are organic materials having carbon as the common element in their makeup.

Characteristics/ properties of polymers:

The properties of polymers vary with the molecular structure, degree of polymerization etc., some of the properties are described below:

1. Low density
2. Good corrosion resistance
3. Low coefficient of friction
4. Good mouldability
5. Can be produced with close dimensional tolerances
6. Excellent surface finish can be obtained
7. Economical
8. Poor tensile strength
9. Low mechanical properties.
10. plastics have comparatively low thermal conductivity
11. Thermal expansion of plastics is very high (approximately five times thermal expansion of aluminum and other metals) . This is the main disadvantage of plastics.
12. Electrical properties: plastics are good electrical insulators.

Types of polymers:

Polymers are classified in to two types: (1) Thermoplastics (Thermoplastic polymers)
(2) Thermosets (Thermoset polymers)

Differences between thermoplastics and thermosetting plastics:

Sl. No.	Thermoplastics	Thermosetting plastics
1	These polymers when molded once can be soften by heating Examples: PVC and Polythene	These polymers when molded once cannot be soften by heating Examples: Bakelite.
2	Thermoplastics can be recycled	Thermosetting plastics cannot be recycled
3	These polymers have resale value	These polymers don't have resale value
4	Thermoplastics can be reshaped	Thermosets can't be reshaped
5	Thermoplastic polymers are usually having linear structures (some have branched structure with flexible chain)	these have cross linked and network structures
6	These polymers can be reused and recycled hence these are economical	These polymers can not be reused and recycled hence these are not economical
7	There are relatively soft and ductile	These polymers are harder, stronger and more brittle than thermoplastics.

8	These have less dimensional stability compared to thermosetting plastics.	These have good dimensional stability.
9	These polymers won`t decompose if heated to excessive temperatures.	These polymers decompose if heated to excessive temperatures.
10	These are soluble in organic solvents.	These are insoluble in organic solvents

Applications of polymers:

- Automotive polymer materials and plastics are essential in the design and manufacture of automotive components. From door panels, flooring and engine components, light weight plastic materials help to realize better fuel efficiency and allow engineers to create innovative designs that are durable and strong, yet attractive.

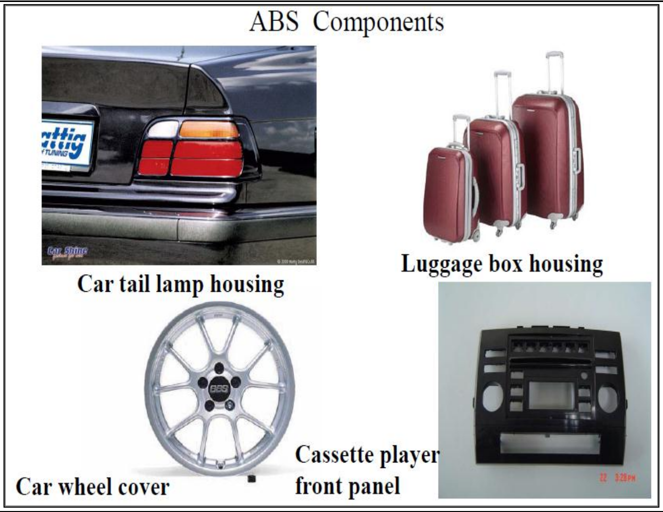
Characteristics and typical applications of few plastic materials.

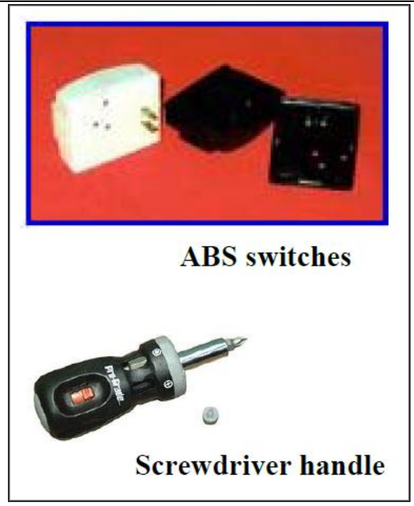
a) Thermo plastics

1. Acrylonitrile-butadiene-styrene (ABS):

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

Application: Refrigerator lining, lawn and garden equipment, toys, highway safety devices, ABS switches, screwdriver handle.





2. Acrylics (Poly-Methyl-Methacrylate (PMMA))

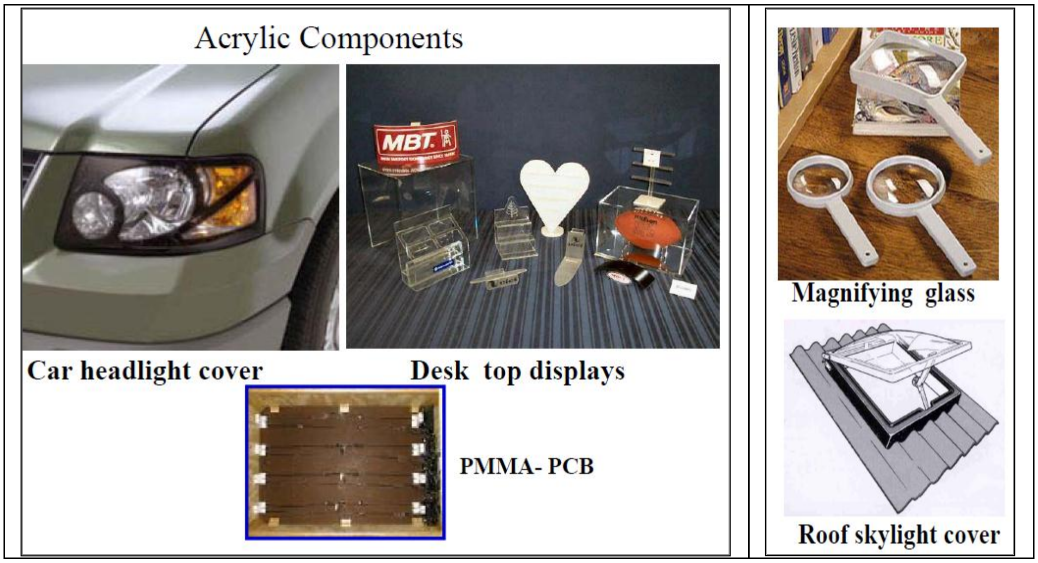
Acrylate polymers belong to a group of polymers which could be referred to generally as plastics. They are noted for their transparency, resistance to breakage, and elasticity. They are also commonly known as acrylics or polyacrylates. Methacrylates are common monomers in polymer plastics, forming the acrylatepolymers.

Poly-Methyl-Methacrylate (PMMA) is a clear plastic, used as a shatterproof replacement for glass.

Characteristics: Outstanding light transmission and resistance to weathering; only fair mechanical properties.Good optical properties, Resistance to wear and chemicals, Transparent (Opaque) and have good electrical resistance.

E.g.: Lenses, lighted signs, displays, window glazing, automotive lenses, wind-shields, lightning fixtures and furniture

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



3. Fluorocarbons (PTFE or TFE)

TEFLON: (POLY TETRA FLOURO ETHYLENE):

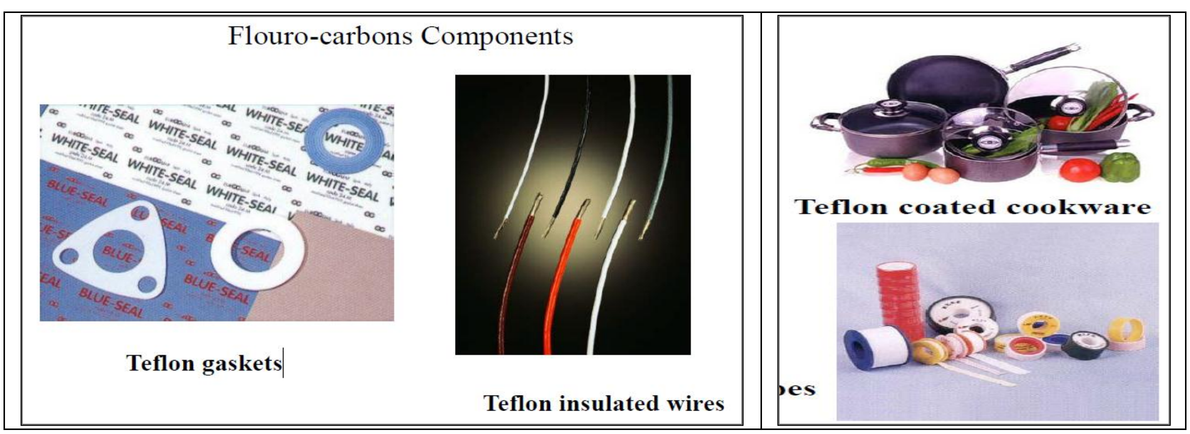
Tough material resistant to heat and chemical actions such as acids and bases. It is an addition polymer of tetra flouro ethylene.

USES:

It is used as a material resistant to heat and chemical attack in household works. For coating articles and cookware to make them non-sticky as non stick utensils. For making gaskets, pump packaging, valve, seals, non-lubricated bearings, etc.

Application: Linings for chemical process equipment, nonstick coatings for cookware, electrical insulation for high temperature wire and cables, gaskets, low-friction surfaces, bearings and seals

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



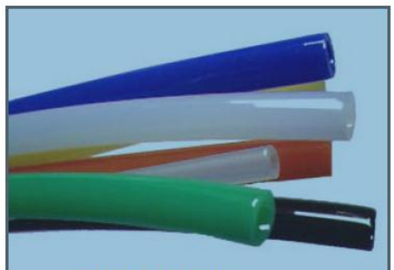
4. Polyamides (nylons) (poly, amine, carboxyl acid)

A polyamide is a macromolecule with repeating units linked by amide bonds. A peptide bond (amide bond) is a covalent chemical bond linking two consecutive amino acid monomers along a peptide or protein chain.

Polyamides occur both naturally and artificially. Examples of naturally occurring polyamides are proteins, such as wool and silk. Artificially made polyamides can be made through step-growth polymerization or solid-phase synthesis yielding materials such as nylons, aramids.

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

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



Nylon tubing

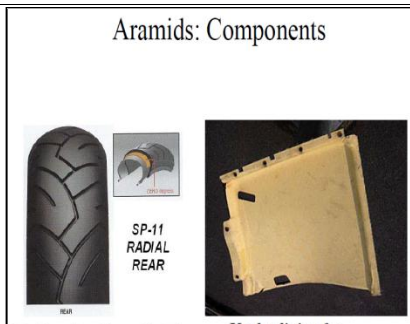
Aramids (aromatic polyamides):

Have very high tensile strength, Good stiffness.

Typical applications - Fibers for reinforced plastic, bullet proof vests, cables and radial tyres.

Kevlar bullet proof vests

Kevlar safety gloves



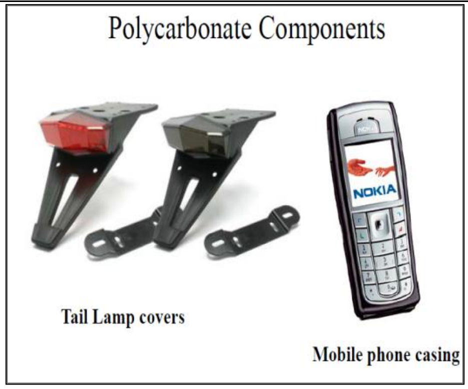
Kevlar wires for radial tires

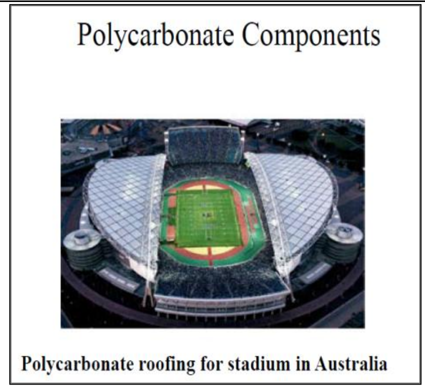
Kevlar lining for bulletproof car door

5. Polycarbonates

Characteristics: Dimensionally stable: low water absorption; transparent; high impact and chemical resistance.

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

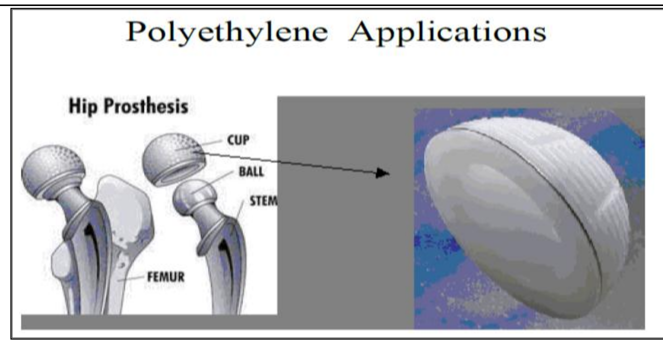




6. Polyethylene

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

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



7. Polypropylene

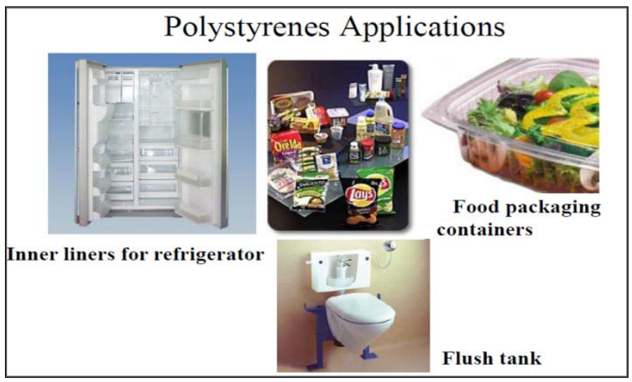
Characteristics: Resistant to heat distortion; excellent electrical properties and fatigue strength; chemically inert; relatively inexpensive; poor resistance to UV light.

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

8. Polystyrene

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

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



9. Polyester (PET or PETE)

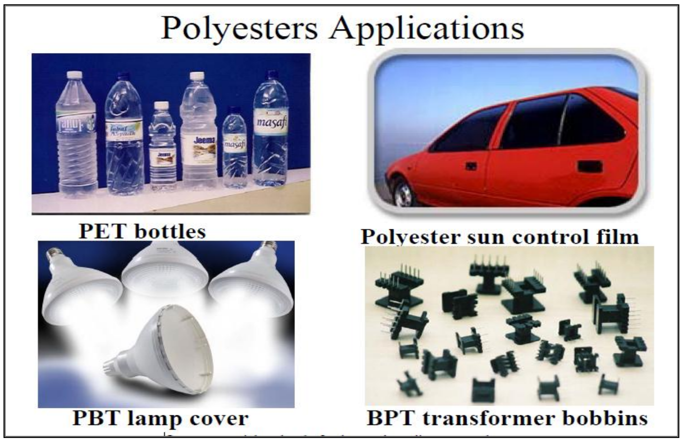
Polyester resins combine excellent mechanical, electrical and thermal properties with very good chemical resistance and dimensional stability. Polyesters also offer low moisture absorption and have good flow properties.

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

PBT (Polybutylene terephthalate), PET (Or) PETE (Polyethylene terephthalate).

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

BPT – Balanced Power Technologies transformers.

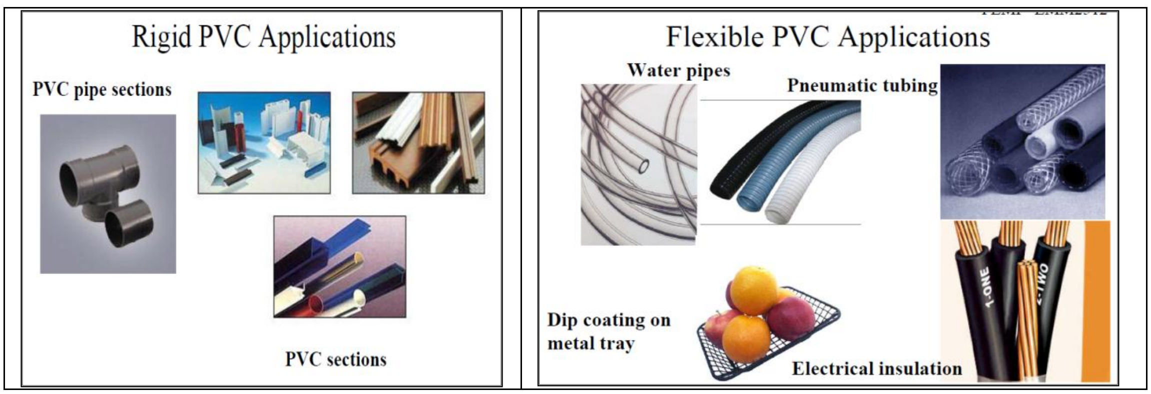


10) POLY VINYL CHLORIDE (PVC):

Its monomer unit is vinyl chloride. It is prepared by heating vinyl chloride in an inert solvent in the presence of peroxides (eg.Dibenzoyl peroxides).It is a hard horny material. It is a thermoplastic polymer and its plasticity can be increased.

USES:

It is used in manufacturing of rain coats, hand bags, curtain clothes, toys, Artificial flooring.As a good insulating material in wires and other electrical goods.For making gramophone records.



b) Thermo setting polymers

1. Epoxies

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

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

2. Phenolics

Although brittle, are rigid and dimensionally stable; Resistant to heat, water, chemicals and electricity; Used as bonding materials to hold abrasive grains together in grinding wheels

Characteristics: Excellent thermal stability to over 150^{o}C; may be compounded with a large number of resins, fillers, etc.; inexpensive.

Application: Motor housing, telephones, auto distributors, electrical fixtures,Handles, knobs, laminated panels, electronic components (insulators, wiring devices)

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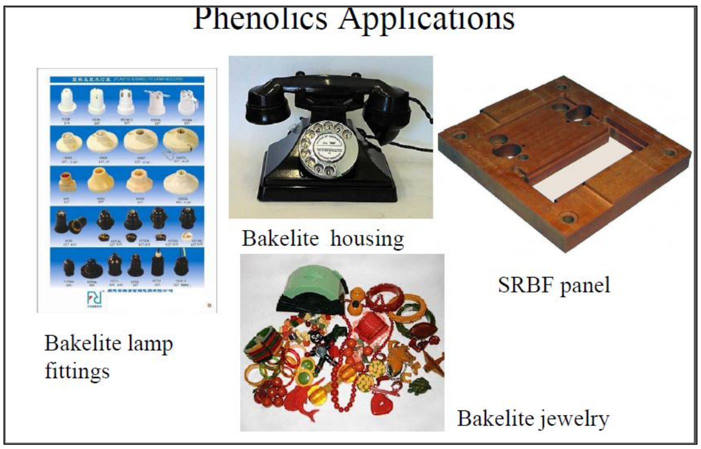


Advantages of Polymers

- Resistance to corrosion and chemicals
- Low electrical and thermal conductivity
- Low density, high strength-to-weight ratio
- Noise reduction
- Wide choice of colors and transparencies avaiable
- Ease of manufacturing and complexity of design possibilities
- Relatively low cost

CERAMICS

Ceramics are inorganic compounds of metallic and non-metallic elements. Ceramic is derived from Greek word , Keramikos which means 'burnt stuff .

Characteristics of Ceramics:

- Low density compared to metals
- High melting point or decomposition temperature
- High hardness and very brittle
- High elastic modulus and moderate strength
- Low toughness
- High electrical resistivity
- Low thermal conductivity
- Thermal Shock resistance
- High corrosion resistance

Main drawback is brittleness and low toughness.

Classification of ceramics:

Ceramics are classified based on function, structure and type of product. They are listed as follows.

(i) Functional classification

- Abrasives – Alumina, carborundum
- Pure oxide ceramics – Mgo, Al_2O_3, Sio_2
- Fire clay products – bricks, tiles, etc.
- Inorganic glasses – window glass,
- Cementing materials – port land cement,
- Rocks
- Minerals
- Refractories - silica bricks

(ii) Structural classification

- Crystalline ceramics
- Non crystalline ceramics
- Glass bonded ceramics
- Cements

(iii) Classification based on the products:

- Whitewares
- Bricks and tiles
- Cements and concretes
- Abrasives
- Glass
- Insulators
- Refractories

Applications of ceramics:

- Used in cutting tools
- In spark plug insulators (Silicon Nitride).
- Glass windows (early 1920s).
- Ceramic oxygen sensors are used in concert with computer controls to optimize combustion and reduce exhaust emissions.
- Computer controls and other electronics in automobiles use a large number of ceramic substrates and components which are critical to the performance of the devices.
- Ceramic clutch
- Piezoelectric sensors: Air bag sensor, air flow sensor, audible alarms, fuel atomiser, keyless door entry, seat belt, buzzers, knock sensors
- Ceramic magnets are used in many of the electrical motors in modern cars for automated adjustment of seats, windows, etc.
- Ceramic components have been introduced in fuel systems and valve trains of heavy-duty diesel engines
- Ceramic composite brake rotors, standard equipment of Formula One race cars, are now used in high-performance passenger vehicles.
- Ceramic brakes reduce vehicle weight, resist heat-induced fading and are expected to last the life of the vehicle.
- Gas-turbine engine components (as rotors) : silicon nitride, silicon carbide, and partially stabilized zirconia.
- Used in electronic and electrical appliances (because of their high electrical resistance and high dielectric strength)
- Cylinder liners, engine antiwear coatings and also scratch proof coatings on automotive bodies.
- Bushings and Seals
- Used in Solid Oxide Fuel Cells (SOFs)
- Space Shuttle tiles (because of their low thermal conductivity, high temperature capability (up to 1400^{o} C)
- Replacement of joints in human body (because of their bio-compatibility)

COMPOSITE MATERIALS

Composite: Definition

- COMPOSITE is a combination of two or more materials, which comes from metals, polymers or ceramics.

Examples of composites:

Pearlite steels, Concrete: RCC (Reinforced Cement Concrete): Vehicle tyres:

Natural composites:

Wood: it consists of strong and flexible cellulose fibres surrounded and held together by a stiffer material called lignin.

Other examples wood, bamboo, banana, bone etc.

Properties of composite materials:

Some of the properties that can be improved by forming composite materials are : Strength , stiffness, corrosion resistance, wear resistance, attractiveness, weight, fatigue life, thermal insulation, thermal conductivity, acoustical insulation, temperature – dependent behavior.

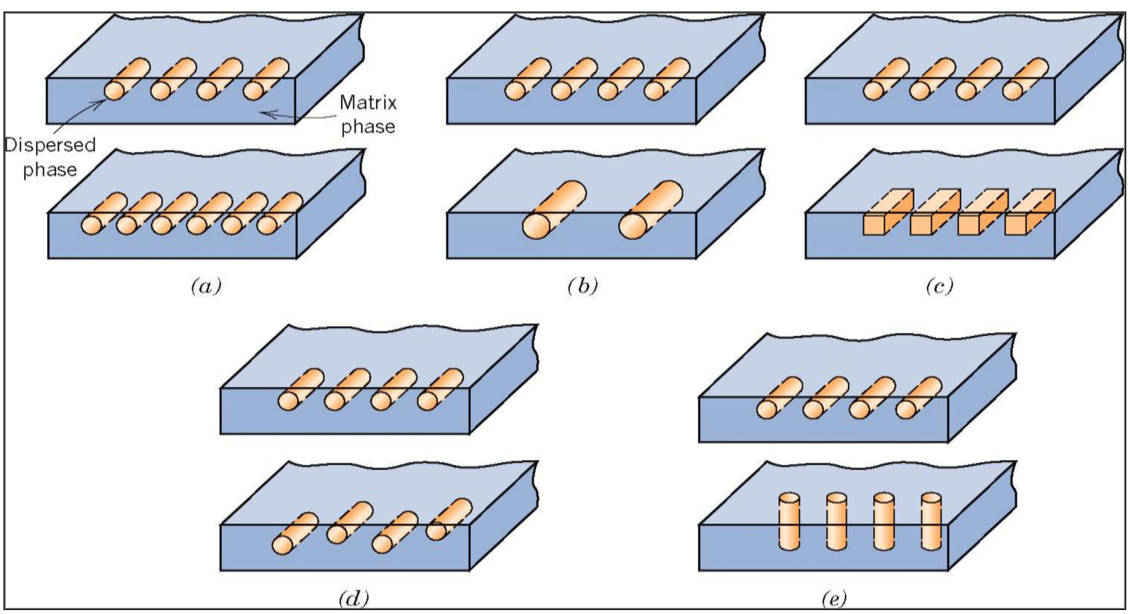
Components in a Composite Material:

Nearly all composite materials consist of two phases: reinforcing phase and matrix phase.

- the reinforcing phase is embedded in the matrix phase.

The reinforcing phase may be in the form of fibers, sheets, particles, or various other geometries. The reinforcing material and the matrix material can be metal, ceramic, or polymer.

These two phases can be seen in the following figure.



Functions of the Matrix Material (Primary Phase):

- Protect reinforcement phase from environment.
- Transfer Stresses to other phases
- Holds the embedded phase in place.
- Protect the surface of the fibers from mechanical abrasion.
- Distributes the loads evenly between fibres.

Desired Properties of a Matrix:

- Low shrinkage.
- Low coefficient of thermal expansion.
- Must be elastic to transfer load to fibres.
- Reasonable strength
- Good Strength at elevated temperature (depending on application).
- Excellent chemical resistance (depending on application).
- Dimensional stability (maintains its shape).

Why Composites are Important?

- Composites can be very strong and stiff, yet very light in weight,
- Fatigue properties are generally better than for common engineering metals
- Toughness is often greater too
- Composites can be designed that do not corrode like steel
- Possible to achieve combinations of properties not attainable with metals, ceramics, or polymers alone
- Specific tensile strength is 4 to 6 times greater than steel or aluminum
- Greater fatigue resistance than steel or aluminum
- Corrosion is significantly reduced

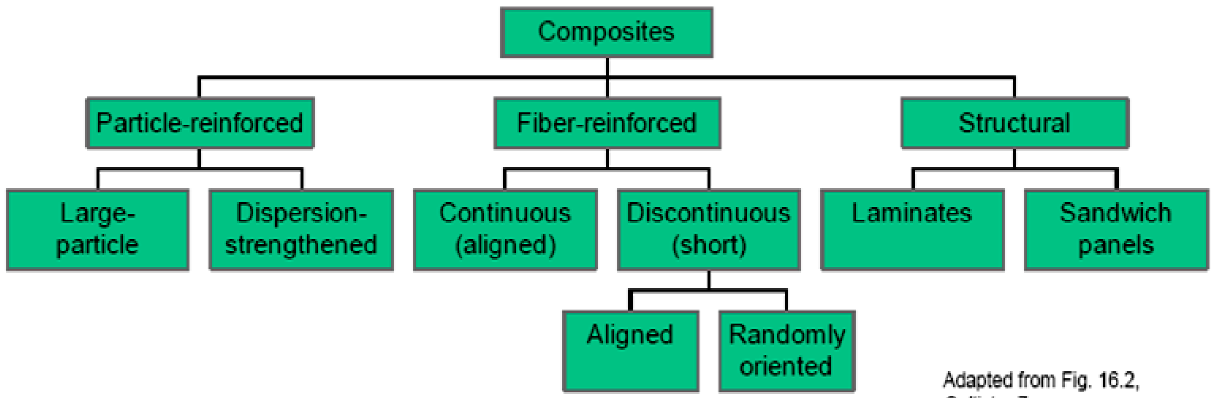
Disadvantages and Limitations of Composite Materials:

- Properties of many important composites are anisotropic (means the properties differ depending on the direction in which they are measured) this may be an advantage or a disadvantage
- Many of the polymer-based composites are subject to attack by chemicals or solvents,
- Composite materials are generally expensive
- Manufacturing methods for shaping composite materials are often slow and costly
- High cost of raw materials and fabrication.

- Transverse properties may be weak.
- Reuse and disposal may be difficult.
- Lack of clear-cut design rules
- Lack of high productivity manufacturing methods
- Analysis is difficult.
- Matrix is subject to environmental degradation.

Classification of composites:

Classification based on reinforcement used is shown in figure below.



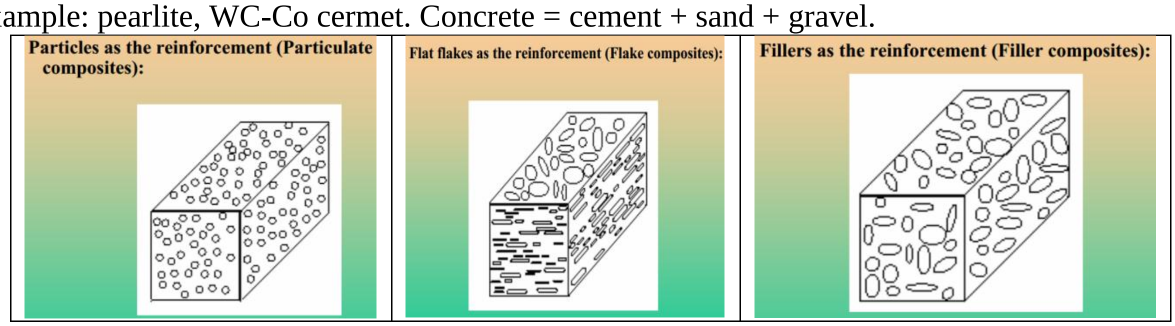
Adapted from Fig. 16.2, *Callister 7e.*

Particle reinforced composite:

Particulate Composites:

In these composites, the reinforcement phase is in the form of particles. The particles are distributed or embedded in a matrix body. The particles may be flakes or in powder form. Flakes are basically two-dimensional particles. The distribution of particles in the composite matrix is random, and therefore strength and other properties of the composite material are usually isotropic.
Concrete and wood particle boards are examples of this category.

Example: pearlite, WC-Co cermet. Concrete = cement + sand + gravel.



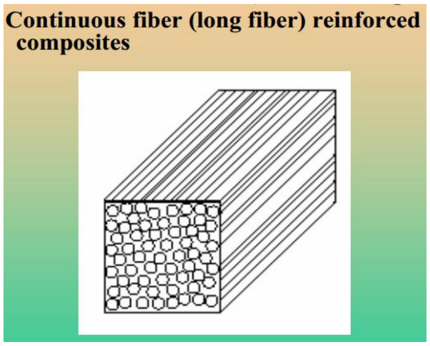
FIBER REINFORCED COMPOSITES:

In these composites, the reinforcement phase is in the form of fibers. Fibers are embedded in matrix body. Its properties depend on geometry and orientation of fiber. Fiber is a filament or thread like piece of any material. Fibers may be of Mineral fibers, Animal fibers, and vegetable fibers. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.

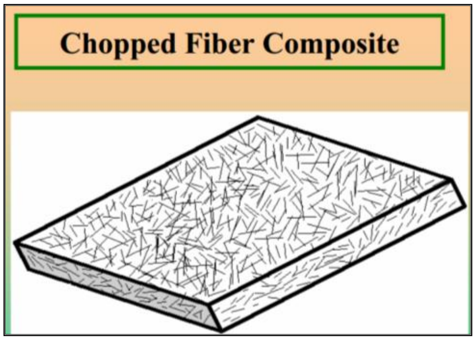
Different forms of fibre are whiskers, fibers and wires.

- Whiskers : these are piece of materials from thin single crystals and is having large length to diameter ratio. These are extremely strong and very expensive.
  Examples: graphite, SiN, SiC
- Fibers: these are piece of materials from polycrystalline or amorphous materials. These are generally polymers or ceramics.
  Ex: Al_2O_3 , Aramid, E-glass, Boron
- Wires: these are piece of materials from metals.
  Examples: steel, Mo, W

Continuous fiber reinforced composite material is shown in figure below.



Chopped Fiber Composite: in this composite, the chopped fibers are embedded in matrix body. It is shown in figure below.



Composite Structures:

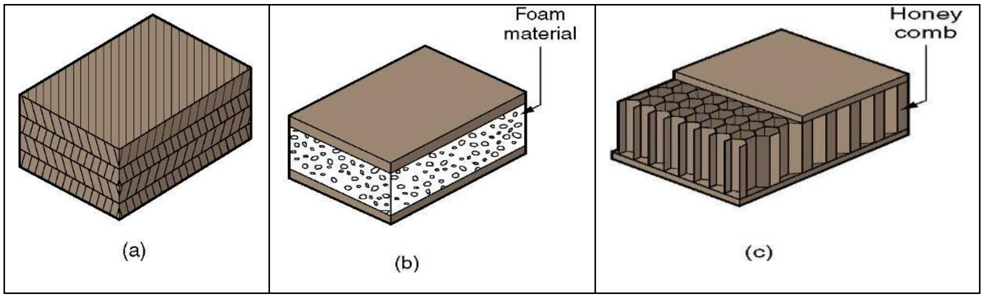
- Laminar composite structure
- Sandwich structure

- Honeycomb sandwich structure

Laminar Composites: are composed of layers of material shield together by matrix. Sandwich structures fall under this category.

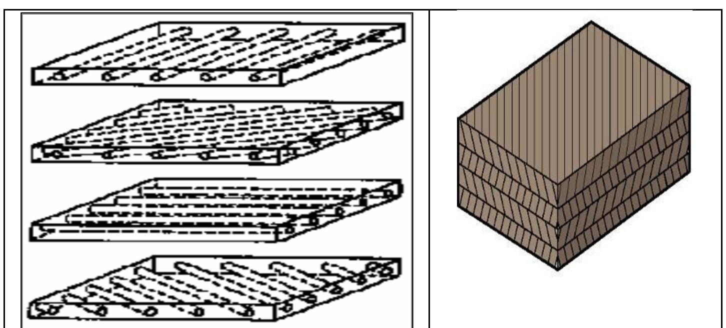
Examples of Laminar Composite Structures:

- Automotive tires - consists of multiple layers bonded together



Lamina (ply): It is a single layer of unidirectional fabric in a matrix.

Laminate: Two or more unidirectional lamina staked together at various orientations is termed as laminate.



four laminae	**laminate composite**

What is laminate? (LAMINATE COMPOSITE)

High stiffness and strength usually require a high proportion of fibres in the composite. This is achieved by aligning a set of long fibres in a thin sheet (a lamina or ply). However, such material is highly anisotropic, generally being weak and compliant (having a low stiffness) in the transverse direction. Commonly, high strength and stiffness are required in various directions within a plane. The solution is to stack and weld together a number of sheets, each having the fibres oriented in different directions. Such a stack is termed a laminate. An example is shown in the diagram.

Composites offer many advantages compared to traditional materials used in corrosion applications.

- **Corrosion Resistance:** FRP composites do not rust or corrode. There are various resin systems available to the fabricator which provide long-term resistance to almost every chemical and temperature environment. Properly designed FRP composites parts have long service life and minimum maintenance as compared to most competitive materials.
- **Inherent Durability:** There are case histories of fiberglass ductwork being in service in chemical manufacturing plants for over twenty-five years – operating in harsh chemical environments twenty-four hours a day, seven days a week. How long do composites last? In many cases, over fifty years and still counting!
- **High strength:** FRP (Fiber Reinforced Polymer) composites are very effective in providing high strength components. FRP composites can be designed to provide a vast range of mechanical properties, including tensile, flexural, impact and compressive strengths. FRP composites are not isotropic, but anisotropic which allows the designer/fabricator to design a laminate with oriented reinforcement to provide strengths in specific areas or direction as the final application requires.
- **Lightweight:** FRP composites have a higher specific strength than many of the materials used in corrosion applications. They can deliver more strength per unit of weight than most metals.
- **Design Flexibility:** FRP composites can be fabricated into virtually any shape a designer may have in mind. A corrosion application can be complex or simple in configuration; large or small; structural, decorative or cosmetic , or all inclusive. FRP composites free designers to try new concepts, from prototype to production.
- **Elevated temperature service:** FRP composite parts fabricated utilizing resins and inert filler technology perform very well in elevated temperature applications.
- **Thermal cycling:** FRP composite parts, in large part due to the polymer matrix selected, operate in applications that experience temperature changes of more than 150º F for extended periods of time without adverse effects.
- **Dimensional Stability:** FRP composites maintain their shape and functionality, even under severe mechanical and environmental stresses. FRP composites typically do not exhibit viscoelastic or “cold-creep” characteristics of thermoplastics. The yield point of FRP composites is generally its break point.
- **High Dielectric Strength:** FRP composites have excellent electrical insulating properties, making them an obvious choice for current carrying applications.

- **Parts Consolidation:** FRP composite parts often have replaced assemblies of many parts and fasteners required for traditional materials such as stainless steel.
- **Ability to Form Shapes:** FRP composites can be formed into complex shapes easier than other competing materials. This ability gives the designer/fabricator the freedom to create any shape or configuration.

Fiber Reinforced Polymer (FRP) Composites:

"A matrix of polymeric material that is reinforced by fibers or other reinforcing material".

Classification of composites based on matrix material used:

- Metal Matrix Composites (MMC)
- Ceramic Matrix Materials (CMM)
- Polymer Matrix Composites, (PMC)/Carbon Matrix Composites or Carbon-Carbon Composites

Metal Matrix Composites (MMCs):

A metal matrix composite (MMC) is a type of composite material with at least two constituent parts, one being a metal. The other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite. An MMC is complementary to a cermet.

Applications:

- Aerospace industry
- Sporting Goods Industry
- Automotive Industry
- Home Appliance Industry

CERMETS :

Cermets: It is a combination of ceramic and metal.

- Cermets are used as Cutting Tools, Dies, Indenters

Cermets can be subdivided into Cemented carbides and Oxidebased cermets. Cemented carbides are commonly used and Oxide based is less commonly used.

Common cemented carbides are based on tungsten carbide (WC), titanium carbide (TiC), and chromium carbide (Cr_3C_2). Tantalum carbide (TaC) and others are less commonly used. Metallic binders used are usually cobalt (Co) or nickel (Ni)

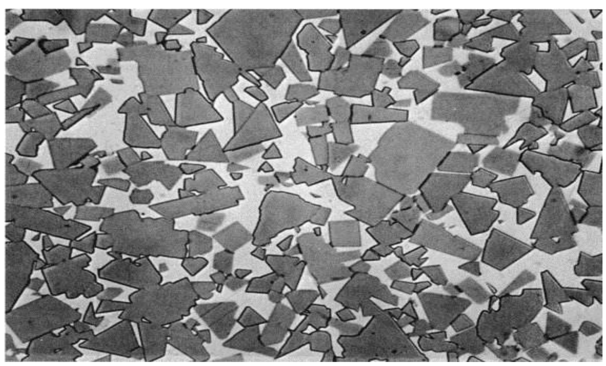
Carbide materials are very hard by their inherent nature. The most common carbides used in the tooling industry are Tungsten Carbide, Titanium carbide and tantalum Carbide. These are formed from powders into sintered forms with different shapes as required.

Sintering is a high temperature process where particles are compacted and under high pressure and temperature, the particles start to fuse together and form a solid (albeit (means though) with some small pores between the particles). Sintered carbides are actually very brittle and tend to break on sudden shocks which are prone to happen in machining if the tool encounters a hard inclusion or a cavity during the process.

In cemented carbides, a metal binder material is added to the carbide particles during the sintering process which gets into the gaps between the fused carbide particles and acts as a binder and cements (meaning is binds) the particles together. They act as a toughener due to the metals inherent ductility, offering improved tool life in machining. The metal used is most commonly Cobalt (Co).

Cemented carbides are hence carbides cemented in a metal.

Photomicrograph (about 1500X) of cemented carbide with 85% WC and 15% Co



In the above figure the particles are tungsten carbide and white space is cobalt. Cobalt acts as matrix metal. Hence above cermet is a metal matrix composite.

Applications of Cemented Carbides:

- Tungsten carbide cermets (Co binder) - cutting tools, wire drawing dies, rock drilling bits and mining tools, dies for powder metallurgy, indenters for hardness testers.
- Titanium carbide cermets (Ni binder) - high temperature applications such as gas-turbine nozzle vanes, valve seats, thermocouple protection tubes, torch tips, cutting tools for steels
- Chromium carbides cermets (Ni binder) - gage blocks, valve liners, spray nozzles, bearing seal rings