

For example, 995 fine gold is 99.5% gold, and 925 fine silver (sterling silver) is 92.5% silver.

Throughout history, gold has been exceptionally valuable due to its numerous qualities.

It is highly malleable, durable to the point of virtual indestructibility, and typically found in nature in a comparatively pure form.

Additionally, it is attractive in colour and luminosity.



## MODULE -V

## CERAMICS, POLYMERS AND COMPOSITES MATERIALS

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### Introduction:

Heat-resistant, non-metallic, inorganic ceramics are composites of metallic and non-metallic materials. Commonly, ceramics are hard, corrosion-resistant, and brittle. Most ceramics insulate well and resist high temperatures. They are used in almost every facet of modern life due to their qualities. The main ceramic categories are conventional and advanced. Traditional ceramics are comprised of clay and cements that have been hardened through high temperatures. Traditional ceramics are used for plates, kitchenware, flowerpots, roof and wall tiles. Advanced ceramics include carbides like SiC, oxides like Al<sub>2</sub>O<sub>3</sub>, nitrides like Si<sub>3</sub>N<sub>4</sub>, and many others, including mixed oxide ceramics that can behave as

superconductors. Medical and engineering improvements have resulted from contemporary ceramic processing processes. Glass is occasionally ceramic. Ceramics are crystalline, while glasses include impurities that hinder crystallization. Amorphous glasses are like liquids. Ceramics have high, well-defined melting points, while glasses soften throughout a range of temperatures before becoming liquids. Ceramics are opaque to visible light, while glasses are translucent. Glass ceramics are made of several small crystalline areas in a non-crystalline substrate. This structure provides them ceramic and glass characteristics. When heated, glass ceramics expand less than most glasses, making them ideal for windows, wood stoves, and radiant glass-ceramic cooktops.

## Composition:

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Some ceramics have two components. Alumina and zirconia are aluminum oxide,  $\text{Al}_2\text{O}_3$  and  $\text{ZrO}_2$ , respectively. Ceramics are good insulators and can resist high temperatures. Artwork with ceramics is popular.  $\text{SiO}_2$ . Numerous minerals and other ceramics have complicated and varied compositions.  $\text{KAlSi}_3\text{O}_8$  is the formula for granite's ceramic material feldspar. The chemical bonding in ceramics can be covalent, ionic, or polar covalent, depending on their composition. The bonding is mostly ionic when the ceramic components are a metal and a nonmetal, such as  $\text{MgO}$  and  $\text{BaTiO}_3$ .  $\text{BN}$  and  $\text{SiC}$  are covalent ceramics made of a metalloid and a nonmetal. Unit cells, three-dimensional units, are repeated throughout most ceramics' extremely crystalline structure. In rock salt, magnesium oxide crystallizes. Along each perpendicular axis,  $\text{Mg}^{2+}$  and  $\text{O}^{2-}$  ions alternate in this arrangement.

## Manufacture of Traditional Ceramics:

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Traditional ceramics are manufactured from clay that has been baked by high temperatures, which drives away water and forms strong chemical bonds between the flakes. The word “ceramic” derives from the Greek word “keramos,” meaning “burnt earth.” Clay, typically blended with other materials, is molded by artists to create ceramic sculptures. Kiln ovens heat and solidify shaped objects “fire” them. Clay is made of several microscopic flat plates layered and separated by thin water layers. Water helps the plates stick together and slide by lubricating them. Clay is easily formed. High temperatures remove water and build connections between plates, keeping them in place and forming a hard solid. Bone ash is added to clay to strengthen bonding and make ceramics break-resistant. Due to iron oxides, flowerpot and roof tile clay is red-orange. Kaolin, a rare and expensive white clay, is used to make white pottery. Figurines from former Czechoslovakia are the oldest known human-made pottery, dating to 27,000 B.C.E. To create figurines, clay was mixed with bone, animal fat, soil, and bone ash, molded into desired shapes, and cooked in a domed pit. Ancient Greece and Egypt made pots, dishes, and storage vessels from 9000 to 6000 B.C.E. White porcelain was a major advance. Porcelain is stronger and less fragile than previous ceramics. Strong enough to make elegant containers with translucent walls. Kaolin and china stone are heated to 1,300°C (2,372°F) to make it. Chinese blue and white porcelain was refined during the Ming dynasty after the T'ang dynasty produced it approximately 600 C.E. The porcelain method originated in the Arab area in the ninth century and moved to Spain and Europe.

## Manufacture of Advanced Ceramics:

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Advanced ceramic materials are made from finely separated powder blended with an organic binder to consolidate and form. The unfired ceramic body is "green." The binder is decomposed or oxidized by heating the green body at a low temperature. It is "sintered," or hardened, at high temperatures into a dense,

robust ceramic. Chemical bonding form between powder particles at this point. Sintering can shrink ceramic by 10–40%. Because shrinkage is uneven, ceramic may need further machining to get a perfect shape.

## Sol-gel Technology:

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Due to molecular mixing of ions in solution, sol-gel technology produces more homogenous ceramics. A sol-gel technique hydrolyzes an organometallic compound solution to create a "sol," a colloidal suspension of a solid in a liquid. A metal alkoxide like tetramethoxysilane in alcohol is typical. Sols occur when formula units polymerize into chains and networks. The sol can be prepared as a thin film, microspheres, or a gel in a mold to create a ceramic object with the appropriate shape. Many cross connections between formula units make this ceramic less fragile. The sol-gel process is expensive, but it allows the ceramist to control porosity and form films, spheres, and other structures that are hard to mold, as well as specialized ceramic compositions and high product purity. Sol-gel creates porous ceramics. These ceramics are sponge-like with many pore-like lacunae, or openings, making up 25–70% of the volume. Pore size ranges from huge to as small as 50 nanometers ( $2 \times 10^{-6}$  inches). Porous ceramics, with their numerous pores, offer high surface areas (up to 500 square meters or 5,382 square feet per gram), making them ideal catalysts. Zirconium oxide, a ceramic oxygen sensor, measures car exhaust air-to-fuel ratios.

**Aerogels** are solid foams created by eliminating liquid during a sol-gel process at high temperatures and low pressures. Aerogels are ideal for spacecraft due to their excellent insulation, low density, and non-melting properties.

## Properties and Uses:

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Ceramics were utilized by persons unfamiliar with their construction for ages. Understanding ceramic structure and qualities allows designers and engineers to create novel ceramics.

Most ceramics are hard, chemically inert, refractory, and poor heat and electrical conductors. Ceramics' densities are low. Ceramics have several uses due to these qualities. Ceramics are utilized as furnace refractories and durable building materials including bricks, tiles, cinder blocks, and others. They are also employed as electrical and thermal insulators in spark plugs, telephone poles, electronics, and spacecraft nose cones. However, ceramics are fragile. A big issue with ceramics is that tiny fractures grow until they break. Ceramic coatings are routinely applied to inexpensive crack-resistant materials to avoid cracking. To minimize heat transfer, engine parts are covered with ceramics. Ceramic fiber-embedded polymer composites feature low densities, corrosion resistance, and toughness without brittleness. Tennis rackets, bicycles, and cars use them. Composites can also be created from two ceramic materials as separate ceramic phases. Cracks won't spread between phases. Thus, the composite material resists cracking well. Spacecraft nose cones are built of composite ceramics from zirconium and hafnium diborides and carbides combined with silicon carbide. Break-resistant ceramic composite cookware has excellent thermal shock resistance.

## Structure and Properties:

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Ceramic materials' qualities depend on atom kinds, bonding, and atom packing. Known as atomic scale structure. Most ceramics are multi-element. This is compound. Alumina ( $\text{Al}_2\text{O}_3$ ) is an aluminum-oxygen combination. Chemical bonds hold ceramic atoms together. Ceramic materials use covalent and ionic bonding most often. Chemical bonds in metals are called metallic bonds. Atoms link stronger in covalent and ionic bonds than metallic bonds. Metals are ductile and ceramics brittle because of this.

Microstructure affects a material's final properties. The microstructure of a material can be observed using a microscope but not by the human eye. Ceramic microstructures can be glassy, crystalline, or a mix of both. The glassy phase bonds tiny crystals in the last case. The atomic structure mostly affects chemical, physical, thermal, electrical, magnetic, and optical properties. The microstructure affects

these parameters, although mechanical properties and chemical reaction rate are most affected. Ceramic materials are used in many ways due to their versatility.

Ceramics are typically hard, wear-resistant, brittle, refractory, thermal and electrical insulators, nonmagnetic, oxidation-resistant, thermal shock-prone, and chemically stable.

There are several exceptions to these generalizations. For instance, borosilicate glasses, certain glass ceramics, and NZP ceramics are thermal shock-resistant and used in ovenware, stove tops, and kiln furniture. Some ceramics are good electrical conductors, and ferrites and their magnetic properties drive a commercial market.

## Overview of Ceramic and Glass Manufacturing:

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Ceramics are made by heating clays and other natural raw materials to make them stiff. Ceramic products made from natural rocks and minerals require particular processing to control purity, particle size, particle size distribution, and heterogeneity. These factors greatly affect ceramic characteristics. Some ceramics start with chemically produced particles. Controlling these synthetic materials produces powders with specific chemical compositions and particle sizes. The ceramic particles must be shaped next. After adding water and/or binders, the shape is formed. Common ceramic forming methods include extrusion, slip casting, pressing, tape casting, and injection molding. Fire or sintering turns "green" ceramic particles into stiff products. Glazing may be applied to electrical insulators, dinnerware, and tile. Advanced ceramics may be machined and polished to suit engineering design specifications. Glass and ceramics are processed differently. Glass is made by melting silica, lime, and soda ash in a furnace and shaping it into pressed plate, fibers, molded bottle, plate glass, etc. After molten glass is created, it is quickly cooled and "frozen" into the final product. Cutting, etching, coating, grinding, decorating, and heat treating are common glass processing steps. Ceramic and glass manufacturers and suppliers confront issues include raw material availability and cost, labor quality and cost,

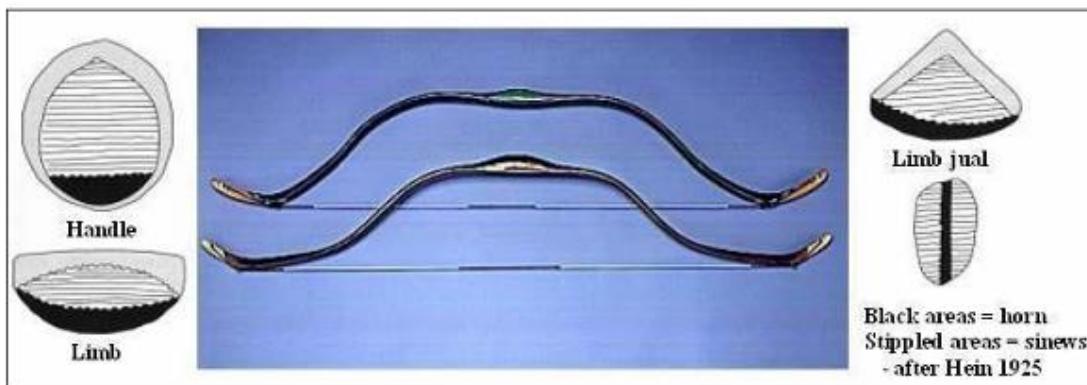
changing markets, quality control, expansion capital, import pressure, and environmental, health, and safety norms.

## Introduction to components:

### Historical Overview / Historical Development:

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Spinning continuous yarns, along with fire and the wheel, is a crucial development that allowed humans to thrive beyond tropical climates and spread throughout the Earth. Locally grown and spun fibers like cotton, flax, and jute provided for flexible textiles, surpassing animal skins. Increasing utilization of natural resources led to the creation of composites, straw-reinforced walls, bows, and chariots built of wood, bone, and horn layers (Figure below). Old composites were replaced by more lasting materials like wood and metal.



## Present:

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In the second half of the 20th century, lightweight composite structures again became popular for various technical solutions after years of neglect. Composites were popular in the latter two decades of the previous century for improving spacecraft and military aircraft structural performance after being utilized mainly for electromagnetic properties (insulators and radar-domes). With improved materials and rising expenses, cost reduction throughout manufacture

and operation is the key technical driver today. Composites are being used to protect humans from fire and impact (Figure below) and are becoming more environmentally friendly, resulting in the return of natural fibers in composite technology (Figure below). By volume and number, composites' success in applications is increasingly evaluated by accessibility and reproductivity of the applied manufacturing techniques.



Following figures both illustrate some examples of how natural fibers can be utilized in various applications.



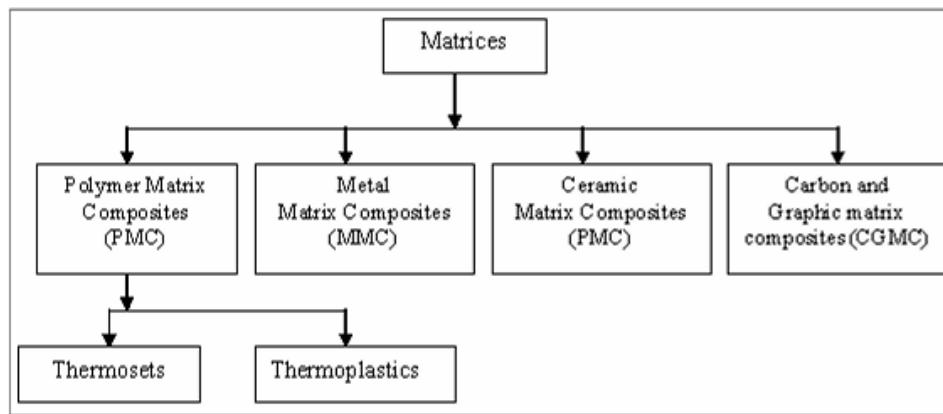
## Concept of Composite:

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Modern composite materials, which are largely structural, are best examples of fibers or particles embedded in matrix. Laminates are composite materials with distinct functions due to their layers. Fabrics lack a matrix, yet fibers of diverse compositions give them character. Reinforcing materials have desirable qualities and can bear maximum stress. Composite kinds are often identifiable, but no definite distinction may be made. The emphasis is typically changed to microscopic

or macroscopic levels to help define. The matrix in matrix-based structural composites binds the reinforcement phases and deforms to distribute stresses among the reinforcement components under strain. Matrixes face several demands. They may be temperature-sensitive, electrical conductors or resistors, or moisture-sensitive. This may offer weight advantages, convenience of handling, and other benefits depending on the purpose of matrices. Potential matrix materials comprise elements that can withstand stress and form strong connections with the reinforcing phase. Several inorganic minerals, polymers, and metals have been successful matrix materials for structural composites. These materials are elastic till failure and have low failure strain in tension and compression.

Composites cannot be created from divergent linear expansion elements. Interface is where reinforcing and matrix materials meet. Regions are sometimes added phases. Each side of an interphase must have two interphases with its neighboring constituent. Interphases form when contrasting elements interact in some composites. The selection of manufacturing method is influenced by matrix qualities and their impact on reinforcing properties. Selecting and making composites requires chemically inert, non-reactive elements. See Figure below for matrix classification.



## Classification of Composites:

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Composite materials are usually divided into two categories:

- The matrix constituent is usually classified first.

Three main composite classifications are Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs), and Ceramic Matrix Composites (CMCs). Organic matrix composites often relate to two types: Polymer Matrix Composites (PMCs) and carbon-carbon composites.

- The second classification level involves reinforcing forms: fiber-reinforced, laminar, and particulate composites. Fiber Reinforced Composites (FRP) can have discontinuous or continuous fibers.
- Fiber Reinforced Composites have fibers in matrix. A discontinuous fiber or short fiber composite has qualities that vary with fiber length. The composite is continuous fiber reinforced when the elastic modulus of the composite does not rise with fiber length. Despite their strong tensile qualities, fibers are tiny and bend easily when forced axially. To prevent bending and buckling, support these fibers.
- Laminar Composites are matrix-held layers of materials. Sandwich structures are included.
- Particulate composites consist of particles embedded in a matrix body. They may be flakes or powder. Wood and concrete particle boards are examples of this group.

## Organic Matrix Composites: Polymer Matrix Composites/Carbon Matrix Composites or Carbon-Carbon Composites:

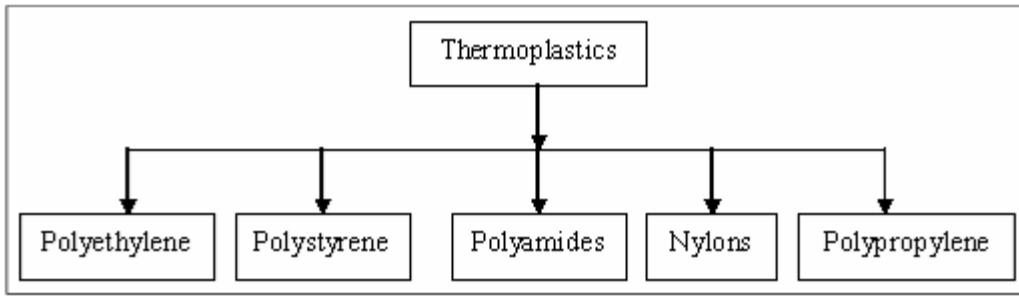
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Polymers are ideal materials due to their lightweight, easy processing, and good mechanical qualities. Thus, high-temperature resins are widely employed in aviation.

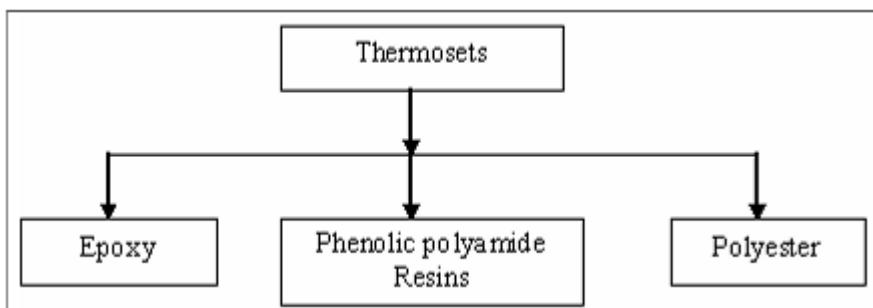
Polymers are mostly thermosets and thermoplastics. Thermosets exhibit a well-bonded three-dimensional molecular structure after curing. Decompose instead of dissolving when hardened. Changing the resin's basic composition changes curing conditions and other properties. Thermosets can remain partially cured for extended durations, making them highly flexible. Thus, they are ideal for advanced fiber reinforced composites as matrix bases. Thermosets are widely used in chopped fiber composites, especially when using premixed or molding compounds with precise fiber quality and aspect ratio, such as epoxy, polymer, and phenolic polyamide resins.

At high temperatures, thermoplastics have an increased melting point because to their one- or two-dimensional molecular structure. Advantages include the ability to reverse softening at high temperatures and restore characteristics during cooling, enabling traditional compression procedures to mold compounds.

Composites reinforced with thermoplastics were appearing. Most efforts in this area aim to improve resin base qualities and maximize functional benefits in innovative ways, such as replacing metals in die-casting processes. In crystalline thermoplastics, reinforcement greatly impacts morphology, enabling nucleation. Whether crystalline or amorphous, these resins can change creep over a wide temperature range. However, resin use is limited in this range, and reinforcing can improve failure load and creep resistance. Following figure depicts thermoplastics.



A little amount of shrinkage and the shape's tendency to preserve its shape must also be considered. However, reinforcements can change this. Plastics systems are better than thermosets since they don't produce gasses or heat through chemical reactions. Time spent heating, shaping, and cooling structures limits manufacturing. As molding compounds, thermoplastic resins are sold. Fiber reinforcement suits these resins. Randomly distributed fibers make the reinforcement practically isotropic. They can be oriented directionally during molding. Several methods can increase thermoplastic heat resistance. Fillers increase heat resistance. But all thermoplastic composites lose strength at high temperatures. However, thermoplastics' rigidity, toughness, and creep resistance make them valuable composite materials. In automobile control panels, electronic product encasing, etc. New breakthroughs promise thermoplastics' expanded applications. Massive sheets of reinforced thermoplastics can be sampled and heated to shape. This makes making big components easier, eliminating molding chemicals. Thermosets are the most prevalent fiber composite matrix, without which structural engineering research would suffer. Aerospace, automotive, and defense systems use these fiber composites extensively. PCBs and other applications use epoxy matrix materials. Some thermosets are shown in Figure below.



Most thermoset resins are produced through direct condensation polymerization and rearrangement processes to create heterocyclic units. Using water as a reaction product in both processes can hamper the creation of void-free composites. These voids reduce composite strength and dielectric characteristics. Polyesters phenolic and epoxies are major thermoset resins.

Prepress-moldable epoxy resins are popular in filament-wound composites. Despite chemical attacks, they are good adherents with modest shrinkage during curing and no volatile gas emissions. Due to these benefits, epoxies are pricey. Note that they cannot be predicted above 140°C. In high-tech sectors with greater service temperatures, their use is not recommended.

Polyester resins are available, affordable, and versatile in various applications. Liquid polyesters can be maintained at room temperature for months or years, and a catalyst can cure the matrix material quickly. They are utilized in cars and structures.

Curing polyester makes it translucent and hard or flexible. Polyesters resist chemicals and weather. These resins can be utilized up to 75°C or more, depending on their formulation or service requirements. Polyesters are compatible with few glass fibers and can be used with reinforced plastic accessories.

Aromatic polyamides are ideal for advanced fiber composites in structural applications requiring continuous exposure at 200-250°C for extended periods.

## Metal Matrix Composites (MMC):

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Metal matrix composites are popular in research but less popular in practice than plastic composites. Metal matrices give superior strength, fracture toughness, and stiffness compared to polymers. They can resist higher temperatures and corrosive environments than polymer composites. Many metals and alloys can serve as matrices, but they need stable reinforcement materials that are non-reactive and temperature-resistant. The selection process is mostly influenced by the matrix material. Light metals create the temperature matrix, and the reinforcements have high moduli together with the above causes. Most alloys

and metals are good matrices. Practically, low-temperature applications have few options. Only light metals are sensitive, and their low density helps. Current matrix metals include titanium, aluminum, and magnesium, which are helpful for aviation. High modulus reinforcements are needed for strong metallic matrix materials. Composites can have greater strength-to-weight ratios than most alloys. Composite service temperatures depend on their melting point, physical, and mechanical qualities. Low melting point alloy matrices work with most metals, ceramics, and compounds. Increased matrix material melting temperature limits reinforcing choice.

## Ceramics Matrix Materials (CMM):

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Ceramics are solid materials with strong ionic and occasionally covalent bonding. High melting points, corrosion resistance, stability at high temperatures, and high compressive strength make ceramic-based matrix materials ideal for structural applications over 1500°C. Ceramic matrices are ideal for high-temperature applications. Most ceramics have high modulus of elasticity and low tensile strain, making reinforcements ineffective. The matrix's insufficient elongation prevents the composite from transmitting an effective load to the reinforcement at stress levels where ceramics rupture, and the composite may fail unless the fiber volume % is high enough. Reinforcement uses fiber's increased tensile strength to boost matrix load bearing capability. High-strength fiber added to a weaker ceramic has often resulted in a weaker composite.

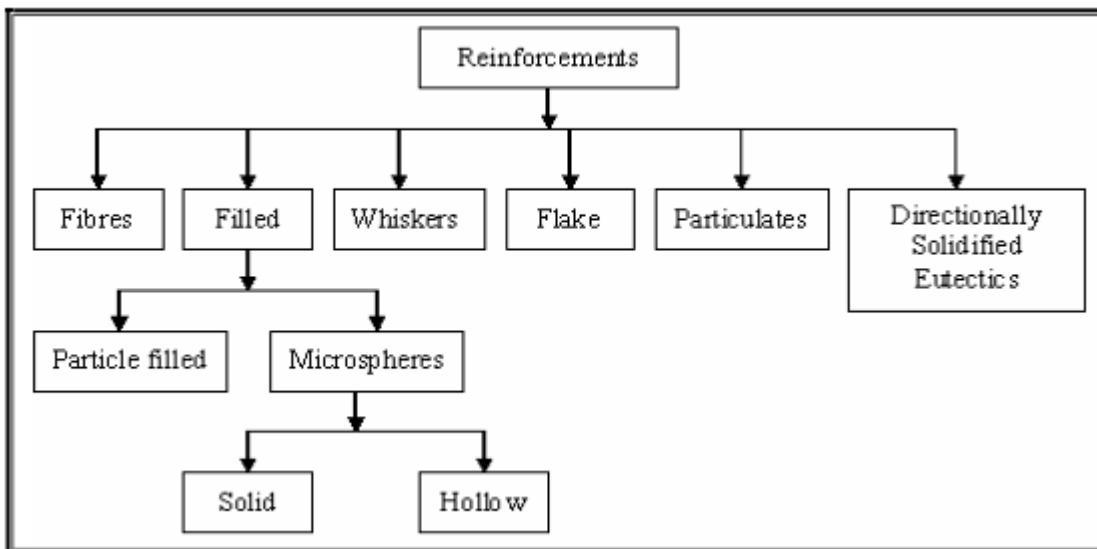
Using reinforcement with high modulus of elasticity may alleviate the issue, and pre-stressing the fiber in the ceramic matrix is becoming a more popular solution.

Composites made from ceramics with a higher thermal expansion coefficient than reinforcing materials are unlikely to be stronger. When cooled, the composite will strengthen within ceramic, causing microcracks from fiber to fiber in the matrix. Microcracking can diminish the tensile strength of a composite compared to the matrix.

## Classification (Based on Reinforcement):

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These include fibers, fabric particles, and whiskers. Fibers typically have one long axis and two circular or near circular axes. Neither particle orientation nor form is desired. Whiskers are shorter and narrower than fibers but have a preferred form. Composite reinforcement types are shown in Figure below.



Reinforcing elements in composites offer the strength that defines the composite. Additionally, they offer heat resistance, corrosion resistance, and stiffness. As needed, reinforcement can accomplish all or some of these functions. For reinforcement to enhance matrix strength, it must be stronger and stiffer than the matrix and capable of modifying failure mechanisms to benefit the composite. This means the composite should be brittle and have little ductility.

## Fiber Reinforced Composites / Fiber Reinforced Polymers (FRP) Composites:

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Fibers are crucial reinforcements because they meet the desired requirements and transfer strength to the matrix constituent, improving their

qualities. Glass fibers were the first reinforcement fibers. Ceramic and metal fibers were discovered and widely used to stiffen and heat-resistant composites. Several variables reduce fiber performance. Fiber composite performance is determined by fiber length, shape, orientation, composition, and matrix mechanical properties. Fiber orientation in the matrix determines composite strength, with longitudinal fiber orientation being strongest. This doesn't mean longitudinal fibers can take the same load in any orientation. For optimal performance, load longitudinal fibers along their direction. The tiniest loading angle change can greatly affect composite strength. Unidirectional loading is rare hence it's recommended to mix fiber orientations in composites, especially where the load is predicted to be the heaviest. Continuous or discontinuous monolayer tapes can be layered into plies with filaments aligned in the same direction. Today, computers can project more complex orientations for specific needs. Thus, planar composites can shift strength from unidirectional fiber-oriented composites with approximately isotropic characteristics.

Angle-plyed composites may exhibit non-isotropic properties depending on the number and direction of plies. Composite variables are believed to have a constant ratio, and matrices are weaker than fibers. Assuming equal volume percentage in all three axes, the fiber's strength in any one axis would be one-third the unidirectional fiber composite. Short fibers can be oriented by random sprinkling on a plane or by adding matrix in liquid or solid form before or after fiber deposition. Even three-dimensional orientations can do this. Several methods of random fiber orientations produce two-dimensional composites with one-third the strength of a unidirectional fiber-stressed composite in the fiber direction. The composite would have a comparable ratio of less than one-fifth in 3D. Moduli and strengths within strong matrices have not been seen.

The strength of composites with various matrices and orientations can be utilized. To compute longitudinal strength in composites with strong matrix and non-longitudinally oriented fibers, assume fibers have been reduced to their effective strength on approximation. Fiber composites can use continuous or short fibers. Continuous fibers (filaments) have better orientation, but not performance. Fibers have a high aspect ratio, meaning their lengths are several times larger than their effective diameters. Filaments are made continuously for this reason.

Well-known mass production of filaments matches with numerous matrices in winding, twisting, weaving, and knitting, which exhibit fabric qualities. Filaments and other fibers have low densities and high strengths; hence their fiber lengths affect composites' mechanical properties and processing responsiveness. Shorter fibers with suitable orientation can make composites of glass, ceramic, or multi-purpose fibers stronger than continuous fibers. The theoretical strength of short fibers is known. Composites commonly link continuous fibers using filament winding, where the matrix impregnated fiber is wrapped around a mandrel shaped like the part.

Short-length fibers incorporated by open or close molds are less efficient than filament winding, despite reduced input costs.

Most fibers in use are solids with a circular cross-section, making them easy to create and handle. However, a few non-conventional shaped and hollow fibers show promise for improving composite mechanical properties. Smaller diameters can increase fiber strength by minimizing or eliminating surface flaws, since the enormous difference in length and effective diameter are benefits to a fiber composite. Fibers with rectangular cross sections offer new choices for high-strength structures after the popularity of flat-thin filaments. Shaped fibers offer optimal packing, while hollow fibers improve structural efficiency for stiffness and compressive strength in composites. When the hollow section is greater than half the fiber diameter, hollow fibers have lower transverse compressive strength than solid fiber composites. They are difficult to handle and make.

## Laminar Composites:

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Laminar composites appear in as many material combinations as materials. They are layers of bound materials. These may have many layers of two or more metal components alternately or in a specified arrangement, in as many numbers as needed. Although clad and sandwich laminates follow the modulus and strength rule of mixes, they have numerous areas as they should. Other intrinsic metal-

matrix, metal-reinforced composite values are also well known. Roll bonding, hot pressing, diffusion bonding, brazing, and other powder metallurgical methods can be used to make sheet, foil, powder, or sprayed alloys. Unlike fiber, high-strength materials are impossible. Two-dimensional sheets and foils are easier to isotropic than fibers. Foils and sheets have high percentages by design. Strong sheets can use over 92% laminar structure, but such fibers are hard to manufacture. Laminates cannot exceed 75% strong fibers. Single-layered metal-metal laminates boast unique features and are cost-effective, but lack high strength or stiffness. They are usually pre-coated or clad.

A thin continuous film of pre-coated metal is generated by layering it on a substrate. Hot dipping and chemical plating or electroplating are used to achieve this. Clad metals are good for denser faces in intense situations. Many sheet-foil pairings are low-temperature adhesives. Plastics and metals can be mixed with a third ingredient. The most popular metal-organic laminate is pre-painted or pre-finished metal, which eliminates user finishing. Up to 95% of metal-plastic laminates are made from vinyl-metal laminates, organic films, and metals. Their construction involves adhesive bonding.

## Particulate Reinforced Composites (PRC):

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Particulate reinforced composites are metal-ceramic composite microstructures with particles of one phase dispersed in the other. Reinforcements are square, triangular, and circular, but their sides are about equal. Dispersoid size and volume concentration separate it from dispersion hardened materials. Particulate composites with volume concentrations over 28% and dispersion of a few microns. Comparatively, difference between particle composite and dispersion-strengthened materials is negligible. The mechanisms that strengthen them differ too. The dispersion-strengthen materials reinforce the matrix alloy by arresting dislocation motion and require significant forces to fracture the restriction. Particulate composites are strengthened by the hydrostatic pressure of fillers in matrices and their hardness. The three systematic orthogonal planes in three-dimensional reinforcement in composites provide

isotropic characteristics. As the array is not homogeneous, material qualities are sensitive to constituent properties, interfacial properties, and geometric shapes. Usually, particle diameter, inter-particle spacing, and reinforcing volume fraction determine composite strength. Matrix characteristics affect particle composite behavior.

## Cermets/Ceramal:

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Cermet stands for "ceramic" and "metal." CerMet is a ceramic-metal hybrid. Cermets combine the best qualities of ceramics and metals, including high temperature resistance, hardness, and plastic deformation. The metal binds oxides, borides, carbides, and alumina. Usually nickel, molybdenum, and cobalt are used. Cermets are usually less than 20% metal by volume, however they can be metal matrix composites depending on their physical structure. Resistances (particularly potentiometers), capacitors, and other high-temperature electronic components are made with it.

Some cermets are being evaluated for spaceship shielding because they withstand high-velocity micrometeoroids and orbital debris better than aluminum and other metals. Solar hot water systems use vacuum tube coatings made from these materials.

Cermets are utilized in dental fillings and prosthesis. Also used in cutting tool machining. Cermets, a leading particle-strengthened composite, contain ceramic grains of borides, carbides, or oxides. A scattered grain 20–85% of the volume is refractory ductile metal matrix. Ceramic and metal elements bond by a tiny mutual solution.

Metal oxide systems need bonding agents due to weak bonding. Cermet structures are typically made utilizing power metallurgy methods. Their characteristics vary according on the relative quantities and compositions of metal and ceramic elements. Cermets are also made by impregnating porous ceramic structures with metallic matrix binder. Cermet coatings can be power-based.

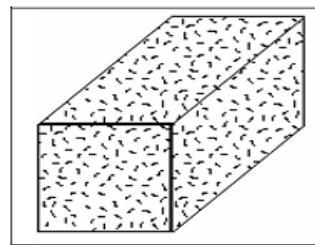
Power is sprayed through a gas flame to fuse a base material. Few cermets have commercial value, but many have been made on a modest scale.

## Categories:

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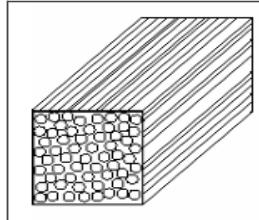
The classification is of Composite Materials based on Fiber length is as follow:

1. Fibers as the reinforcement (Fibrous Composites):
  - a. Random fiber (short fiber) reinforced composites



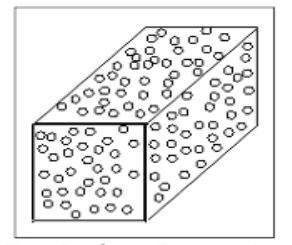
**Short-fibre reinforced composites**

- b. Continuous fiber (long fiber) reinforced composites



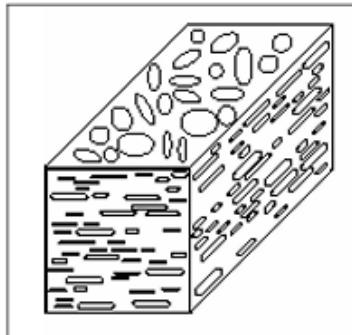
**Long-fibre reinforced composites**

2. Particles as the reinforcement (Particulate composites):



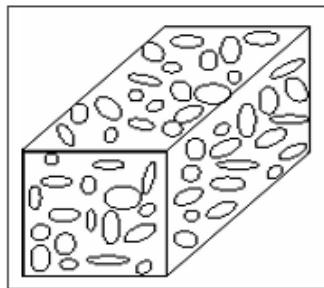
**Particulate Composites**

3. Flat flakes as the reinforcement (Flake composites):



**Flake Composites**

4. Fillers as the reinforcement (Filler composites):



**Filler Composites**

## Role and Selection of Fibers:

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When choosing reinforcements, it's important to think about how well they work with the core material, how stable they are at high temperatures, how dense they are, how hot they melt, and so on. How well discontinuously reinforced composites work depends on how strong they are and how dense the reinforcing stages are. It is important that the reinforcement and matrix material are compatible in terms of density, chemical and temperature stability, and how well they work together during the making of the material and in its final use. When thermal cycling is used, one important thing to look at is the thermal discord strain between the matrix and the support. The gap between the matrix's and reinforcement's coefficients of thermal expansion has to do with it. The crystal structure is changed by the production process and the reinforcement.

What kind of reinforcement is used also changes what part it plays in structural composites. The matrix is what holds most of the weight in powder and whisker-reinforced composites. The reinforcement's job is to make the composite stronger and stiffer by keeping the matrix from deforming through mechanical control. This restriction is usually based on the amount of the distance between particles to their diameter.

## Matrix Materials:

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### Introduction:

The strength of composites is mostly attributable to fiber reinforcement, but matrix material is also crucial as it supports and helps bear loads. Additionally, it stabilizes composite materials. Resin matrix system binds fibers to structural components. When resin is overused, the part is resin rich. If there is insufficient resin, the part is called resin starved. A resin-rich part is more prone to breaking due to insufficient fiber support, while a resin-starved part is weaker due to voids and unsupported fibers.

### Matrix Selection:

High-temperature metal matrix composites require thermodynamically stable dispersoids. An alloy dispersoid system minimizes solid state diffusivity, interfacial energy, and elemental solubility, minimizing coarsening and reactions. Aluminum and magnesium alloys are popular matrices for their low density and strong heat conductivity. Composites with low matrix alloying exhibit desirable ductility, toughness, and strength. Discontinuous reinforced metal matrix composites do not require minor alloying elements employed as grain refiners in wrought alloys. Avoid additives that cause coarse inter-metallic compounds during consolidation, limiting composite tensile ductility.

### Advantages and Limitations of Composites:

#### Advantages of Composites:

Composite materials, used in aircraft, have these benefits:

- High fatigue and corrosion resistance.
- High ‘strength or stiffness to weight’. Compared to standard metallic designs, weight savings are 25–45%.
- Greater reliability reduces inspections and structural repairs.
- Directional customization for design. The fibre pattern can be laid to efficiently support loads.

Fiber-to-fiber redundant load route.

- Dent resistance usually improves. Composite panels are less susceptible to damage than thin metal sheets.

Aerodynamic profiles are easier to smooth for drag reduction. One manufacturing operation can make complex double-curvature pieces with flat surfaces.

Composites improve torsional stiffness. This means high spinning speeds, fewer intermediate bearings, and structural support. So, part count and manufacturing & assembly costs decrease.

- High impact resistance.
- Rapid process cycles make thermoplastics ideal for high-volume commercial applications that sheet metals have historically served. Also, thermoplastics can be reformed.
- Like metals, thermoplastics stay forever.
- Composites are dimensionally stable with minimal thermal conductivity and expansion. Composite materials can be designed to meet several thermal expansion design criteria and reduce thermal stresses.
- Part integration simplifies manufacturing and assembly (joint/fastener reduction), lowering costs.
- Composites' corrosion resistance, durability, and marine weatherability save maintenance downtime.

No machining is needed for close tolerances.

- Composite components and structures are often constructed to shape rather than being machined like metals, saving material.
- Composites, notably Carbon-Carbon, are used in airplane brakes due to their lightweight and heat sink qualities.
- Better friction and wear.
- Tailoring Laminate material properties enables innovative aeroelastic flying structure design.

## Limitations of Composites

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The following are some downsides of advanced composites:

High raw material and production costs.

Composites are brittle and more quickly damaged than wrought metals.

Transverse characteristics may be poor.

Toughness is low due to weak matrix.

Disposal and reuse may be tricky.

Hard to attach.

Repair causes new issues because: Materials need refrigeration and limited shelf life.

- Hot curing often requires special tooling.
- Time-consuming curing.
- Difficulty in analysis.
- Matrix degrades in the environment.

However, good design and material choices can overcome many of these drawbacks. New technology offers a choice of reinforcing fibers and matrices that can be used to create composites with extraordinary qualities. As modern composites offer structural efficiency at lower weights than equivalent metallic constructions, they are becoming the principal materials for future use. Advanced fiber reinforced composites are used in floor beams, engine cowlings, flight control surfaces, landing gear doors, wing-to-body fairings, and vertical and horizontal stabilizer main torque boxes in aircraft.

# **Polymers:**

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## **Introduction:**

Polymer comes from the Greek words poly (“many”) and meros (“parts” or “units”). Polymers are made of many monomers, tiny molecules. In polymerization, monomers are united end-to-end. Silicates and silicones can be used to produce polymers, but carbon compounds are the most prevalent. Naturally occurring polymers include protein, cellulose, resins, starch, shellac, and lignin. Their presence is prevalent in leather, fur, wool, cotton, silk, rubber, wood, and others. Synthetic polymers including polyethylene, polystyrene, nylon, Terylene, Dacron, and others fall under plastics, fibers, and elastomers. Their properties are better than natural ones. Thus, we focus on synthetic polymers, or plastics or resins.

**Polymerization:** Linking monomers to form macromolecules is called polymerization. This can be done through Addition Polymerization or Condensation Polymerization.

Plastics, fibers, and elastomers are polymers. Plastic products can be shaped in any desired shape since they acquire plasticity during manufacturing. Chemically, plastics are high polymers.

## **Engineering Plastics:**

“Plastics” refers to compositions with high molecular compounds, fillers, plasticizers, stains, pigments, lubricants, and other components. Some plastics contain only resin. Plastics comes from the Greek term Plastikos, meaning molded. Plastics are easy to mold, manufacture, and join. Thus, engineering and home applications use plastics. Plastics come in rods, sheets, films, and tubes.

## **Types of Plastics:**

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### **(a) Thermosetting Plastics:**

These harden permanently when heated and shaped with or without pressure. Heat softens the plastic, but adding heat or chemicals hardens it by "polymerization" and cannot be resoftened. Plastic thermosetting is phenol formaldehyde. Urea formaldehyde, epoxy, etc. Plastics used to make TV cabinets, phone receivers, camera bodies, and car parts are thermosetting.

### **(b) Thermoplastics:**

Molding thermoplastics does not modify their chemical properties. While hot, they are soft till cooled. These polymers can be recycled by melting and remoulding. The most regularly used thermoplastics include polystyrene, polytene, PVC, nylon, and Teflon. Products created from thermoplastics include photographic films, insulating tapes, and hose pipes.

### **Properties of Plastics:**

Plastics are widely used in engineering and other industries due to their diverse physical, chemical, and mechanical qualities and simplicity of production.

Plastics' low density, excellent mechanical strength, and anti-friction qualities make them a viable alternative to metals. Plastics can sometimes substitute ferrous metals with unique qualities. Their low melting temperatures and moldability are their key manufacturing advantages. Extracting machine parts is easy. There is typically only one production process needed to turn chemically generated plastic into a final product.

Product damping and finish are good. Plastics are used as dielectrics in radio and electrical engineering because to their superior thermal and electric insulation, replacing porcelain, ebonite, shellac, mica, and natural rubber. Plastics are valuable engineering materials in the automobile, tractor, shipbuilding, and other sectors due to their chemical stability against solvents and certain oxidizing agents, water resistance, gas and steam resistant qualities.

# Comparison between Thermo plastics and Thermosetting Plastics:

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Thermo Plastics	Thermosetting Plastics
<ol style="list-style-type: none"><li>1. Heat does not soften them once hardened.</li><li>2. Stronger and tougher.</li><li>3. Plastics can be used at high temperatures.</li><li>4. Monomeric or partly polymerized liquids or semisolids are given.</li><li>5. These plastics make TV cabinets and car parts.</li></ol>	<ol style="list-style-type: none"><li>1. Heat and cooling can repeatedly soften and harden them.</li><li>2. They are weaker and softer.</li><li>3. Heat softens thermo-plastics; thus, they cannot be used at higher temperatures.</li><li>4. Granular material is frequently supplied.</li><li>5. Plastics make insulating tapes and photo films.</li></ol>

## Advantages of Plastics:

1. Lighter than metals.
2. Excellent finish.
3. Tight dimensions.
4. Rust- and moisture-resistant.
5. Easily molded.

## Disadvantages of Plastics:

1. Weakness.
2. Low heat resistance.
3. Fade in sunlight.

## Applications of Plastics:

1. Film industry photo films.
2. Insulating tapes
3. Electrical components: plugs, switches, etc.
4. Radio, TV cabinets
5. Chairs and tubs

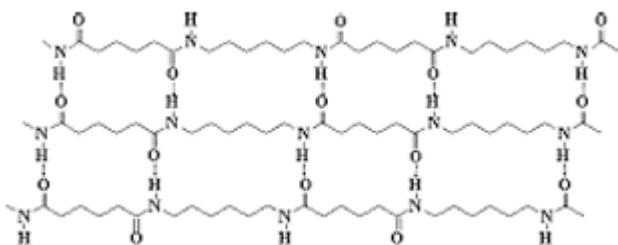
6. Telephone receivers
7. Camera parts
8. Gears, Bearings
9. Toys, bottles, buckets, etc.
10. Hosepipes
11. Automobile parts

## Polymers of Commercial Importance:

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### Nylon:

Nylon is a synthetic polymer created in labs and by companies for commercial use. The textile and fabric industry uses it extensively. Nylon belongs to the linear polyamide family. Both nylon 6 and nylon 6,6 are popular. Nylon 6,6—a popular fiber—is manufactured from adipic acid and hexamethylene diamine. A tight molecular structure makes them abrasion-resistant. Hydrogen bonding links monomers. Nylon is valuable due to its strength, sheen, elasticity, and oil and chemical resistance.

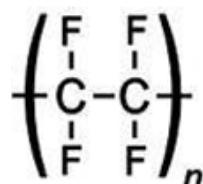


### Nylon Fiber:

Nylon fiber is commonly used in clothing such as shirts, underwear, raincoats, and lingeries. Nylon is used in manufacturing conveyor belts, nets, ropes, parachutes, and tents.

### Polytetrafluoroethylene:

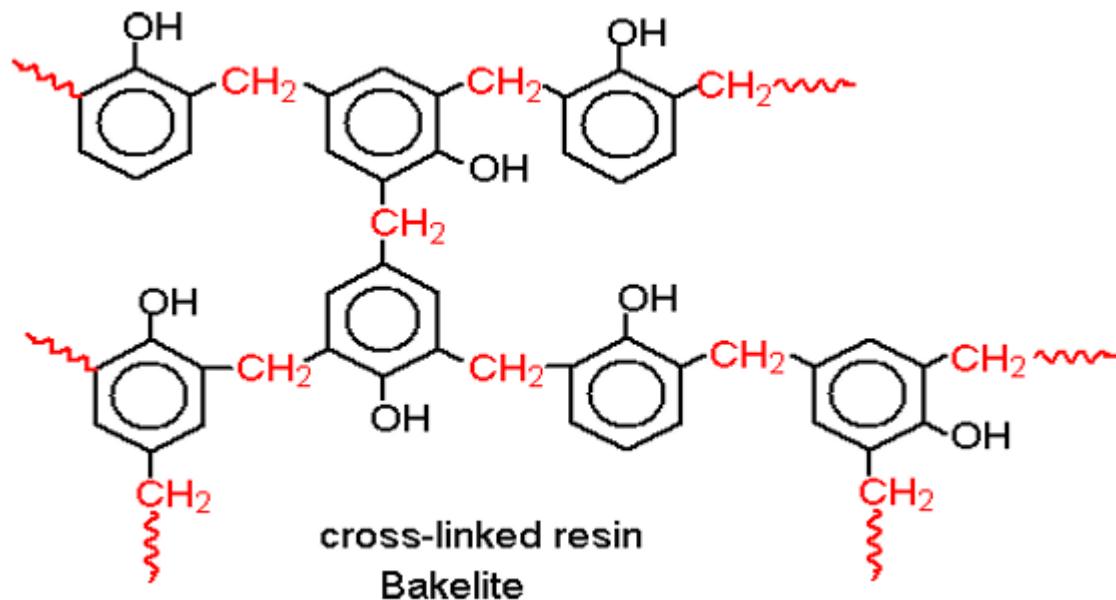
PTFE is a synthetic tetrafluoroethylene fluoropolymer. Its carbon and fluorine content makes it heavy. Teflon, used in non-stick pans, is the most famous PTFE-based compound.



**Structure of PTFE**

**Bakelite:**

Bakelite is one of the oldest man-made polymers. This thermosetting polymer is strong and holds its shape after molding. It was one of the first lab-made polymers/plastics. The polymer is created by condensing formaldehyde and phenol. Its chemical formula is  $(C_6H_6O \cdot CH_2O)_n$ . Bakelite is most often used to make electrical switches because it resists heat and chemicals and has limited electrical conductivity. Many utensil handles are made of Bakelite. It is one of the most widely used polymers for producing parts and components. This polymer is also used in pipe stems.

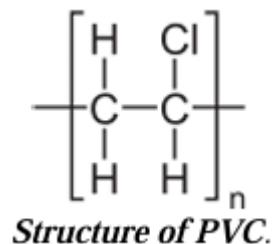


## Polyvinyl Chloride (PVC)

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Discussion of commercial polymers must include PVC. One of the most frequently used polymers on Earth. PVC is widely utilized in building, transport, packaging, electrical, and other industries due to its versatility.

PVC is long-lasting and durable. It's thermoplastic. Polymerization of vinyl chloride monomer creates it. It can be rigid or flexible, white, black, or a variety of colors, and is exceedingly sturdy and long-lasting. Commercial items using polymer PV Care include window frames, drainage pipe, medical equipment, cable, and wire insulation. PVC is used to make credit cards and vinyl records. Recently, PVC has entered the textile sector.



**Structure of PVC.**

## Elastomers:

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Elastomers (rubbers) are elastic polymers. These materials are amorphous and minimally cross-linked, having a glass transition temperature much below ambient temperature. They form a big macroscopic molecule. Polymer chains have weak intermolecular forces. Crosslinks prevent irreversible flow, but chains remain flexible above the glass transition, causing significant deformation with modest forces. Unlike other polymers, elastomers have a low Young's modulus and significant elongation at break. Elastomers and rubber are commonly used interchangeably, however vulcanized rubbers are better. Elastomeric pieces are made by injection, transfer, or compression molding. The molding method selection depends on criteria such as part shape, size, tolerance, quantity, elastomer type, and raw material cost. The right elastomeric product for the

application depends on many factors, including mechanical and physical service requirements, chemical exposure, operating temperature, service life, part manufacturability, and raw material and manufacturing cost, as with most materials.

## Liquid Crystal Polymers:

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Liquid Crystal Polymers (LCPs) are thermoplastics with unusual characteristics. They are highly heat-, electrical-, and chemical-resistant in severe settings. LCPs are highly anisotropic in solid and liquid crystal phases, unlike ABS or nylon. This causes one direction to have higher strength, stiffness, and thermal expansion. Other LCPs are possible, but PET copolyester, copolyamide, and polyester-amide are the most prevalent. Unlike ABS and nylon, LCPs have a highly crystalline molecular chain. The semi stiff, nearly linear, stacking orientation of molecules keeps them highly organized even in liquid crystal phase (Fig. 1 (a)). In contrast, ABS and nylon contain interweaving molecular chains (Fig. 1(b)). Anisotropic tendencies in LCPs' layered molecular architecture give them numerous intriguing features. The main bonds of the molecule cause anisotropy by increasing its attractive force. Less attractive secondary bonds make the molecules more prone to separation. Applied transversely to the molecular orientation, secondary bonds receive most of the load, making separation easier. The main bonds of molecules are more highly loaded in the longitudinal direction, making separation harder.

LCPs are typically injection molded, but other processing methods can be used to accommodate the material. LCP melt temperatures range from 280-330°C, while mold temperatures should be 70-130°C. Melt molecular chains are substantially aligned along resin flow. To produce resin flow, which determines molecule orientation and anisotropic characteristics, mold gating positions must be carefully considered. This affects the final part because anisotropic qualities including tensile strength, thermal expansion, and elastic modulus can be three times stronger in the longitudinal direction than in the transverse direction. High melt flow and moderate thermal expansion in molecular orientation provide LCPs

exceptional cycle repeatability. This makes molding thin-walled pieces easy without warping. LCPs resist heat, fire, weather, and UV radiation and provide good electrical insulation. LCPs resist hydrolysis, weak acids and bases, alcohols, aromates, chlorinated hydrocarbons, esters, and ketones at many temperatures. They also have excellent mechanical qualities, including high strength, modulus of elasticity, and toughness. Table 1 compares LCP thermal expansion to two other common polymers and shows the difference between longitudinal and transverse thermal expansion. Table 1 gives the thermal expansion coefficient in meters per degree Celsius per meter.

## Conductive Polymers:

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Applying a voltage causes charges in a substance to move orderly and generate an electric current. Positive charges follow the electric field, while negative charges go in the opposite direction. The flux of electrons, known as electric conduction, creates a current in most materials. These materials have conjugated chains, or alternating single and double bonds between atoms. Conjugated bonds simplify the doping procedure for conductive polymers. Polymeric chain flaws and deformations result from this process. Polarons—electrons-deformation pairs or electron-phonon cloud pairs—control polymer conductivity. The conductivity mechanism also involves quasi-particles like bipolarons and solitons. Dopants determine soliton, bipolaron, or polaron formation. The meaning and physics behind them are beyond the scope of this topic. Charges from doping in conductive polymers contribute to their high conductivity. Constant movement of double bonds stabilizes charge in neighboring atoms, leading to charge mobility and conductivity. Resonance describes delocalized electrons in a molecule by moving double bonds (see [d] of "Links" Section). A  $\pi$  bond electron shared by three or more atoms is called a delocalized electron. Polaron production changes the band structure of conductive polymers. It forms polaronic conduction bands, permitted bands in the band gap, reducing band gap energy and allowing the polymer to conduct (see figure).

## High Performance Fibers:

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High-performance fibres are new. These fibers differ from normal ones and can meet certain technical requirements due to their unique features. High-performance fibers like Kevlar, Nomex, carbon, and glass offer superior tensile strength, heat and flame resistance, and chemical resistance compared to traditional materials like steel. Metal car bodies have been replaced with fiber composites. The aerodynamic design and weight reduction have improved. Sportswear uses textured nylon fiber for strength and breathability. Additionally, high-performance fibers are utilized in aerospace, metals, and medical industries. These fibers can be customized to offer versatile properties such as dyeability, adhesion, absorbance, conductivity, flame retardance, and a variety of special surface characteristics.

Fibers with high performance require special qualities such as

1. Exceptional strength and modulus.
2. Stiffness.
3. Resistance to heat.
4. Chemical-resistant.

Examples of fibers include carbon, glass, aramid, kevlar, nomex, PBO, and chlorinated fibers like PVDV.

## List of High Performance Fibers:

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1. Glass Fiber.
2. Carbon Fiber.

3. Aramid Fiber.

4. Spandex Fiber.

### Glass Fiber:

One of the oldest and most popular high-performance fibers is glass. It has been produced since the 1930s. Early versions were strong yet rigid, making them unsuitable for textile uses. SiO<sub>2</sub> is the building block of glass fibers. Polymer (SiO<sub>2</sub>)<sub>n</sub> is its pure form. Despite having no melting point, it softens about 1200 °C.

Modern glass fibers have many characteristics and are used in numerous applications.

- Mat-making material.
- Thermal insulation fabric
- Sound insulation fabric • Heat and corrosion resistant fabric.



### Carbon Fiber:

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One of the strongest and lightest materials available, carbon fiber is commonly employed in high-performance applications. Carbon fiber, one-third the weight of steel and roughly five times stronger, is utilized in aerospace, aviation, civil engineering, military, vehicle and automobile, and sports applications. Carbon fiber, also known as graphite fiber, is a material made of carbon atoms and has filaments of 5-10 µm in diameter. Carbon fibers vary in elasticity, electrical conductivity, heat, and chemical resistance. Carbon fibers are

produced by extruding pre-made materials like rayon, PAN, and pitch into filaments, then carbonizing them because carbon cannot be easily formed into fibers.

Carbon fiber applications include

1. aerospace.
2. Sporting goods.
3. Wind turbine blades.
4. Auto.

## Biomedical Applications of Polymers:

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### Containers:

Many polymer devices are utilized to package medications and devices. PVC with DEHP is commonly used in extracorporeal perfusion tubes for drug delivery, blood leading tubes for dialysis, and oxygenation. Also, polymer bags are used to keep blood donations and merchandise. Since the plasticizer is lipophilic, it moves from the polymer surface to red blood cell lipids and membranes. Alternative polymers like polyolefins and polyethylene and polyurethane tubings are employed for platelet storage. The peristaltic pump tubing is usually silicone.

### Vascular Catheters:

Mechanical flexibility and non-collapsing qualities are needed. Long-lasting central venous catheters typically contain antimicrobial fittings that prevent bacterial biofilm growth and adhesion. Plasticized PVC was an early catheter polymer. Today, plasticizers make it unpopular and utilized only for short-term peripheral venous catheters. In catheters, thermoplastic polyurethanes are used since they don't need plasticizers.

## Urinary Catheters and Ureteral Stents:

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For patient comfort, catheters and stents must be strong and gentle. The surface must have low-friction. Generally, coating technologies are used. Silicone is the least encrustation-prone biocompatible material, but its poor mechanical rigidity and high friction make application challenging. Polyurethane and PMMA/pharma co-polymers have been optimized to have better mechanical characteristics than silicone. Stents are coated with GAGs, heparin, phosphoryl choline, PVP, or hydrogels to minimize bacterial colonization, encrustation, and improve patient comfort.