# What are “composites”?

Composite: Two or more chemically different constituents combined macroscopically to yield a useful material.

Examples of naturally occurring composites –Wood: Cellulose fibers bound by lignin matrix

Bone: Stiff mineral “fibers” in a soft organic matrix permeated with holes filled with liquids

Granite: Granular composite of quartz, feldspar, and mica

Some examples of man-made composites are –Concrete: Particulate composite of aggregates (limestone or granite), sand, cement and water.

Plywood: Several layers of wood veneer glued together

Fiberglass: Plastic matrix reinforced by glass fibers

Cermets: Ceramic and metal composites

Fibrous composites: Variety of fibers (glass, kevlar, graphite, nylon, etc.) bound together by a polymeric matrix

These are not composites:

Plastics: Even though they may have several “fillers”, their presence does not alter the physical properties significantly. Alloys: Here the alloy is not macroscopically heterogeneous, especially in terms of physical properties. Metals with impurities: The presence of impurities does not significantly alter physical properties of the metal properties of the metal.

Where are composites used?

Automotive industry: Lighter, stronger, wear resistance, rust-free, aesthetics –Car body – Brake pads –Drive shafts –Fuel tanks –Hoods –Spoilers

Aerospace: Lighter, stronger, temperature resistance, smart structures, wear resistance – Aircraft: Nose, doors, struts, trunnion, fairings, cowlings,ailerons,outboard and inboard flaps, stabilizers, elevators, rudders, fin tips, spoilers, edges edges.

Rockets & missiles: Nose, body, pressure tanks, frame fuel tanks, turbo-motor stators, etc.

Satellites: Antennae, frames, structural parts

Sports: Lighter, stronger, toughness, better aesthetics, higher damping properties. Tennis, – Bicycles –Badminton –Boats –Hockey –Golfing Motorcycles – Motorcycles …

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Transportation & Infrastructure: Lighter, stronger, toughness, damping. –Railway coaches, Bridges, Ships and boats. Dams, Truck bodies and floors, RV bodies.

And many more industry sectors – Biomedical industry, Consumer goods. Agricultural equipment, Heavy machinery, Computers and healthcare.

# Classification of Composites

Engineered Composites – Particulate and Fibrous

Particulate could be Random Orientation or

Preferred Orientation

Fibrous could be Single Layer or Multi-Layer

Multi-layer is subdivided into laminate or hybrid laminate. Whereas Single layer is subdivided into

continuous & long fibers and discontinuous & short Fibers. The continuous and long could be

unidirectional or bi-directional whereas the discontinuous & short can be divided into random orientation and preferred orientation

Particulatecomposites have one or more material particles suspended in a binding matrix. A particle by definition is not “long” vis-à-vis its own dimensions.

Fibrous composites have fibers of reinforcing material(s) suspended in binding matrix. Unlike particles a fiber has high length-to diameter ratio, and further its diameter may be close to its crystal size.

Random orientation: Orientation of particle is randomly distributed in all directions (e.g.concrete);

Preferred orientation: Particle orientation is aligned to specific directions (e.g. extruded plastics with reinforcement particles)

Note: Particulate composites in general do not have high fracture resistance unlike fibrous composites. Particles tend to increase stiffness of the materials, but they do not have so much of an influence on composite’s strength. In several cases, particulate composites are used to enhance performance at high temperatures. In other case these composites are used to increase thermal and electrical properties.

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In cermets, which are ceramic-metal composites, the aim is to have high surface hardness so that the material can be used to cut materials at high speeds or is able to resist wear .

Fibrous Composites: In general, materials tend to have much better thermomechanical properties at small scale than at macro-scale. At macro-scale, imperfections in material have an accumulated effect of degrading bulk mechanical properties of materials significantly. This is one reason why fibrous composites have been developed to harness micro-scale properties of materials at larger scales. Man-made fibers, have almost no flaws in directions perpendicular to their length. Hence they are able to bear large loads per unit area compared to bulk materials .

## Advantages of Composites

Composites are engineered materials. We can engineer them specifically to meet our needs on a case-to-case basis. In general, the following properties can be improved by using composite materials. Strength, Electrical conductivity, Modulus, Thermal conductivity , Weight, behavior at extreme temps., Fatigue, Acoustical insulation, Vibration damping , Aesthetics , Resistance to wear , Resistance to corrosion etc.

## Limitations of Composites

Like all things in nature, composites materials have their limitations as well. Some of the important ones are: –Anisotropy: A large number of composites have direction dependent material properties. This makes them more difficult to understand, analyze and engineer, vis-à-vis isotropic materials.

–Non-homogenous: Further, these materials by definition are not homogenous hence their material properties vary from point to point.

This factor as well makes them difficult to model and analyze

Costly: Composite materials are in general expensive. Thus, they are used in applications where their benefits outweigh their costs.

Difficult to fabricate: Further, fabricating structures from such materials is difficult, time taking, and expensive.

–Sensitivity to temperature: Laminated composites are particularly sensitive to temperature changes. They come in with residual thermal stresses, because they get fabricated at high temperatures, and then cooled. Such a process locks in thermal stresses into the structure.

–Moisture effects: Laminated composites are also sensitive to moisture, and their performance varies significantly when exposed to moisture for long periods of time.

## Glass Fibers

Glass fibers are the most commonly used fibers. They come in two forms: – Continuous fibers and Discontinuous or “staple” fibers. Chemically, glass is sillicon dioxide ($SiO2$). Glass fibers used for structural applications come in two“flavours”:E -Glass and S-Glass. E-glass is produced in much larger volumes vis-à-vis S glass.

Principal advantages: Low cost and High strength

Limitations: –Poor abrasion resistance causing reduced usable strength, Poor adhesion to specific polymer matrix materials and Poor adhesion in humid environments

Glass fibers are coated with chemicals to enhance their adhesion properties. These chemicals are known as “coupling agents”. Many of coupling agents are silane compounds.

## How are Glass Fibers Made?

Both continuous and staple forms of glass fibers are produced by partially similar methods.

Process of producing continuous fibers: Raw materials (sand, limestone, alumina) are mixed and melted in a furnace at approximately 1260 C. Molten glass then : Either flows directly into a fiber-drawing facility. This process is known as “direct melt” process. Most of fiberglass in the world is produced this way.

Or gets formed into marbles. These marbles are later fused and drawn into fibers.

For producing continuous fibers, molten glass passes through multiple holes to form fibers. These fibers are quenched through a light spray of water. Subsequently fibers are coated with protective and lubricating agents.

Next fibers are collected in bundles known as “strands”. Each strand may have typically 204 individual fibers. Next, strands wound on spools. Fibers in these spools are subsequently processed further to produce textiles.

Staple fibers are produced by pushing high pressure air-jet across fibers, as they emanate from holes during the drawing process. These fibers are subsequently collected, sprayed with a binder and collected into bundles known as “slivers”.These slivers may subsequently be drawn and twisted into yarns.

## Surface Treatment of Glass Fibers

During production, glass fibers are treated chemically . These treatments are known as sizes. There are two types of sizes: Temporary and Compatible. –

Temporary sizes are used to reduce degradation of fiber strength attributable to abrasion of fibers due to inter-fiber friction during fiber drawing process.

They are also used to bind fibers for easy handling. They are made from starch-oils (starch, gelatin, polyvinyl alcohol, etc.). These sizes inhibit good resin-fiber adhesion. They also promote moisture absorption.

During composite fabrication, these sizes are removed by heating the fibers at

340 C for 15-20 hours. Post their removal, these fibers are coated with coupling agents (also known as finishes), which promote resin-fiber adhesion. These agents also inhibit deteriorating effects of humidity on the fiber-resin bond. Many of these agents are organo-functional silanes.

Composition & Properties of Glass Fibers

Typical Chemical Composition of E & S Glass in %

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|---|---|---|
| SiO2 | 54.3 | 64.2 |
| Al2O3 | 15.2 | 24.8 |
| CaO | 17.2 | 0.01 |
| B2O3 | 8.0 | 0.01 |
| MgO | 4.7 | 10.3 |
| Na2O | 0.6 | 0.27 |
| BaO | | 0.2.0 |
| FeO | | 0.21 |
| Others | | 0.03 |

## Graphite Fibers

Graphite and carbon fibers are extensively used in high-strength,high modulus applications.
Graphite fibers have carbon content in excess of 99%. –
Carbon fibers have carbon content in the range 80-95%

Fiber’s carbon content depends on processing method for these fibers. They are significantly more expensive than glass fibers.

Key application areas include aerospace, sporting, railway, infrastructure, automotive, oil drilling, as well as consumer sector industries.

Graphite structure consists of hexagonally packed carbon atoms in layers, and several such layers are interconnected through weak van der Waals forces. Thus such a structure generates high in-plane modulus and significantly less modulus in out-plane direction

## How are Graphite Fibers Produced?

A precursor material, which is rich in carbon, is subjected to pyrolysis to extract its carbon content.
Pyrolysis:Thermo-chemical decomposition of organic material when it is subjected to elevated temperatures, but no oxygen. Through such a process, the precursor organic material breaks down into gases, liquids, and a solid residue which is rich in carbon.

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Precursor:It is a carbon-rich chemical compound used as "raw" material for pyrolysis. Currently, three materials are used as precursors. These are: Polyacrylonitrile(PAN)

Pitch: It is a viscous substance produced by plants, and also extracted from petroleum.

Rayon: It is regenerated cellulose fiber produced from naturally occurring polymers.

A good precursor material should have the following characteristics: Sufficient strength and handling properties so that it can hold together fibers during carbon fiber production process. Should not melt during production process. Should not be completely volatile, as it will drastically reduce yield of carbon fiber. Carbon atoms should self-align in graphite structure during pyrolysis, as this will enhance fiber's mechanical properties. It should be inexpensive.

How are Graphite Fibers Produced?

Production of Graphite Fibers from PAN

PAN precursor material is initially spun into fiber form. These precursor fibers are then stretched through application of tensile load.

During stretching, they are also subjected to high temperatures (200 -240 C), for approximately 24 hours in an oxidizing atmosphere. This process is called stabilization These stabilized fibers are next subjected to pyrolysis at 1500 C in inert atmosphere

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This process is called “carbonization”. During this process, most of non-carbon elements are driven out of PAN fibers. Next these fibers are graphitized by heating them at 3000C in inert environment. This improves tensile modulus of fibers as graphite

crystals develop in carbon.

Overview of Different Types of Graphite Fibers :
PAN based carbon fibers: –Low cost.

Have reasonable mechanical properties. Very popular in aircraft, missile and space applications.

Pitch-based carbon fibers

Higher stiffness,Higher thermal conductivity: This makes them particularly useful in thermal management systems and satellite structures.

Rayon-based carbon fibers:

Not used much in structural applications. Have Low thermal conductivity: Useful for insulation materials, and heat shields –Used in rocket nozzles missile re-entry nose cones, heat insulators.

# Aramid Fibers .

Aramid is short for “aromatic-polyamide”. Aramids are a class of polymers, where self repeating units contain large phenyl rings, linked together by amide groups. As per US based FTC, aramid fibers are manufactured fibers where “the fiber-forming substance is a long-chain synthetic polyamide in which at least 85% of the amide linkages, (-CO-NH-) are attached directly to two aromatic rings”. Important properties of these fibers are: –High resistance to abrasion, High resistance to organic solvents, Tough as well as strong. Non-conductive. No melting point (they start degrading at 500 C). Low flammability. Sensitive to acids, and solvents. Kevlar is a very well known and widely used aramid fiber. It was invented by DuPont and widely used in ballistic applications. Comes in different flavors.

# Boron Fibers

Boron fibers are relatively more popular in composites, vis-à-vis other fibers (aluminum, steel, etc.).These fibers are made using a chemical vapor deposition (CVD) process.

Here, boron tri-chloride is chemically reduced in a hydrogen environment on a tungsten or carbon filament substrate. The tungsten or carbon filament is resistively heated at temperatures in excess of 1500 C. Due to application of temperature, Boron trichloride interacts with hydrogen, and reduces to pure boron.

This boron gets deposited on the tungsten or carbon filament

As the filament is continuously pulled out of reduction chamber, a well controlled boron layer deposits on the substrate wire. These wires have a boron “outside” and a tungsten or carbon core.

# Ceramic Fibers

Ceramic fibers are used in high temperature applications.

These fibers have high strength, high elastic modulus, as well as the ability to withstand high temperatures without getting chemically degraded. Commonly used fibers for such applications are made from alumina and SiC Alumina fibers are madeby spinning a slurry of alumina and firing of the slurry. These fibers retain their strength up to 1370 C.Silicon carbide fibers are produced either by a chemical vapor deposition (CVD) or through pyrolysis. SiC fibers retain their tensile strength up to 650C. Alumina and SiC fibers work well in metal matrices, unlike carbon and boron fibers, since the latter react with metal matrices. Further, due to their resistance to high temperatures, these fibers are also used in turbine blades.

# HPPE Fibers

HPPE stands for High Performance Polyethylene .

HPPE fibers have a density slightly less than that of water. Thus, though their modulus and strength are slightly less than Kevlar fibers, on aspecific strength, and specific modulus are 30-40% more than that for Kevlar fibers.

HPPE fibers have very high energy absorption characteristics. Thus they are widely used in ballistic armor applications.

HPPE fiber’s modulus and strength increases significantly with increasing strain rates. Thus HPPFE composites work very well when subjected to high-velocity impacts.

HMPE (high modulus polyethylene) and ECPE (extended chain polyethylene) are other materials with chemical structure similar to HPPE material. Their fibers are also used in composites.