COMPOSITE MATERIALS

- Combination of **two or more chemically distinct materials** whose physical characteristics/properties are **superior to its constituents** acting independently
- They have high strength/stiffness to weight ratio
- These materials are stronger, lighter when compared to traditional materials but expensive
- Most composites are made of just two materials.
- One is the **matrix or binder**. It surrounds and binds together fibres or fragments of the other material, which is called the **reinforcement**.
- Within the composite we can easily tell the different materials apart as they do not dissolve or blend into each other
- Composites consist of Combination of two or more materials
    - Composite = matrix + fiber (filler)

Matrix:
- material component that surrounds the fiber
- Usually **a ductile or tough material with low density**
- **Offers strength**
- Examples include: thermoplastic or thermoset
- Thermoset most common (epoxy, phenolic)
- Serves to hold the fiber (filler) in a favorable orientation

Fiber or reinforcing material or Filler:
- **Materials that are strong with low densities**
- Examples include glass, carbon or particles
- **Composites** are designed to display a combination of the best characteristics of each material i.e. **fiberglass acquires strength from glass and flexibility from the polymer**
- Matrix and filler bonded together (adhesive) or mechanically locked together!

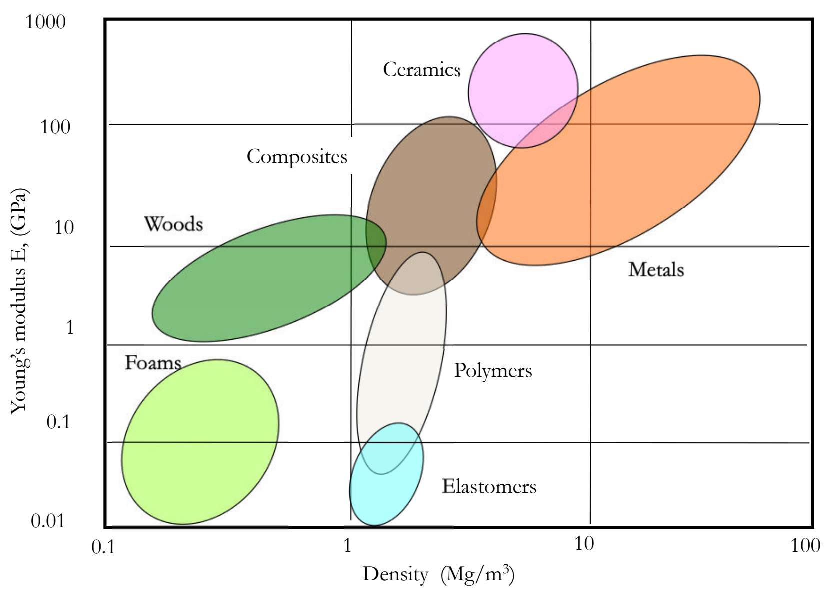
Advantages:
- **High strength to weight ratio** (low density high tensile strength) or high specific strength ratio!
- High **creep resistance**
- High **tensile strength at elevated temperatures**
- **High toughness**
- Generally perform better than steel or aluminum in applications where cyclic loads are encountered leading to potential fatigue failure (i.e. helicopter blades).
- Can **with stand Impact loads or vibration** – composites can be specially formulated with high toughness and high damping to reduce these load inputs
- Some composites can have much **higher wear resistance** than metals
- **Corrosion resistance**
- Dimensional changes due to temperature changes can be much less

Disadvantages (or limitations):

- **Material costs**
- **Fabrication/ manufacturing difficulties**
- Repair can be difficult
- Wider range of variability (statistical spread)
- **Operating temperature** can be an issue for polymeric matrix (i.e. 500 F). Less an issue for metal matrix (2,700 F)
- Inspection and testing typically more complex

Youngs modulas vs Density Graph

Young's modulus (E) is a property of the material that tells us how easily it can stretch and deform and is defined as the ratio of tensile stress (σ) to tensile strain (ε). Where stress is the amount of force applied per unit area ($\sigma = F/A$) and strain is extension per unit length ($\varepsilon = \Delta L/L$).



Examples and applications

- **Reinforced plastics (fibre glass)** : composed of glass fibres embedded in a resin matrix

- **Carbon fibre reinforced plastic** : lighter and stronger than fibreglass but more expensive

- **Airbus 380**
  - More than 20% of the A380 is made of composite materials, mainly plastic reinforced with carbon fibres.
  - **Glass-fibre-reinforced aluminium**, a new composite that is 25 % stronger than conventional airframe aluminium but 20 % lighter.
  - Cost (fuel) effective

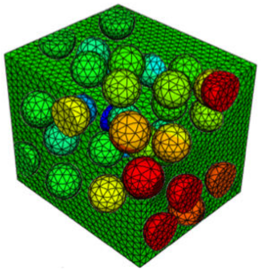
Classification of Composites by Filler Type

- Particle-reinforced composites
- Fiber-reinforced composites
- Structural composites

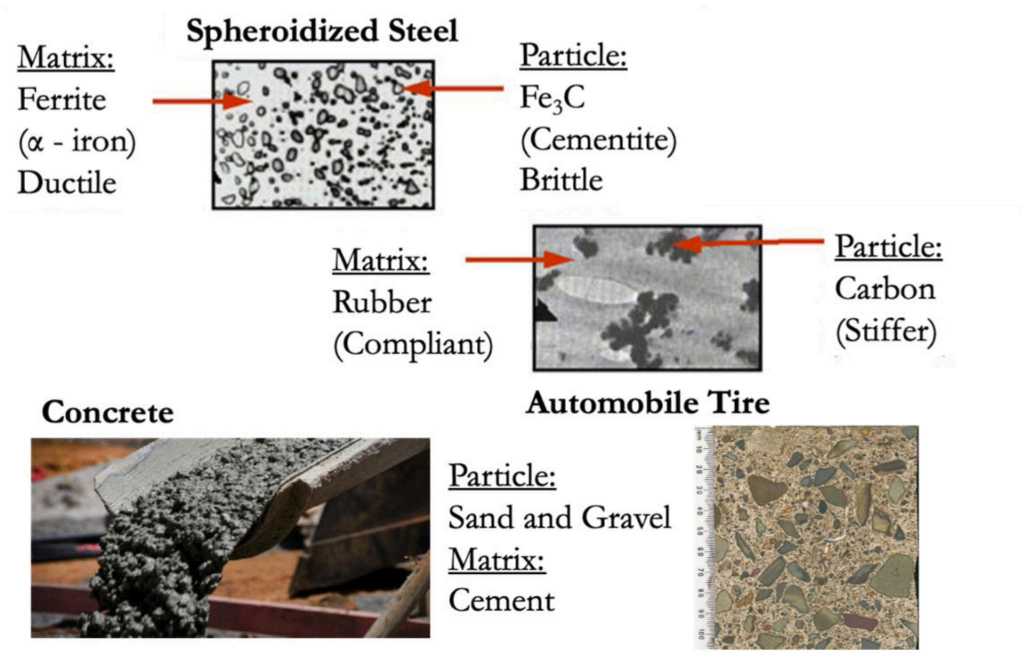
Particle Reinforced Composites

Particles used for reinforcing include:

- **ceramics and glasses** such as small mineral particles
- **metal particles such as aluminum and amorphous materials, including polymers and carbon black**

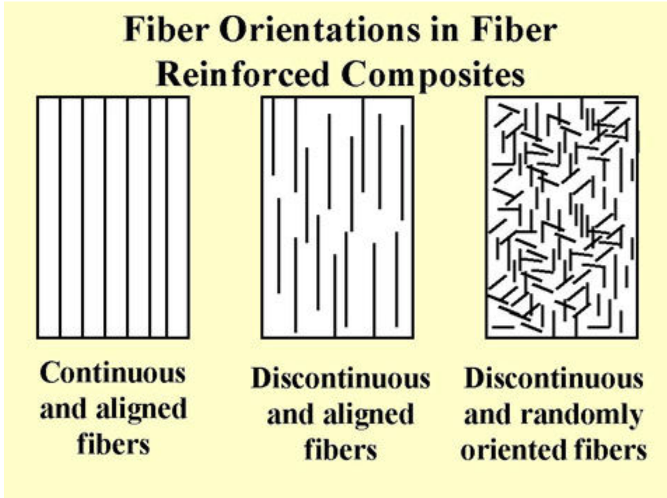


- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of the matrix.
- Particle reinforced composites **support higher tensile, compressive and shear stresses**
- Particles are also used to produce inexpensive composites
- **Examples**:
  - Automobile tire which has carbon black particles in a matrix of elastomeric polymer
  - Spheroidized steel where cementite is transformed into a spherical shape which improves the machinability of the material
  - Concrete where the aggregates (sand and gravel) are the particles and cement is the matrix



Fiber-Reinforced Composites

- Composed of **glass or carbon fiber in a plastic resin**
- Resins can be of the form of **thermoset or thermoplastic** materials which each have their own unique advantages and disadvantages
- The glass or carbon fibers are significantly stronger than the plastic matrix but they also tend to be brittle
- A composite construction, therefore, allows one to take advantage of the excellent stiffness and strength properties of glass or carbon by embedding the fibers in a more compliant matrix
- **Carbon fiber is a material consisting of fibers about 5 -10 μm in diameter** and composed mostly of carbon atoms
- **Fiber – High length-to-diameter ratio, Its diameter approximates its crystal size**.
- **Whiskers are similar in diameter to fibers, but in general, they are short and have low length-to- diameter ratios, barely exceeding a few hundreds**
- Modern composites exploit the fact that small scale samples of most of the materials are much stronger than bulk materials. Thus, **thin fibers of glass are 200-500 times stronger than bulk glass**
- Fibers are significantly stronger than bulk materials because: – **They have a far more "perfect" structure**, i.e. **their crystals are aligned along the fiber axis.**
- There are **fewer internal defects, lesser number of dislocations**.
- For this reason fibers of several engineering materials are far more strong than their equivalent bulk material samples.

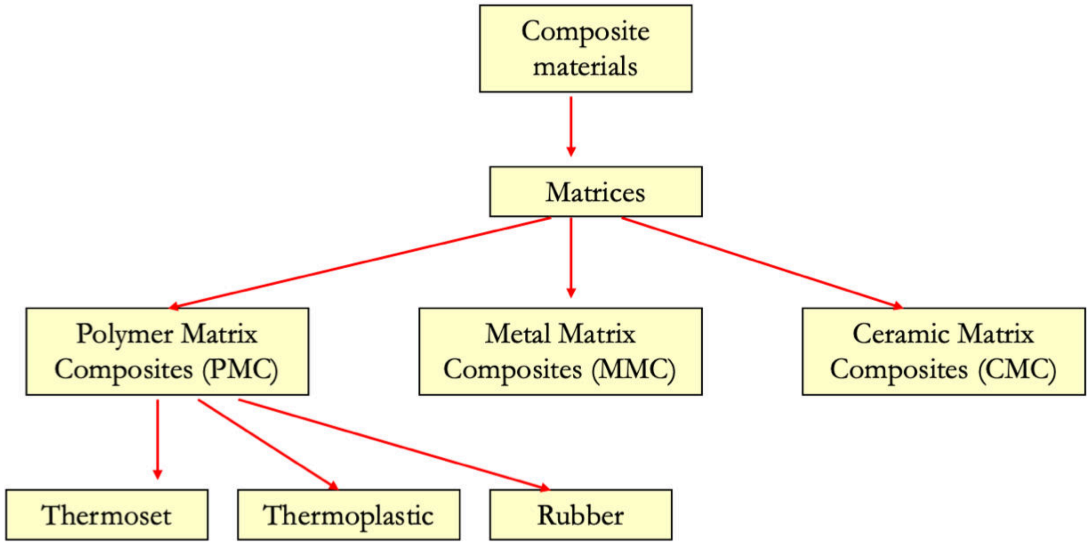


- **Carbon fiber composites are now quite common in commercial and military aviation. The Boeing 787 and Airbus A350 XWB have roughly 50% of their structure from composite materials**
- Fiber reinforced composites have only really been used in high end sports cars
- Fiberglass has been the common material for recreational boats and yachts for many years.
- **Major advantage is its thermal expansion is basically zero – this means that a metal for instance is expanding when heated, carbon fiber remains in its basic form**
- Carbon fiber composite structures do not suffer any fatigue issues if designed and dimensioned properly.
- **Does not corrode, which is a huge issue with metals**
- The strength of the composite depends primarily on the **amount, arrangement and type of fiber (or particle) reinforcement in the resin**
- Typically, **the higher the reinforcement content, the greater the strength**
- In some cases, glass fibers are combined with other fibers, such as carbon or aramid (Kevlar29 and Kevlar49), to create a "hybrid" composite that combines the properties of more than one reinforcing material.

Most Common Fibers for FRP

Property	**Glass**	**Carbon**	**Kevlar**
Strength	Worst	In - between	Best
Stiffness	Worst	Best	In – between
Cost	Best	Worst	In – between
Weight	Worst	Best	In-between

Classification based on Matrix



Matrix - Functions

- Holds the fibres together, Protects the fibres from environment
- **Distributes the loads evenly between fibres** so that all fibres are subjected to the same amount of strain.
- Improves impact and fracture resistance of a component
- Helps to **avoid propagation of crack** growth through the fibres

Desired Properties of a Matrix

- Reduced moisture absorption
- Low shrinkage
- Excellent chemical resistance
- Low coefficient of thermal expansion
- Should be easily processable into the final composite shape
- Good flow characteristics so that it penetrates the fibre bundles completely and eliminates voids during the compacting/curing process
- Must be elastic to transfer load to fibres

Metal matrix composites (MMC):

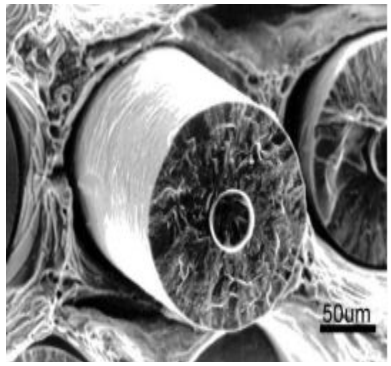
- Metal matrix: Al, Ti, Mg, Fe, Cu, Ni
- Example: Al-SiC (silicon carbide) CERMETS
- Example: Al-Al_2O_3 (aluminum oxide)
- High strength, high stiffness, abrasion resistance, dimensional stability, high temperature and toughness.

The metal matrix composites offer higher modulus of elasticity, ductility, and resistance to elevated temperature than polymer matrix composites. But, they are heavier and more difficult to process.

Fiber	Matrix	Applications
Graphite	Aluminum	Satellite, missile, and helicopter structures
	Magnesium	Space and satellite structures
	Lead	Storage-battery plates
	Copper	Electrical contacts and bearings
Boron	Aluminum	Compressor blades and structural supports
	Magnesium	Antenna structures
	Titanium	Jet-engine fan blades
Alumina	Aluminum	Superconductor restraints in fission power reactors
	Lead	Storage-battery plates
	Magnesium	Helicopter transmission structures
Silicon carbide	Aluminum, titanium	High-temperature structures
	Superalloy (cobalt-base)	High-temperature engine components
Molybdenum, tungsten	Superalloy	High-temperature engine components

Ceramic matrix composites (CMC):

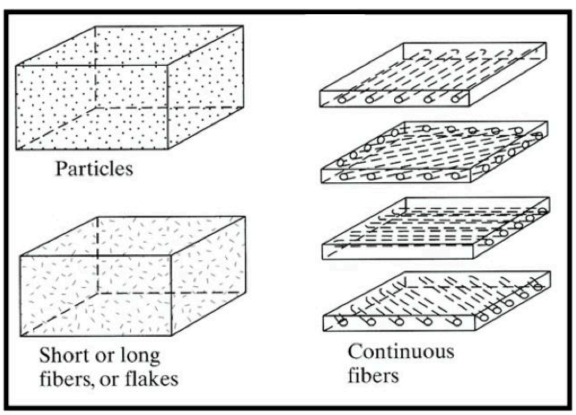
- **Ceramic matrix composites** (CMC) are used in applications where **resistance to high temperature and corrosive environment is desired**. CMCs are strong and stiff but they lack toughness (ductility)
- **Matrix materials** are usually **silicon carbide, silicon nitride and aluminum oxide, and mullite (compound of aluminum, silicon and oxygen). They retain their strength up to 3000 ^{o}F**.
- **Fiber materials** used commonly are carbon and aluminum oxide.
- **Applications** are in jet and automobile engines, deep-see mining, cutting tools, dies and pressure vessels.
- Carbon fiber reinforced silicon carbide is a very strong composite made of a silicon carbide matrix with carbon fiber reinforcement.
- The material is very suitable for oil quenching processes in metal hardening due to its low porosity. Furthermore, by its low weight it fits perfectly to your automation idea for your hardening process.

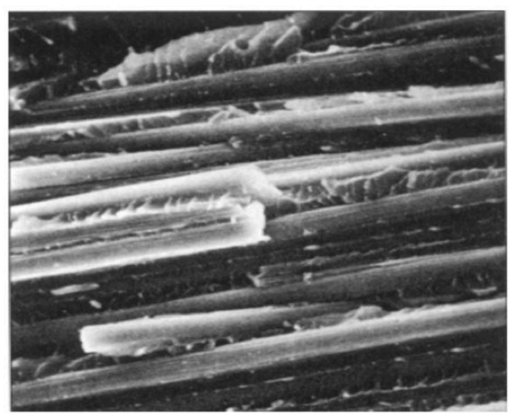


- **Silicon carbide-silicon carbide (SiC-SiC)** is also a Ceramic matrix composite
- Same material both **matrix and filler BUT filler different form such as whiskers**, chopped fibers or strands to achieve preferred properties.

Polymer matrix composites (PMC):

Polymer matrix composites (PMC) and fiber reinforced plastics (FRP) are referred to as ***Reinforced Plastics.*** Common fibers used are glass (GFRP), graphite (CFRP), boron, and aramids (Kevlar). These fibers have ***high specific strength*** (strength-to-weight ratio) and ***specific stiffness*** (stiffness-to-weight ratio)





Matrix materials are usually thermoplastics or thermosets; polyester, epoxy (80% of reinforced plastics), fluorocarbon, silicon, phenolic.