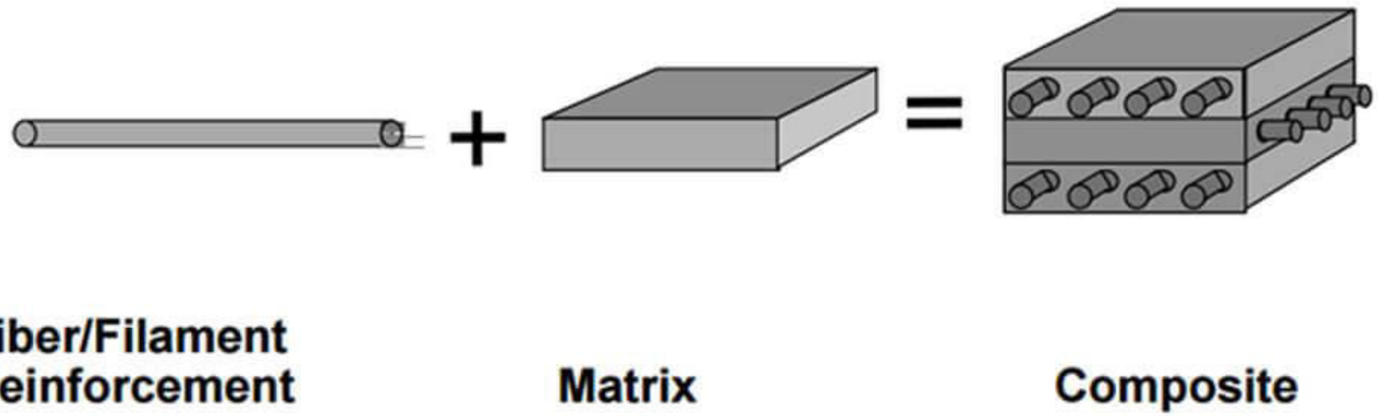
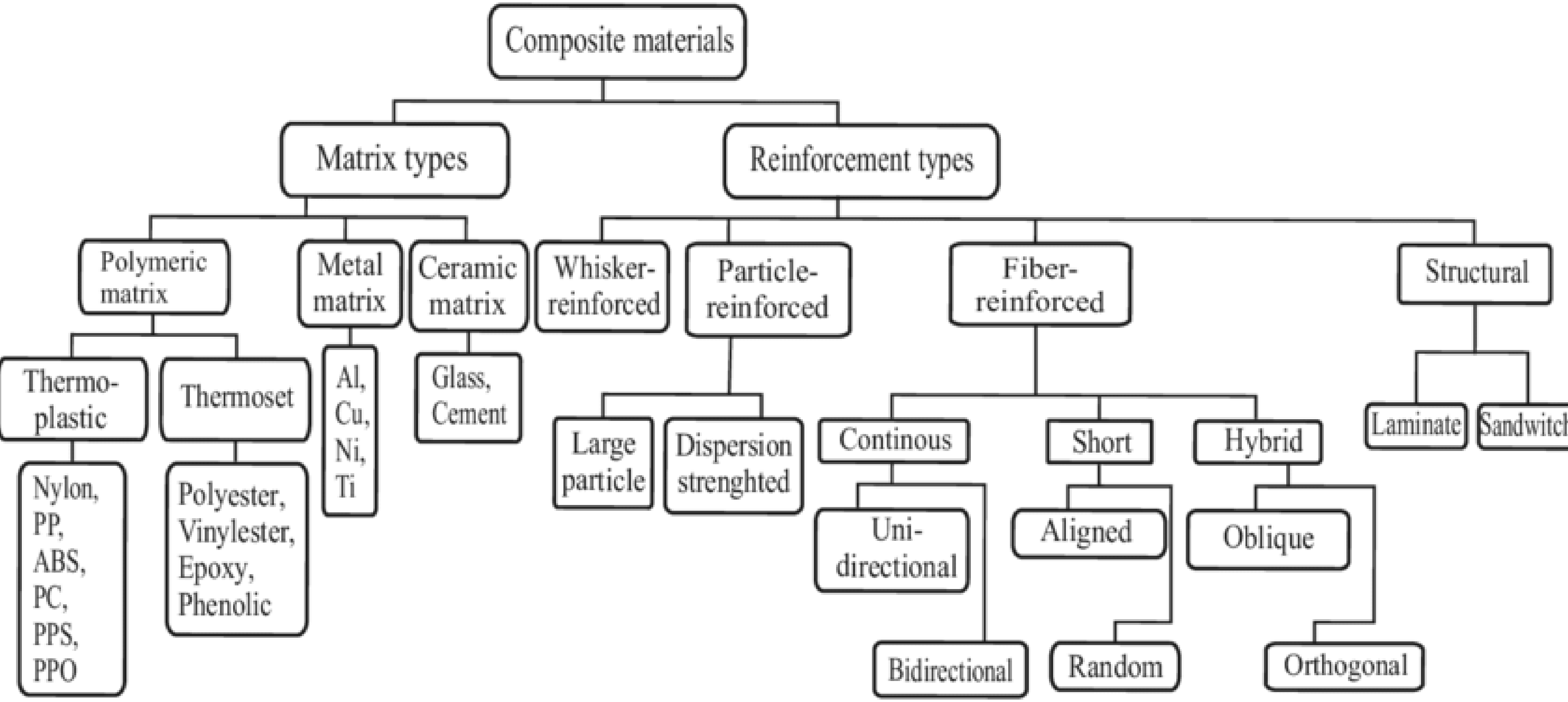
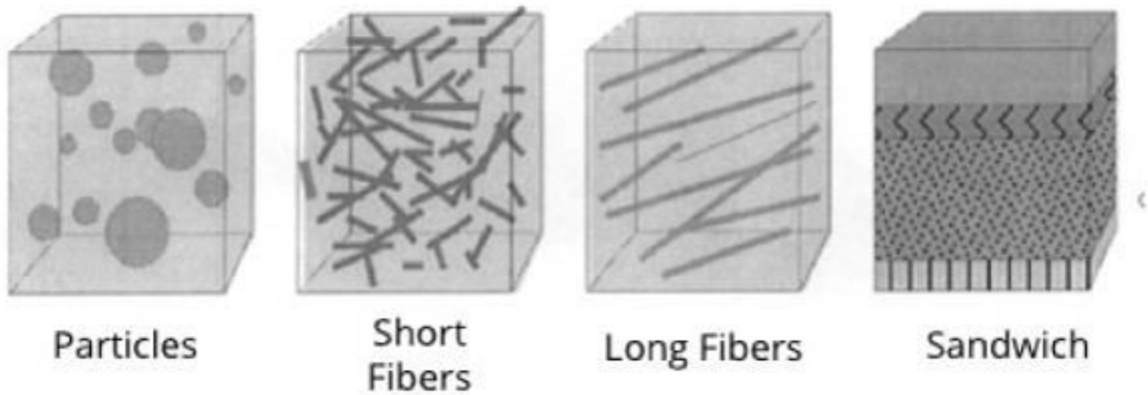
Composition of Composites



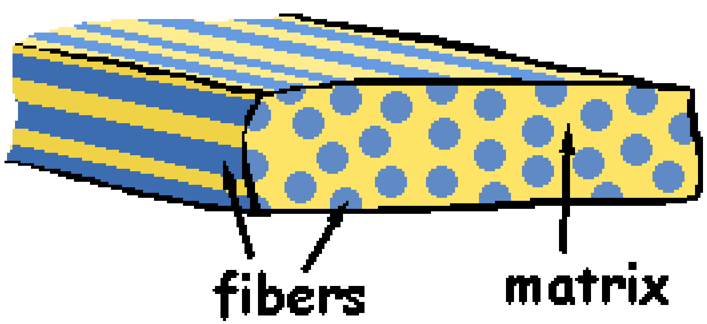

Composite materials
Matrix types
Reinforcement types
Polymeric matrix
Metal matrix
Ceramic matrix
Whisker-reinforced
Particle-reinforced
Fiber-reinforced
Structural
Thermo-plastic
Thermoset
Al, Cu, Ni, Ti
Glass, Cement
Large particle
Dispersion strenghted
Continous
Short
Hybrid
Laminate
Sandwitch
Nylon, PP, ABS, PC, PPS, PPO
Polyester, Vinylester, Epoxy, Phenolic
Uni-directional
Bidirectional
Aligned
Random
Oblique
Orthogonal

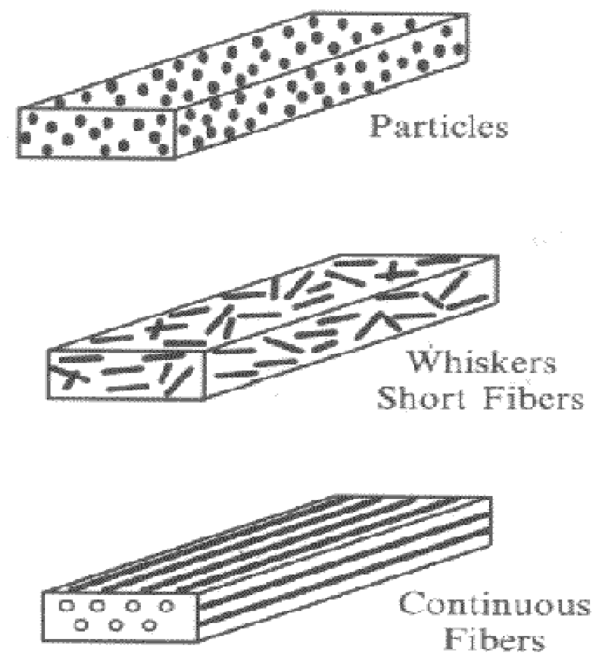
Type of Composites

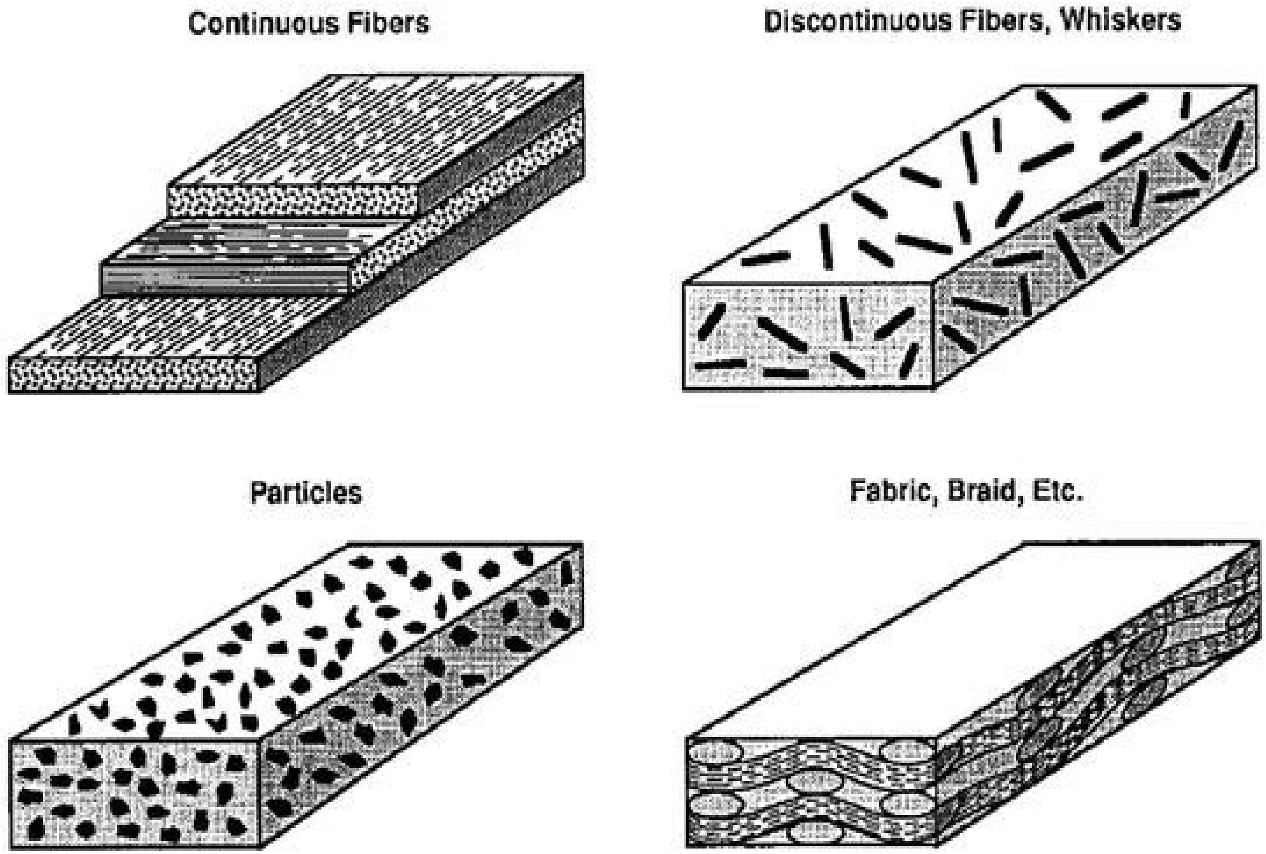


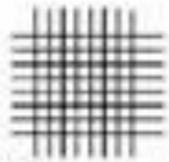
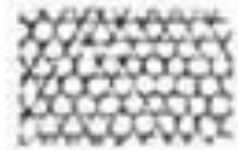
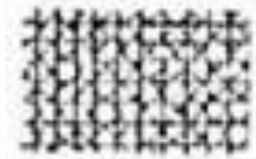
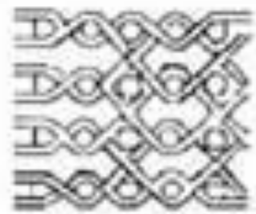
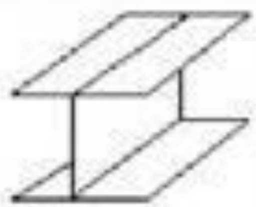
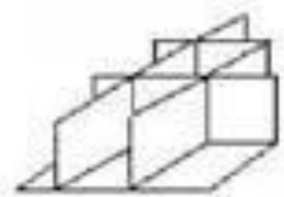
Design and Evaluation of Tribological Coatings, Hogmark, Jacobson, Larsson Wear 246 (2000) 20-33

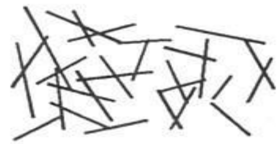
a close-up of what a compostie might look like






Continuous Fibers
Discontinuous Fibers, Whiskers
Particles
Fabric, Braid, Etc.

Axis / Dimens		0 Monoaxial	1 Nonaxial	2 Biaxial	3 Triaxial	4 Multiaxial
1D			 Roving yarn			
2D		 Chopped strand mat	 Preimpregnation sheet	 Plain weave	 Triaxial weave	 Multiaxial
3D	Linear element		 3D solid braiding	 Multiply weave	 Triaxial 3D weave	 Multiaixial 3D weave
	Plane element		 Laminate	 Beams	 Honeycomb	



Chopped fibers (random)

Oriented short fibers

Fiber/particulate hybrids

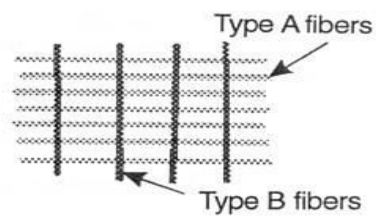
Short fiber hybrids

Unidirectional continuous fibers

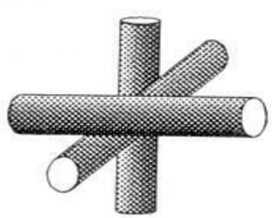
Filament wound cylindrical

Long/interpenetrating

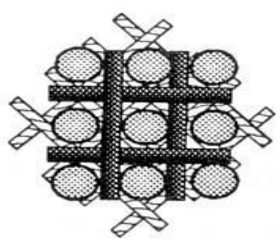
Woven fabrics



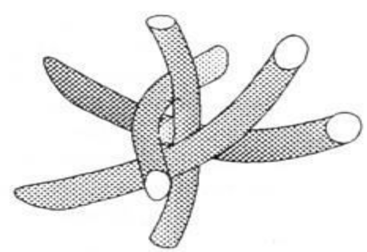
Continuous/hybrid



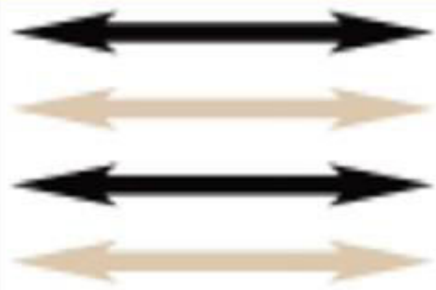
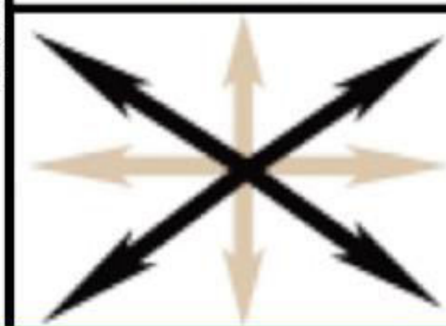
Orthogonal 3-D

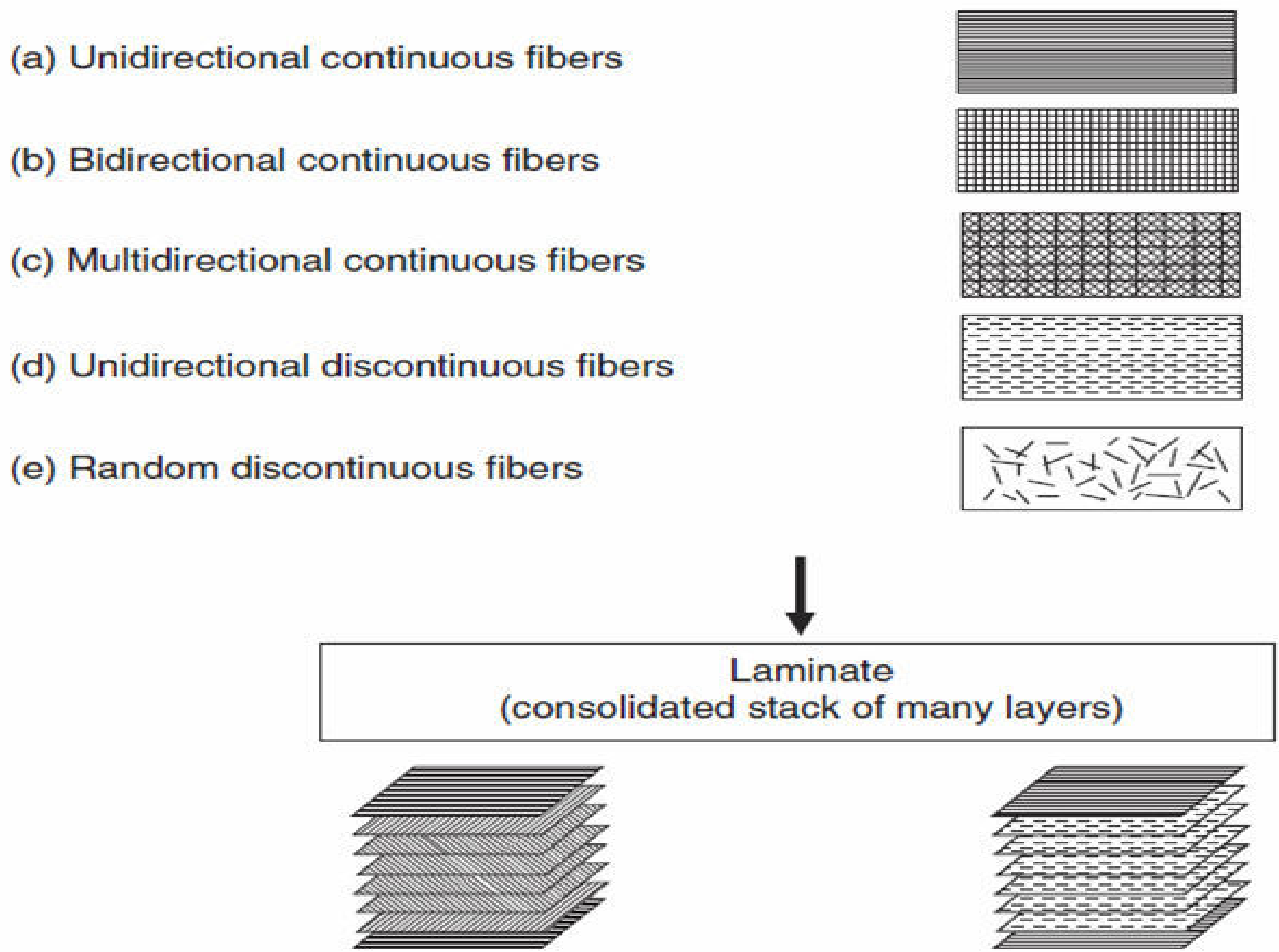


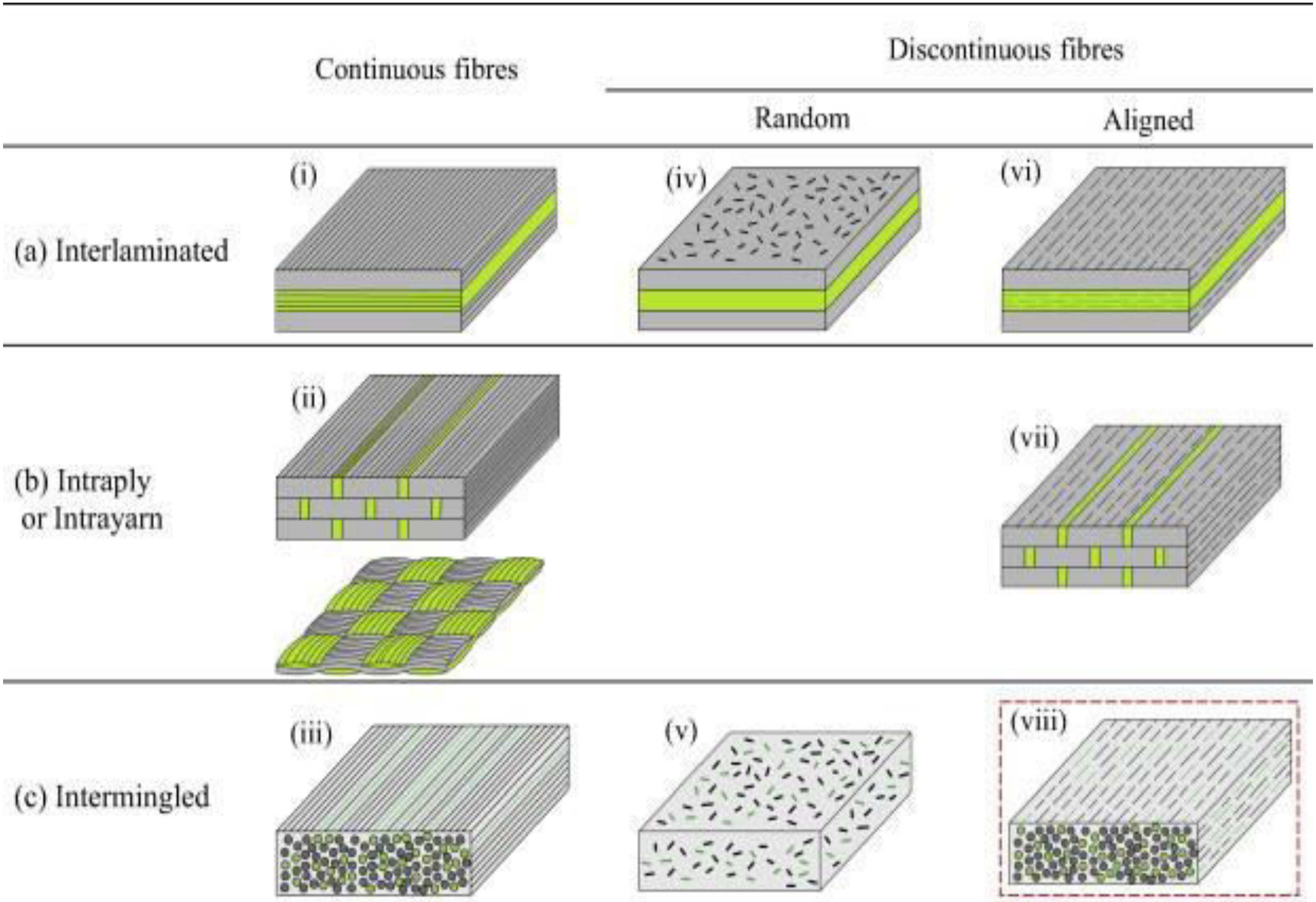
Multi-axial 3-D weave

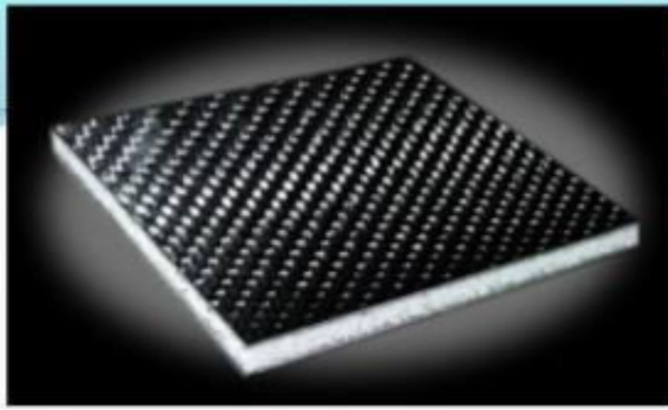


3-D braid

Fiber orientation	Percentage of fiberglass reinforcement increases strength in direction of fiber orientation		Reinforcement types and processes
Unidirectional Fiber Orientation			**Reinforcement types:** Continuous strand roving **Processes:** Continuous pultrusion, compression molding
Bidrectional Fiber Orientation			**Reinforcement types:** Continuous strand roving **Processes:** Filament winding, compression molding **Reinforcement types:** Woven fabrics, woven roving **Processes:** Hand lay-up
Multidirectional FIber Orientation			**Reinforcement types:** Chopped strands, continuous, chopped strand mat tri axial fabric **Processes:** Compression and injection modling, spray-up pressure bag, preform


(a) Unidirectional continuous fibers
(b) Bidirectional continuous fibers
(c) Multidirectional continuous fibers
(d) Unidirectional discontinuous fibers
(e) Random discontinuous fibers
Laminate
(consolidated stack of many layers)


Continuous fibres
Discontinuous fibres
Random
Aligned
(a) Interlaminated
(i)
(iv)
(vi)
(b) Intraply
or Intrayarn
(ii)
(vii)
(c) Intermingled
(iii)
(v)
(viii)



CARBON FIBRE COMPOSITE
COMPOSITE

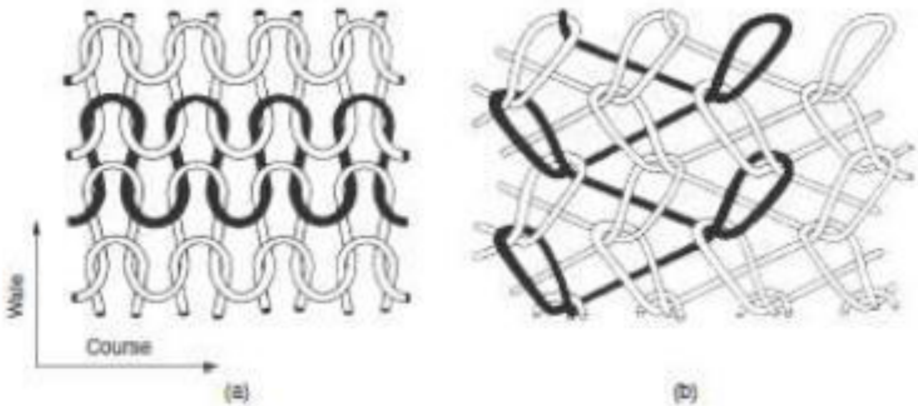
GLASS FIBRE

ARAMID FIBRE COMPOSITE
COMPOSITE

WOVEN FABRIC

Knitted fabric-reinforced composites

The major advantages of knitted fabric-reinforced composites are the possibility of producing net shape/near net shape preforms, on the one hand, and the exceptional drapability/formability of the fabrics, which allows for forming over a shaped tool of complex shape, on the other. Both of these features follow from the interlooped nature of the reinforcing fibres/yarns which permits the fabric to have the stretchability to adapt to complex shapes without crimp.

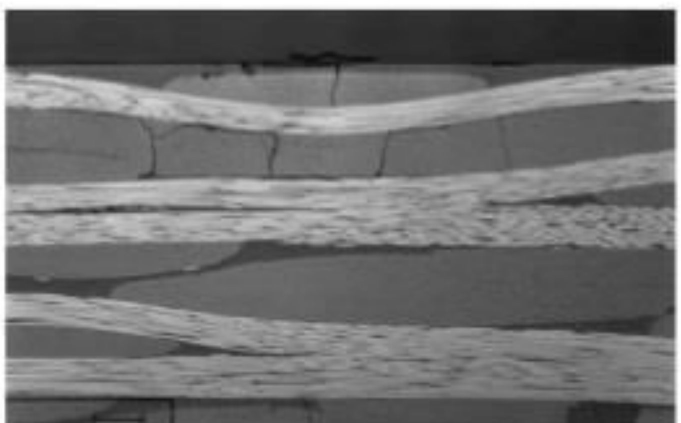


11.6 Schematic diagrams of (a) weft-knitted and (b) warp-knitted reinforcement.

Woven fabric-reinforced composites

Woven fabrics, characterized by the interlacing of two or more yarn systems, are currently the most widely used textile reinforcement with glass, carbon and aramid reinforced .

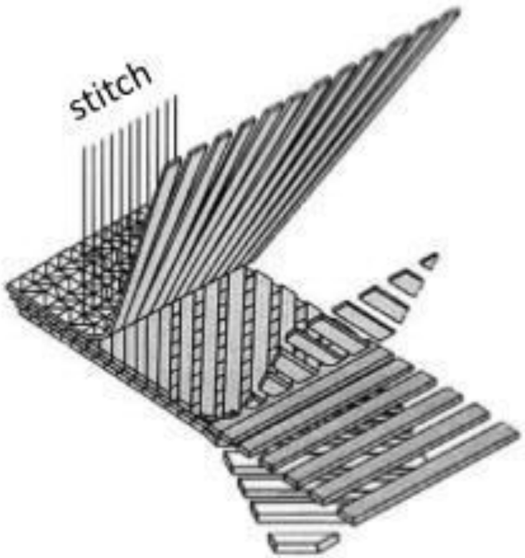
woven composites being used in a wide variety of applications, including aerospace (Fig. 11.4).Woven reinforcement exhibits good stability in the warp and



Optical micrograph of woven composite- side view

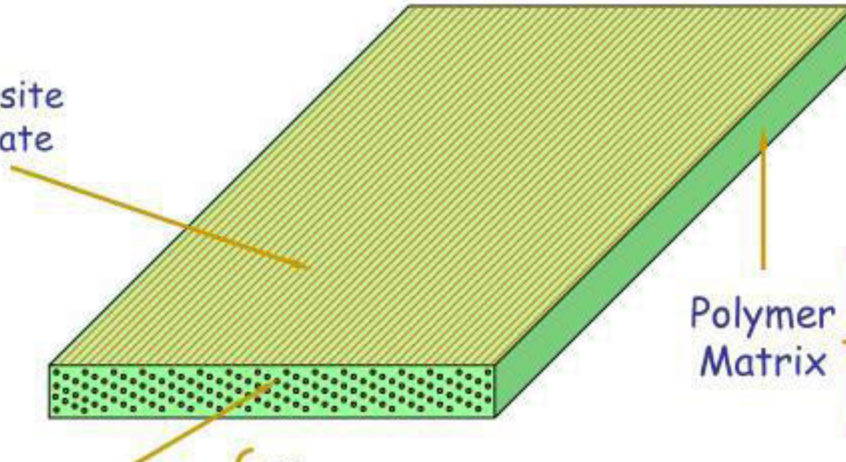
Stitched fabric- reinforcement composites

Stitching of composites adds one further production step with the use of a sewing machine to introduce lock stitches through the full thickness of the laminate. The stitching can be performed on unimpregnated fibres or fibres in the prepreg form, although the latter is usually to be avoided owing to excessive fibre damage. Stitching in this way can be carried out with carbon, glass or aramid fibre yarns.



Fiber-Reinforced Composites

Composite Laminate



Polymer Matrix: Polyester, Epoxy, Vinylester

Fiber Materials: Glass, Aramid (Kevlar), Carbon

Function of fibers:

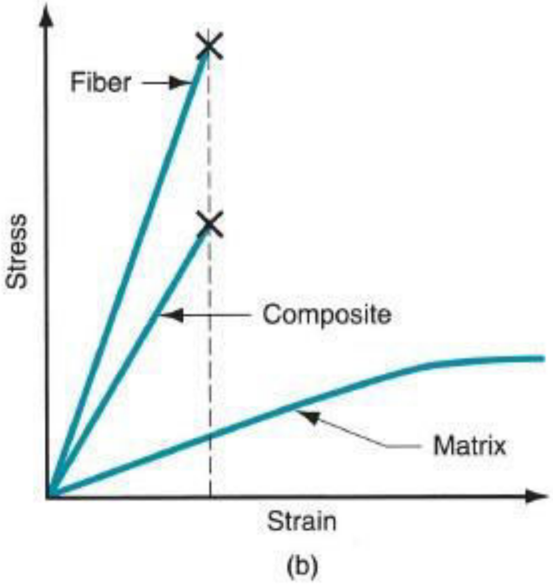
- Provide stiffness
- Tensile strength

Functions of matrix:

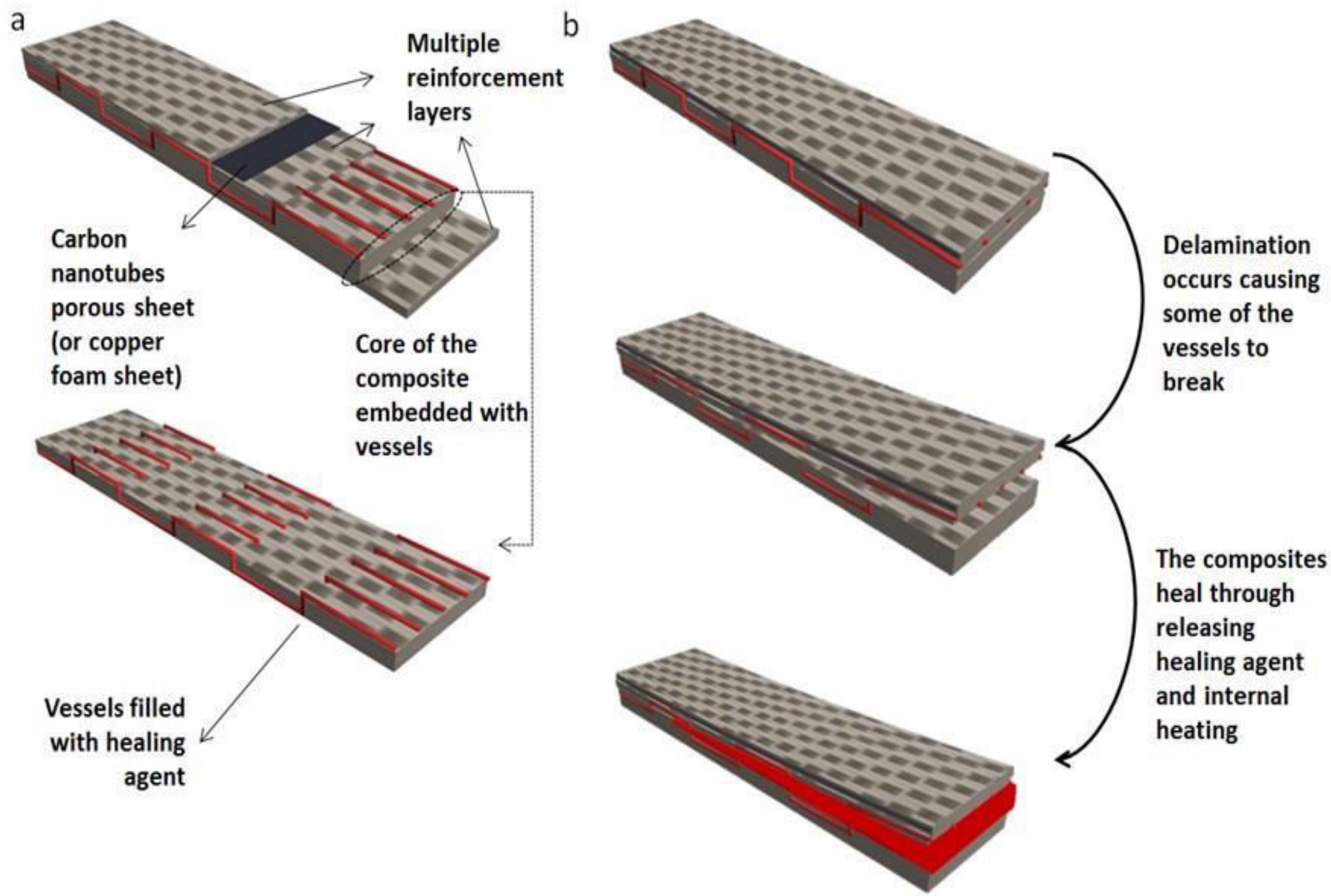
- Force transfer to fibers
- Compressive strength
- Chemical protection

Example: Fiber Reinforced Polymer (continued)

- Stress-strain relationships for the composite material and its constituents
- The fiber is stiff but brittle, while the matrix (commonly a polymer) is soft but ductile



©2010 John Wiley & Sons, Inc. M P Groover, *Fundamentals of Modern Manufacturing* 4/e



a
Multiple reinforcement layers
Carbon nanotubes porous sheet (or copper foam sheet)
Core of the composite embedded with vessels
Vessels filled with healing agent
b
Delamination occurs causing some of the vessels to break
The composites heal through releasing healing agent and internal heating

Fibers

- **Glass Fibers:** Based on an alumina-lime-borosilicate composition, “E” or “E-CR” glass produced fibers are considered the predominant reinforcements for polymer matrix composites due to their high electrical insulating properties, low susceptibility to moisture and high mechanical properties. E-CR glass is further distinguished from E-glass by having superior corrosion resistance properties. Other commercial compositions include “S” glass, with higher strength, heat resistance and modulus, H-glass with higher modulus, and AR glass (alkali resistant) with excellent corrosion resistance. Glass is generally a good impact resistant fiber but weighs more than carbon or aramid. Glass fibers have excellent mechanical characteristics, stronger than steel in certain forms. The lower modulus requires special design treatment where stiffness is critical. Glass fibers are transparent to radio frequency radiation and are used in radar antenna applications.
- **Carbon Fibers:** Carbon fibers are made from organic precursors, including PAN (polyacrylonitrile), rayon, and pitches, with the latter two generally used for low modulus fibers. The terms “carbon” and “graphite” fibers are typically used interchangeably, although graphite technically refers to fibers that are greater than 99 percent carbon composition, versus 93-95 percent for PAN-based carbon fibers. Carbon fiber offers the highest strength and stiffness of all the reinforcement fibers. High temperature performance is particularly outstanding for carbon fibers. The major drawback to PAN-based fibers is their high relative cost, which is a result of the cost of the base material and an energy-intensive manufacturing process. Carbon fiber composites are more brittle than glass or aramid. Carbon fibers can cause galvanic corrosion when used next to metals. A barrier material such as glass and resin is used to prevent this occurrence.
- **Aramid Fibers (Polyaramids):** The most common synthetic fiber is aramid. Aramid fiber is an aromatic polyimid that is a man-made organic fiber for composite reinforcement. Aramid fibers offer good mechanical properties at a low density with the added advantage of toughness or damage/impact resistance. They are characterized as having reasonably high tensile strength, a medium modulus, and a very low density as compared to glass and carbon. Aramid fibers are insulators of both electricity and heat and increase the impact resistance of composites. They are resistant to organic solvents, fuels and lubricants. Aramid composites are not as good in compressive strength as glass or carbon composites. Dry aramid fibers are tough and have been used as cables or ropes, and frequently used in ballistic applications. Kevlar® is perhaps the best known example of aramid fiber. Aramid is the predominant organic reinforcing fiber replacement for steel belting in tires.
- **New Fibers:** Polyester and nylon thermoplastic fibers have recently been introduced both as primary reinforcements and in a hybrid arrangement with fiberglass. Attractive features include low density, reasonable cost, and good impact and fatigue resistance. Although polyester fibers have fairly high strengths, their stiffness is considerably below that of glass. More specialized reinforcements for high strength and high temperature use include metals and metal oxides such as those used in aircraft or aerospace applications.

Reinforcement Forms

Regardless of the material, reinforcements are available in forms to serve a wide range of processes and end-product requirements. Materials supplied as reinforcement include roving, milled fiber, chopped strands, continuous, chopped or thermoformable mat. Reinforcement materials can be designed with unique fiber architectures and be preformed (shaped) depending on the product requirements and manufacturing process.

- **Multi-End and Single-End Rovings:** Rovings are utilized primarily in thermoset compounds, but can be utilized in thermoplastics. Multi-end rovings consist of many individual strands or bundles of filaments, which are then chopped and randomly deposited into the resin matrix. Processes such as sheet molding compound (SMC), preform and spray-up use the multi-end roving. Multi-end rovings can also be used in some filament winding and pultrusion applications. The single-end roving consists of many individual filaments wound into a single strand. The product is generally used in processes that utilize a unidirectional reinforcement such as filament winding or pultrusion.
- **Mats & Veils:** Reinforcing mats and non-woven veils are usually described by weight-per-unit-of-area. For instance, a 2 ounce chopped strand mat will weigh 2 ounces per square yard. The reinforcement type, the fiber dispersion, and amount of binder that is used to hold the mat or veil together dictate differences between mat products. In some processes such as hand lay-up, it is necessary for the binder to dissolve. In other processes, particularly in compression molding, and pultrusion the binder must withstand the hydraulic forces and the dissolving action of the matrix resin during molding. Therefore, from a binder point of view, two general categories of mats or veils are produced and are known as soluble and insoluble binders.
- **Woven, Stitched, Braided & 3-D Fabrics:** There are many types of fabrics that can be used to reinforce resins in a composite. Multidirectional reinforcements are produced by weaving, knitting, stitching or braiding continuous fibers into a fabric from twisted and plied yarn. Fabrics can be manufactured utilizing almost any reinforcing fiber. The most common fabrics are constructed with fiberglass, carbon or aramid. Fabrics offer oriented strengths and high reinforcement loadings often found in high performance applications. Fabrics allow for the precise placement of the reinforcement. This cannot be done with milled fibers or chopped strands and is only possible with continuous strands using relatively expensive fiber placement equipment. Due to the continuous nature of the fibers in most fabrics, the strength to weight ratio is much higher than that for the cut or chopped fiber versions. Stitched fabrics allow for customized fiber orientations within the fabric structure. This can be of great advantage when designing for shear or torsional stability.
- **Unidirectional:** Unidirectional reinforcements include tapes, tows, unidirectional tow sheet and roving (which are collections of fibers or strands). Fibers in this form are all aligned parallel in one direction and uncrimped, providing the highest mechanical properties. Composites using unidirectional tapes or sheets have high strength in the direction of the fiber. Unidirectional sheets are thin and multiple layers are required for

most structural applications. Typical applications for unidirectional reinforcements include highly loaded designed composites, such as aircraft components or race boats.

- **Prepreg:** Prepregs are a ready-made material made of a reinforcement form and polymer matrix. Passing reinforcing fibers or forms such as fabrics through a resin bath is used to make a prepreg. The resin is saturated (impregnated) into the fiber and then heated to advance the curing reaction to different curing stages. Thermoset or thermoplastic prepregs are available and can be either stored in a refrigerator or at room temperature depending on the constituent materials. Prepregs can be manually or mechanically applied at various directions based on the design requirements.
- **Milled:** Milled fibers are chopped fibers having very short fiber lengths (usually less than 1/8”). These products are often used in thermoset putties, castings, or syntactic foams to prevent cracking of the cured composition due to resin shrinkage.

Fibers and its Manufacturing

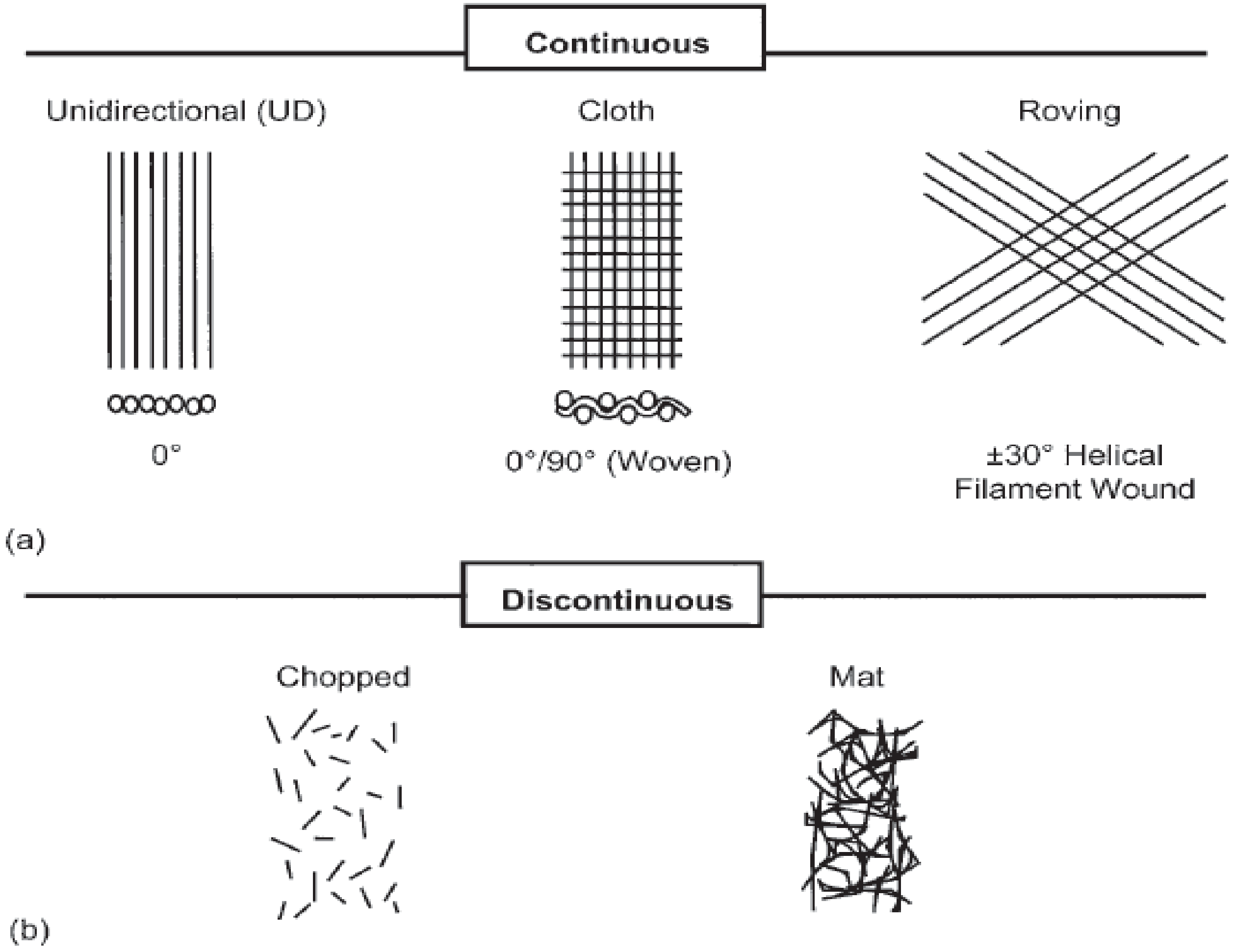
jYOTIPRAKASH

Introduction

Fiber-A general term used to refer to filamentary materials. Often, fiber is used synonymously with filament. It is a general term for a filament of finite length. A unit of matter, either natural or manmade, which forms the basic element of fabrics and other textile structures.

- Fibers provide strength and stiffness relative to matrix.
- Carry tension load.
- Orthotropic.

- Fiber composites consist of matrices reinforced by short (discontinuous) or long (continuous) fibers.



- Discontinuous (fibers are chopped and dispersed in matrix resin)
    - Short fibers: fiber lengths 3mm or less (most injection molded materials)
    - Long fibers: fiber lengths greater than 6 mm. (Some injection molded materials with 6mm fibers, Sheet Molding Compound (SMC) with 1” fibers, DFP Directed Fiber Preforms for RTM and SRIM)
    - Particulates: fibers is forms as spheres, plates, ellipsoids (some injection molded materials reinforced with mineral fibers)
- Continuous (fibers are throughout structure with no break points)
    - Glass roving: glass bundles are wound up in a packet similar to yarn.
    - Roving is woven into several weaves using a loom machine like in apparel.
        - Mat products: random swirl glass pattern.
        - Woven product: roving is woven into machine direction (warp) and cross direction (weft)
        - Uni product: roving is woven in one direction with a cross thread given to hold mat together.

Four fiber factors contribute to the mechanical performance of a composite-

1. Length- can be long or short.
2. Orientation- one direction.
3. Shape- circular.
4. Material- expected to have high elastic moduli and strengths.

– The higher the fiber %, the higher the properties
  - Fiber % for automotive is 35% by volume
  - Fiber % for aerospace is 60% by volume

Typical properties of these fibers compared with bulk steel and aluminum

Property	Units	Graphite	Aramid	Glass	Steel	Aluminum
System of units: USCS						
Specific gravity	—	1.8	1.4	2.5	7.8	2.6
Young's modulus	Msi	33.35	17.98	12.33	30	10.0
Ultimate tensile strength	ksi	299.8	200.0	224.8	94	40.0
Axial coefficient of thermal expansion	μin./in./°F	–0.722	–2.778	2.778	6.5	12.8
System of units: SI						
Specific gravity	—	1.8	1.4	2.5	7.8	2.6
Young's modulus	GPa	230	124	85	206.8	68.95
Ultimate tensile strength	MPa	2067	1379	1550	648.1	275.8
Axial coefficient of thermal expansion	μm/m/°C	–1.3	–5	5	11.7	23

Types of Fiber

Fiberglass, Kevlar®, Carbon, Graphite, Boron, Ceramic Fibers, Lightning Protection Fibers

- Although the terms carbon/Graphite are frequently used interchangeably they are different. Carbon fibers have 93 to 95% carbon content , but graphite has more than 99% carbon content

The most common fibers used are glass, graphite, and Kevlar.

Glass fiber

- consisting of numerous extremely fine fibers of glass.
- They exhibit useful bulk properties such as hardness, transparency, resistance to chemical attack, stability, and inertness, as well as desirable fiber properties such as strength, flexibility, and stiffness.

Types

E-Glass	:	Commonly referred to as lime-alumina borosilicate glass. Primarily used for electrical applications.
S-Glass	:	Contains silicon oxide, aluminium oxide and magnesium oxide (commonly referred to as magnesia-alumina-silicate glass). It is a high tensile strength glass. Tensile strength and modulus of elasticity are nearly 30% and 20% respectively more than that of the E-glass. Primarily used for structural applications.
D-Glass	:	Improved di-electric glass developed for high performance electronic applications.
A-Glass	:	A high alkali or soda glass, used for making bottles or window glass. Contains high alkali content due to which it is susceptible to moisture.
C-Glass	:	A material based on soda borosilicate. It is a chemical glass. Used where greater resistance to acid is required.

L-Glass	:	Silicon dioxide and lead oxide glass, used where radiation protection is required.
T-Glass	:	A recent developed material, having higher tensile strength and modulus; and lower coefficient of thermal expansion than E-glass.
R-Glass	:	A special glass composition that produces fibre, which is alkali resistant and is used in reinforcing concrete.
Low K	:	An experimental fibre produced to improve dielectric loss properties in electricai applications (similar in performance to D-Glass).
Hollow Fibre	:	Special glass whose fibres are tube like or hollow. The material has specific applications in reinforced aircraft parts where weight has special significance.

- Advantages of fiberglass are high strength, lower cost than other composite materials, chemical or galvanic corrosion resistance, and electrical properties (fiberglass does not conduct electricity).

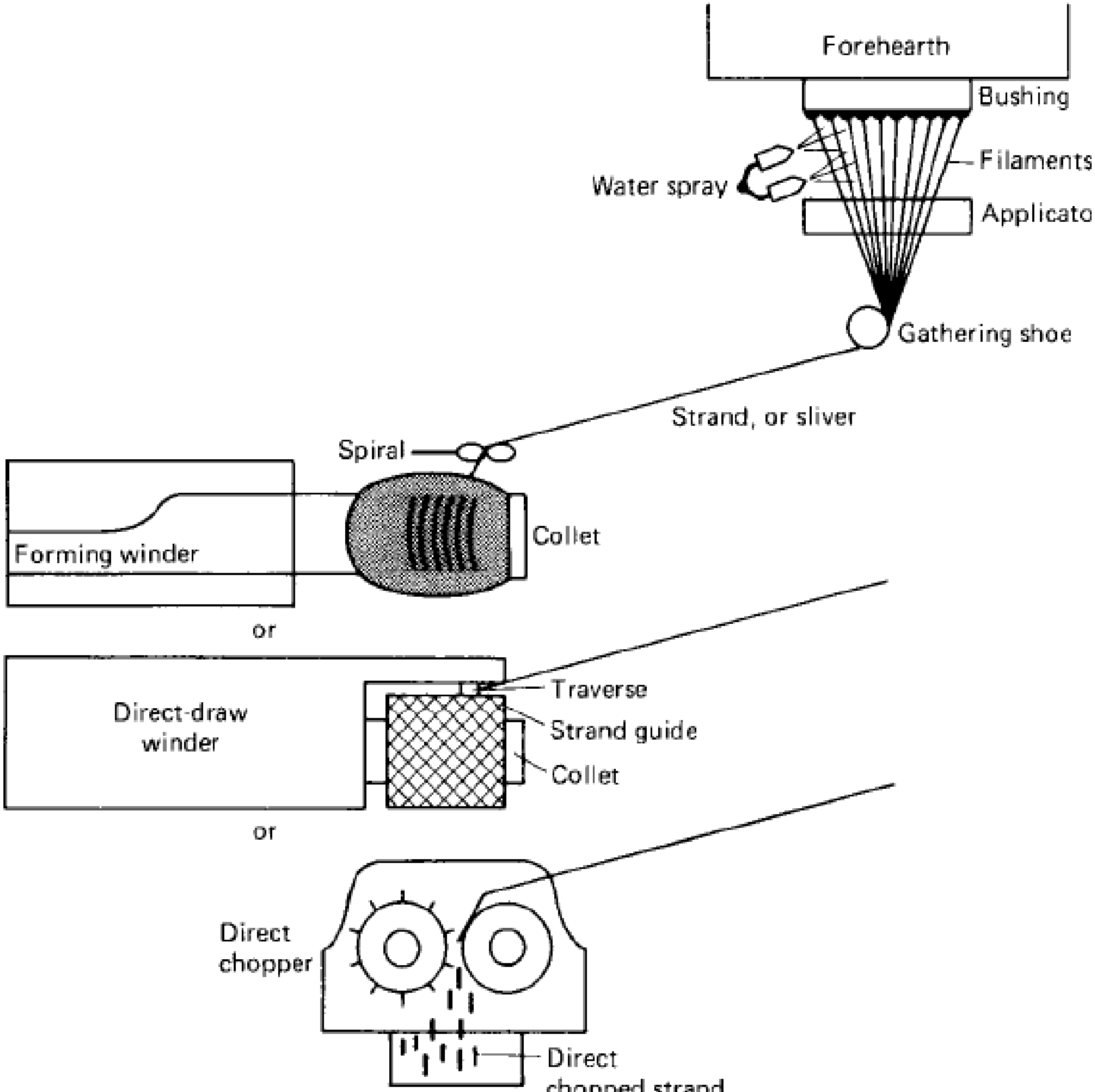
- The drawbacks include low elastic modulus, poor adhesion to polymers, high specific gravity, sensitivity to abrasion (reduces tensile strength), and low fatigue strength.

- Fiberglass has a white color and is available as a dry fiber fabric or prepreg material.

- Fiberglass is often used for secondary structure on aircraft, such as fairings, radomes, and wing tips. Fiberglass is also used for helicopter rotor blades.

Glass Fiber Manufacturing

- Glass fiber manufacturing is the high temperature conversion of various raw materials (predominantly borosilicates) into a homogeneous melt, followed by the fabrication of this melt into glass fibers.
- Glass fiber production can be segmented into 3 phases: raw materials handling, glass melting and refining, and wool glass fiber forming and finishing, this last phase being slightly different for textile and wool glass fiber production.


Forehearth
Bushing
Filaments
Water spray
Applicator
Gathering shoe
Strand, or sliver
Spiral
Collet
Forming winder
or
Traverse
Direct-draw
winder
Strand guide
Collet
or
Direct
chopper
Direct
chopped strand

- The melt is formed in a refractory furnace at about 2550° F (1400°C) from a mixture that includes sand, limestone, and alumina.
- The molten glass flows through a platinum rhodium alloy bushing with a large number of holes or tips (400 to 8000, in typical production).
- A sizing is then applied to the surface of the fibers by passing them over an applicator that continually rotates through the sizing bath to maintain a thin film through which the glass filaments pass.
- The components of the sizing impart strand integrity, lubricity, resin compatibility, and adhesion properties to the final product, thus tailoring the fiber properties to the specific end-use requirements.
- Fibers are then drawn into strands and wound on a forming tube. Strands are groups of more than 204 filaments. The wound array of strands is then removed and dried in an oven to remove any water or sizing solutions.

Graphite

- 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%

UNIDIRECTIONAL GRAPHITE

PLAIN WEAVE GRAPHITE

- 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 inplane modulus
  - Significantly less modulus in out-plane direction
- Graphite fiber have been evaluated for use in aircraft structural components, primarily as a means of reducing the weight of selected metal part. Control surface , fairings, internal structures, and landing gear.
- Weight savings of 15-30% have been demonstrated; and, through less conservative design estimates, saving in excess of 40% appear feasible.

- The advantages of graphite fibers include high specific strength and modulus, low coefficient of thermal expansion, and high fatigue strength and corrosion resistance.

- The drawbacks include high cost, low impact resistance, and high electrical conductivity.

Graphite Manufacturing

- **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.

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) -most popular precursor and the process to manufacture

✓ 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 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.

✓ Inexpensive

Production of Graphite Fibers from PAN

- PAN precursor material is initially spun into fiber form.

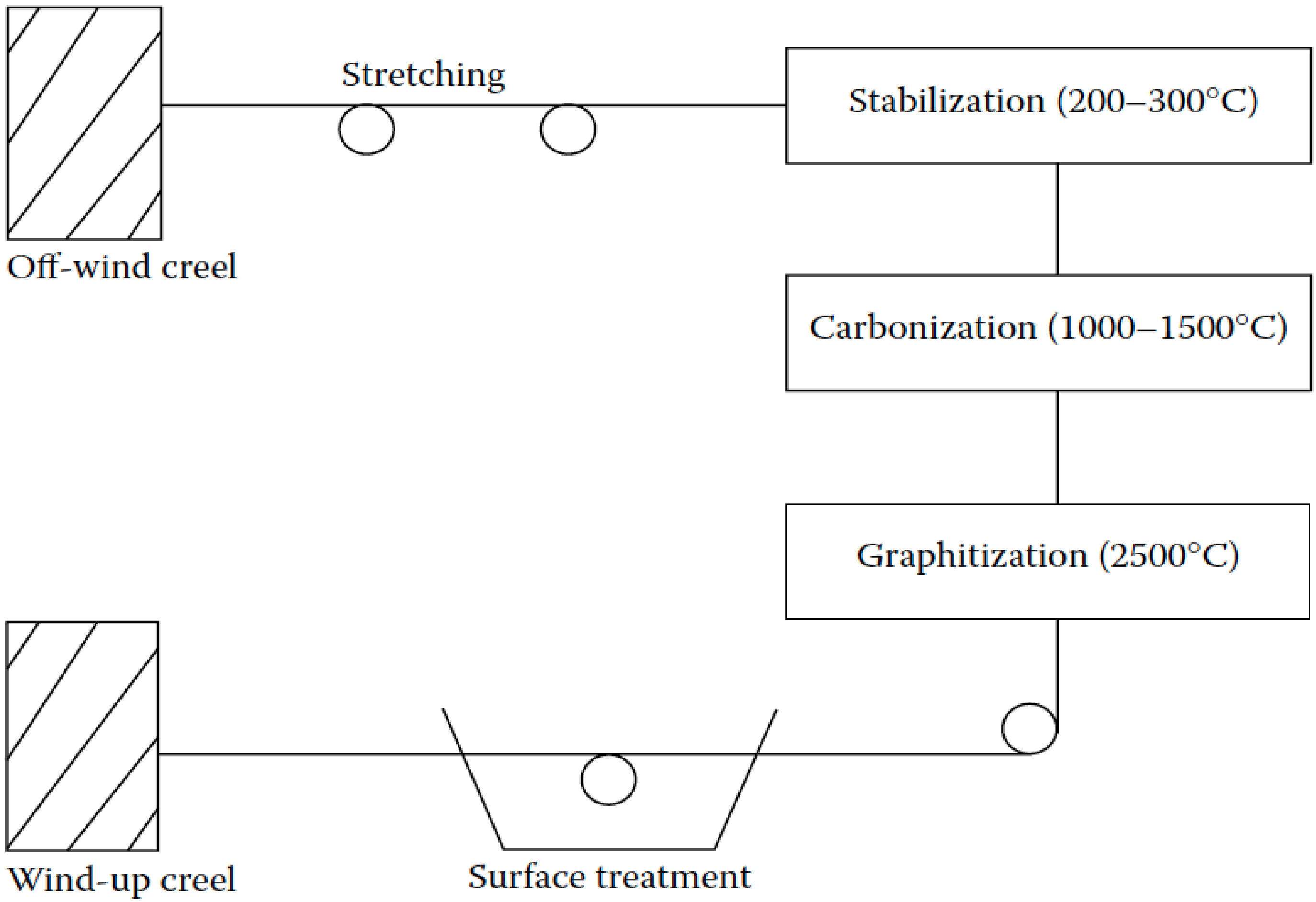
- These precursor fibers are then stretched through application of tensile load.

- 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”.

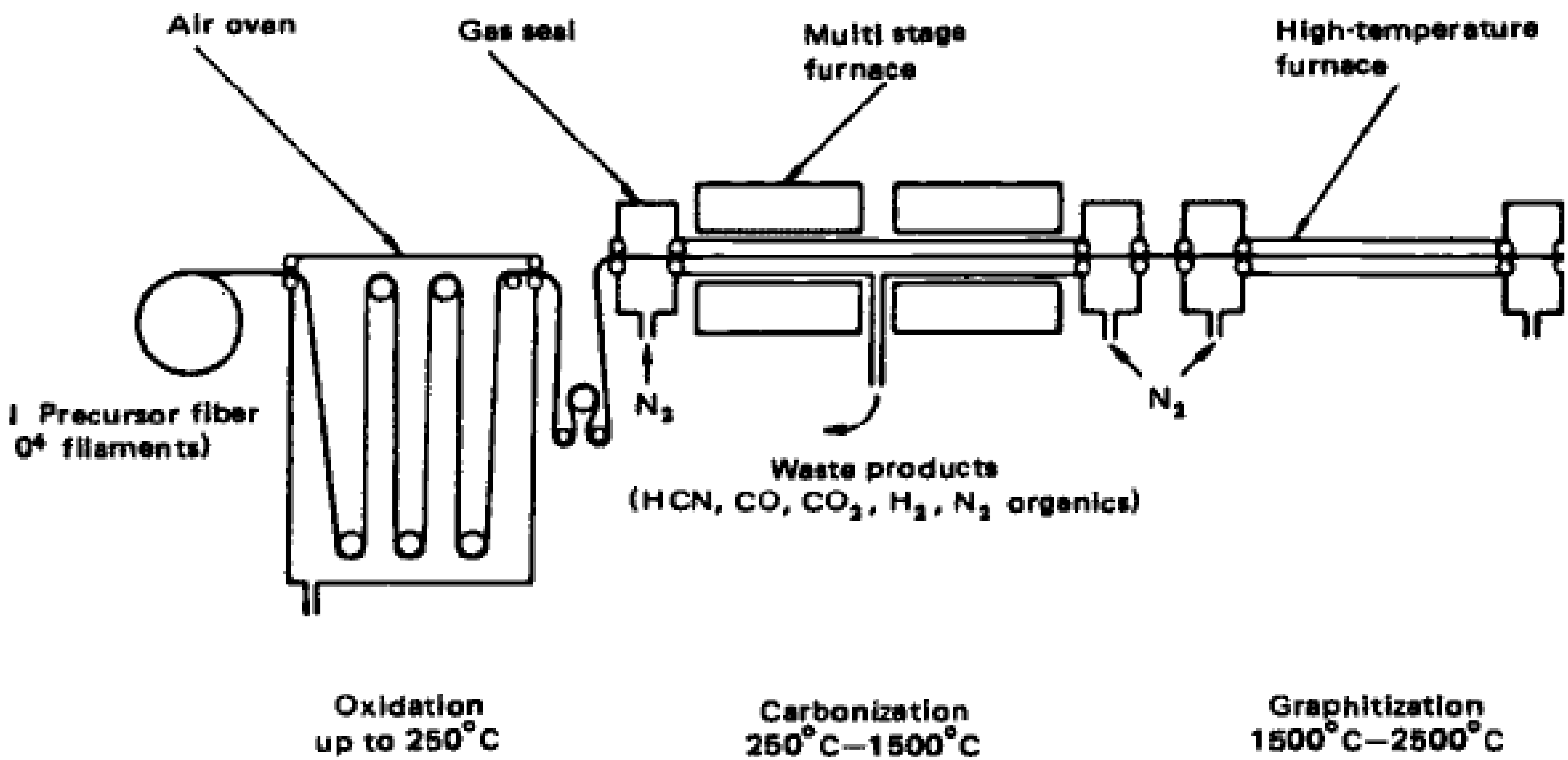
- These stabilized fibers are next subjected to pyrolysis at 1500 C in inert atmosphere. This process is called “carbonization”. During this process, most of non-carbon elements are driven out of PAN fibers.

- Next, these fibers are “graphitized” by heating them at 3000 C in inert environment. This improves tensile modulus of fibers as graphite crystals develop in carbon.

Stages of manufacturing a graphite fiber from PAN-based precursors.



Conversion of PAN fibers into graphite fibers



Overview of Different Types of Graphite Fibers

- PAN based carbon fibers:
  - Low cost
  - 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
  - Low thermal conductivity: Useful for insulation materials, and heat shields
  - Used in rocket nozzles, missile re-entry nose cones, heat insulators

Important Properties of Graphite Fibers

Important Properties of Graphite Fibers

Property	**PAN**	**Pitch**	**Rayon**
Fiber diameter (microns)	5 to 8	10 to 11	6.5
Specific gravity	1.71 to 1.96	2.0 to 2.2	1.7
Tensile modulus (GPa)	230 to 595	170 to 980	415 to 550
Tensile strength (MPa)	1925 to 6200	2275 to 4060	2070 to 2760
Elongation at failure (%)	0.40 to 1.20	0.25 to 0.70	
CTE (Axial, X 1E-06/C)	-0.75 to -0.40	-1.6 to -0.90	
Thermal conductivity (W/m-K)	20-80	400-1100	

Kevlar®

- Kevlar® is DuPont's name for aramid fibers.
- An aramid fiber is an aromatic organic compound made of carbon, hydrogen, oxygen, and nitrogen.
- Two types of Aramid fiber are used in the aviation industry.

✓ Kevlar® 49 has a high stiffness.

✓ Kevlar® 29 has a low stiffness.

Properties of Kevlar Fibers

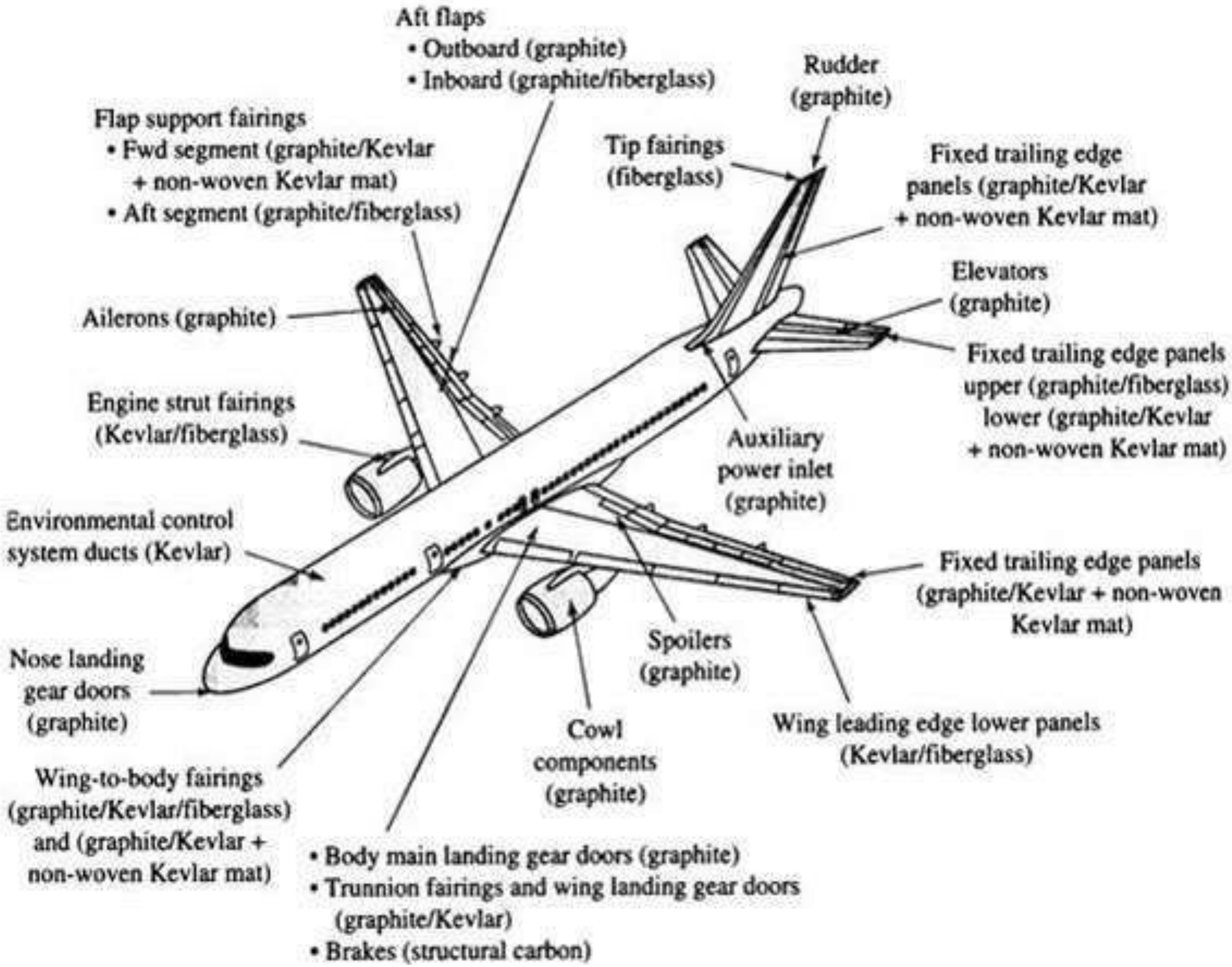
Property	Units	Kevlar 29	Kevlar 49
System of units: USCS			
Specific gravity	—	1.44	1.48
Young's modulus	Msi	9	19
Ultimate tensile strength	ksi	525	525
Axial coefficient of thermal expansion	µin./in./°F	–1.111	–1.111
System of units: SI			
Specific gravity	—	1.44	1.48
Young's modulus	GPa	62.05	131.0
Ultimate tensile strength	MPa	3620	3620
Axial coefficient of thermal expansion	µm/m/°C	–2	–2

- Both types of Kevlar fibers have similar specific strengths, but Kevlar 49 has a higher specific stiffness
- High performance applications in the aircraft industry use Kevlar 49.

- Aramid fibers are light weight, strong, and tough. An advantage of aramid fibers is their high resistance to impact damage, so they are often used in areas prone to impact damage.
- Its drawbacks include low compressive properties, degradation in sunlight and hygroscopy.
- Another disadvantage is that Kevlar® is difficult to drill and cut.
- It has a natural yellow color and is available as dry fabric and prepreg material.
- Kevlar® 49 is used for specialist boat hulls and in the aerospace industry.
- Kevlar® is used as a reinforcement material for some car tyres and bicycle tyres. It helps dramatically reduce puncture rates.
- Kevlar® 29 is used in the manufacture of body armour (panels) for lightweight military vehicles.

Manufacturing Kevlar®

- The fiber is produced by making a solution of proprietary polymers and strong acids such as sulfuric acid. The solution is then extruded into hot cylinders at 392°F (200° C) washed, and dried on spools. The fiber is then stretched and drawn to increase its strength and stiffness.



Aft flaps
• Outboard (graphite)
• Inboard (graphite/fiberglass)
Rudder (graphite)
Flap support fairings
• Fwd segment (graphite/Kevlar + non-woven Kevlar mat)
• Aft segment (graphite/fiberglass)
Tip fairings (fiberglass)
Fixed trailing edge panels (graphite/Kevlar + non-woven Kevlar mat)
Elevators (graphite)
Ailerons (graphite)
Fixed trailing edge panels upper (graphite/fiberglass) lower (graphite/Kevlar + non-woven Kevlar mat)
Engine strut fairings (Kevlar/fiberglass)
Auxiliary power inlet (graphite)
Environmental control system ducts (Kevlar)
Fixed trailing edge panels (graphite/Kevlar + non-woven Kevlar mat)
Nose landing gear doors (graphite)
Spoilers (graphite)
Cowl components (graphite)
Wing leading edge lower panels (Kevlar/fiberglass)
Wing-to-body fairings (graphite/Kevlar/fiberglass) and (graphite/Kevlar + non-woven Kevlar mat)
• Body main landing gear doors (graphite)
• Trunnion fairings and wing landing gear doors (graphite/Kevlar)
• Brakes (structural carbon)

Ceramic Matrix Composites

Ceramic Matrix Composites

- ***Ceramic materials* are in general brittle, and, according to the fracture mechanics, the strength is governed by the flaw size and the fracture toughness.**
- **General approaches for producing strong ceramics are to reduce the maximum size of processing flaws or to enhance the fracture toughness.**

Ceramic Matrix Composites

- **The former approach, however, is limited by the nature of the microstructure of ceramics, since a grain boundary itself can be a flaw responsible for brittle fracture, and surface flaws generated in use may also reduce the strength of ceramics.**
- **The fracture toughness of ceramics is improved by introduction of secondary phases into matrix materials when the secondary phases are chosen to act as barriers to crack propagation.**

Ceramic Matrix Composites

- **Whiskers introduced into a ceramic matrix, for example, can retard the crack propagation because the stresses in a whisker spanning the crack plane will tend to pull the crack shut. This phenomenon, known as "crack bridging", leads to higher fracture toughness due to the additional stress required for further propagation of the crack**

Ceramic Matrix Composites

Ceramic matrix composites may be classified into two categories:-

- ✓ **Toughened Ceramics Reinforced with Particulates and Whiskers** and their properties are exhibit brittle behavior in spite of considerable improvements in fracture toughness and strength. The maximum in **fracture toughness** is around **10 MPa.m$^{1/2}$** or more.

- ✓ **Continuous-fiber Composites,** the **fracture toughness** of this class of materials can be higher than **20 MPa.m$^{1/2}$** when produced with weak interfaces between the fibers and matrix.

Ceramic Matrix Composites

Some important point that should be considered when study Ceramic-Matrix Composites :-

- The matrix is relatively hard and brittle.
- The reinforcement must have high tensile strength to arrest crack growth.
- The reinforcement must be free to pull out as a crack extends, so the reinforcement-matrix bond must be relatively weak

TYPES OF FIBERS AND WHISKERS FOR *REINFORCEMENT*

Types of Fibers and whiskers for reinforcement (typical diameters – fibers 10 µm, whiskers 1-5 µm):-

- Carbon fibers
- SiC fibers
- Oxide fibers (glass fibers, mullite fibers, zirconia fibers, alumina fibers)
- SiC whiskers

Types of Ceramic-Matrix *Composites*

- Carbon- Carbon Composites
- Glass-Matrix Composites
- SiC- SiC Composites
- Eutectic Composites (Al_2O_3-$Y_3Al_5O_{12}$)

The choice of method is *determined by*

The choice of method is determined by the:-

- ✓ Geometry,
- ✓ The complexity of shape and
- ✓ The production volume of the component
- ✓ To put a ***rigidized or densified matrix*** in place, the precursor of the matrix has to be positioned within the mass of reinforcement. This can be done by a ***number of methods***:-

- Powder dispersion
- Liquid precursors
- Gaseous infiltration

Powder Dispersion

Impregnating the reinforcement with a suspension of matrix precursor in powder form, either by passing the reinforcement through a slurry or by pressure impregnation of a preform, or by electrophoretic infiltration.

Liquid Precursors

- Impregnating the reinforcement preform with a liquid organic or organometallic or inorganic substance, typically a polymer or a sol, which on heating rigidizes by curing or gelling, and then decomposes to leave a ceramic matrix.

Gaseous infiltration

- Using a reactive gas mixture which deposits a ceramic material within a preform of the reinforcement, commonly known as chemical vapor deposition (CVD) or chemical vapor infiltration (CVI), and typically performed at high temperature.

Ceramic-Matrix Composites
may be fabricated using these methods

- Hot Pressing
- Hot Isostatic Pressing
- Liquid Phase Sintering Techniques

APPLICATION

CMC materials overcome the major disadvantages of conventional technical ceramics, namely brittle failure and low fracture toughness, and limited thermal shock resistance. Therefore, their **applications** are in fields requiring reliability at high-temperatures (beyond the capability of metals) and resistance to corrosion and wear. These include:-

APPLICATION

- Heat shield systems for space vehicles, which are needed during the re-entry phase, where high temperatures, thermal shock conditions and heavy vibration loads take place.
- Components for high-temperature gas turbines such as combustion chambers, stator vanes and turbine blades.
- Components for burners, flame holders, and hot gas ducts, where the use of oxide CMCs has found its way.

Application

- Brake disks and brake system components, which experience extreme thermal shock (greater than throwing a glowing part of any material into water).
- Component for slide bearings under heavy loads requiring high corrosion and wear resistance.

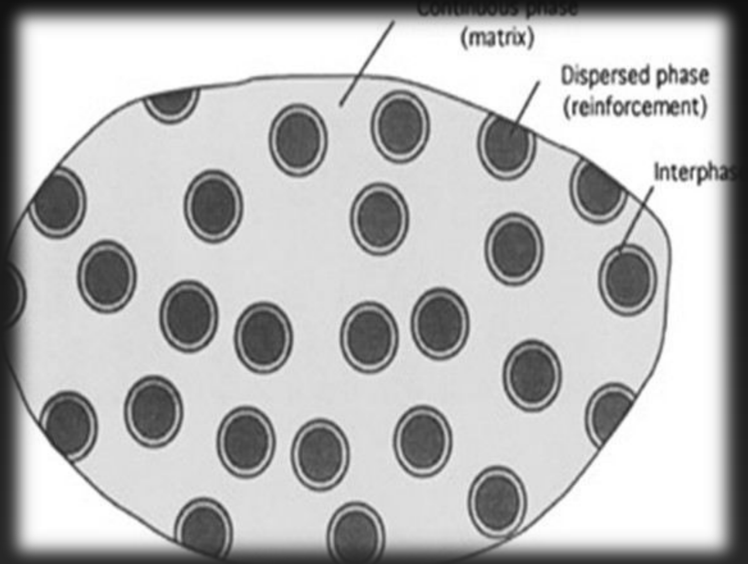
Fig (1) Shows Ceramic Matrix Composite Turbine Blade

Carbon-Carbon Composites

What Is a Composite

- A "composite" is when two or more different materials are combined together to create a superior and unique material.

- Composite = matrix + fiber (filler)



Phases In Composite

- Continuous Phase – Matrix/Binder

- Dispersed Phase – Reinforcement/Filler

- Interphase – An interface between matrix and filler

PROPERTIES OF COMPOSITES

- HIGH STRENGTH TO WEIGHT RATIO
- LIGHTWEIGHT
- FIRE RESISTANCE
- ELECTRICAL PROPERTIES
- CHEMICAL & WEATHERING RESISTANCE
- COLOUR
- DESIGN FLEXIBILITY
- LOW THERMAL CONDUCTIVITY
- MANUFACTURING ECONOMY

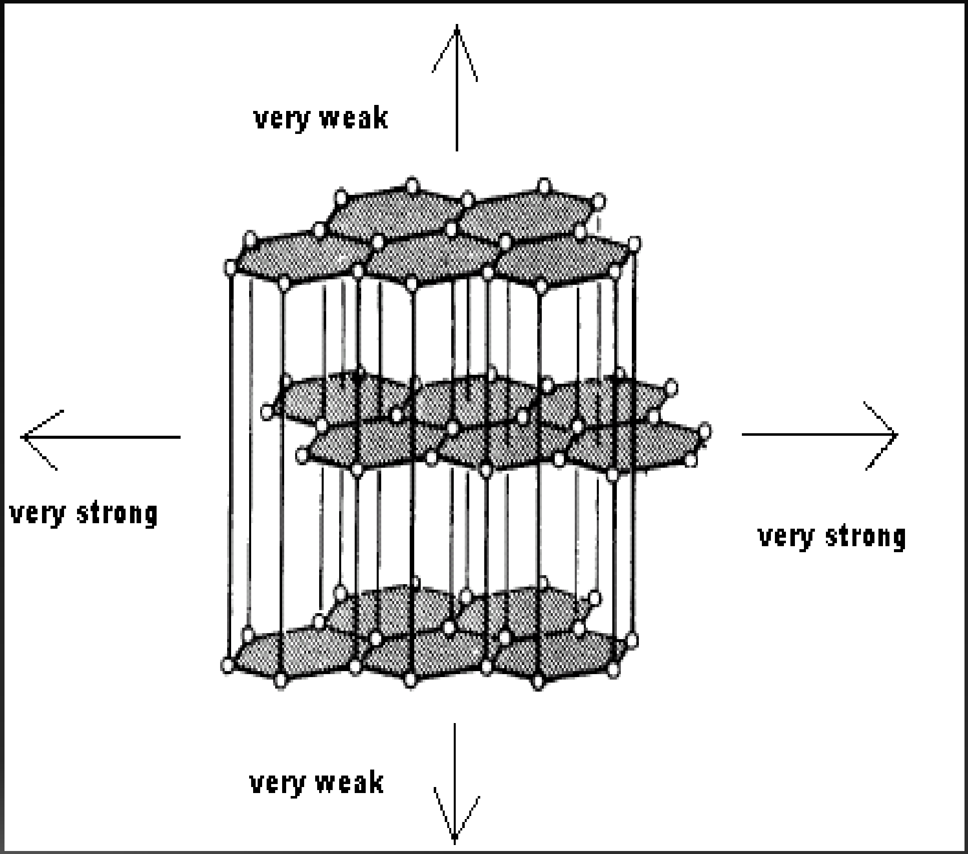
Classification Of Composite

➢ Based On Matrix Material

1. Polymer Matrix Composites (PMC)
2. Metal Matrix Composites (MMC)
3. Ceramic Matrix Composites (CMC)
4. Carbon – Carbon Composites (CCC)
5. Bulk Metallic Glass Composites (BMGC)

Carbon – Carbon Composites (CCC)

- Is also known as Carbon Fiber - Reinforced Carbon Composite (CFRCC).
- Amorphous carbon matrix composite.
- Carbon matrix reinforced by graphitic carbon fibers.
- First developed in 1958, but not intensively researched until the Space Shuttle Program.



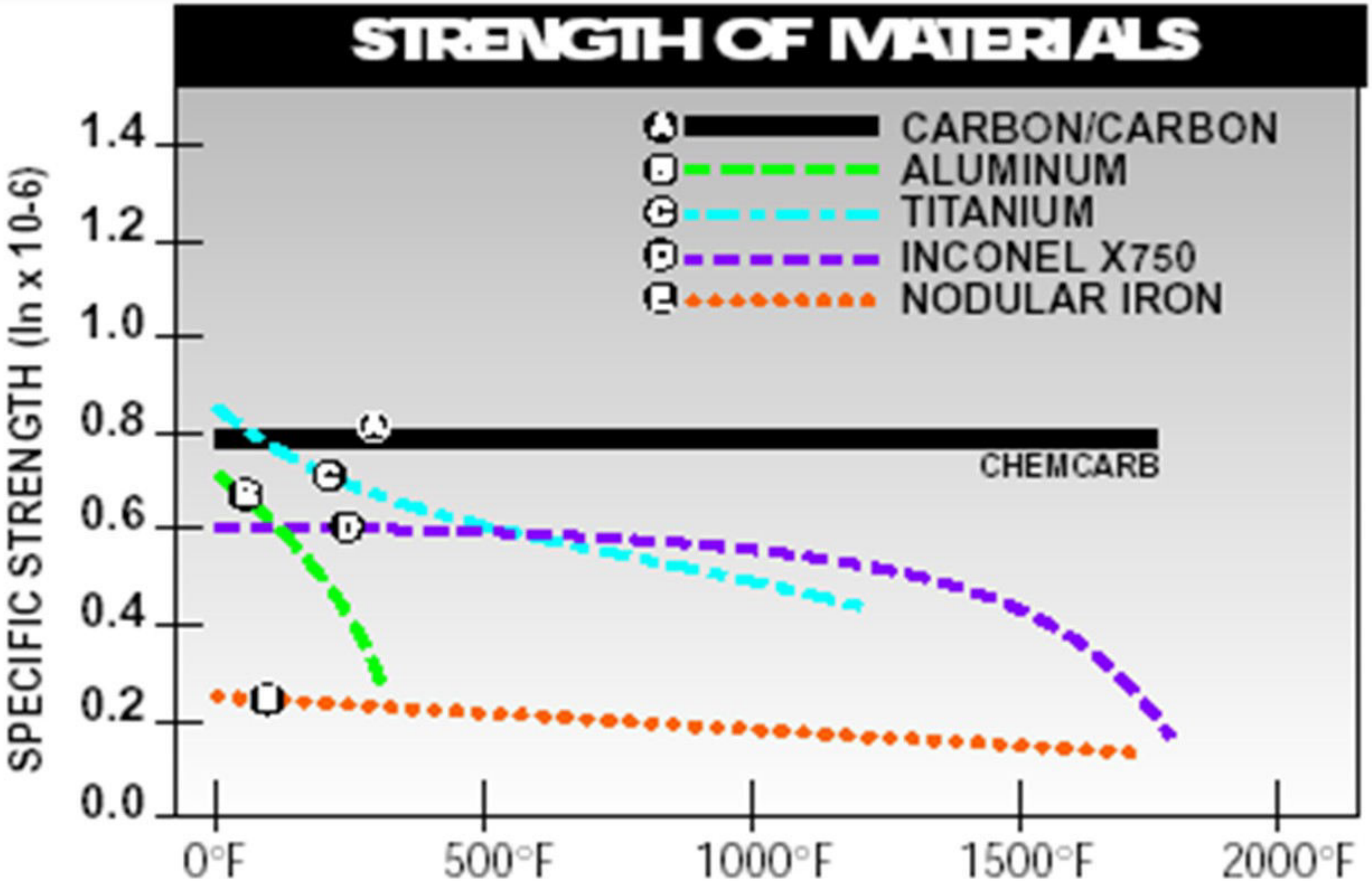
Carbon – Carbon Composites (CCC)

- Carbon Carbon Composites are those special composites in which both the reinforcing fibers and the matrix material are both pure carbon.
- Carbon-Carbon Composites are the woven mesh of Carbon-fibers.
- Carbon-Carbon Composites are used for their high strength and modulus of rigidity.
- Carbon-Carbon Composites are light weight material which can withstand temperatures up to 3000°C.
- Carbon-Carbon Composites' structure can be tailored to meet requirements.

Properties Of C–C Composites (CCC)

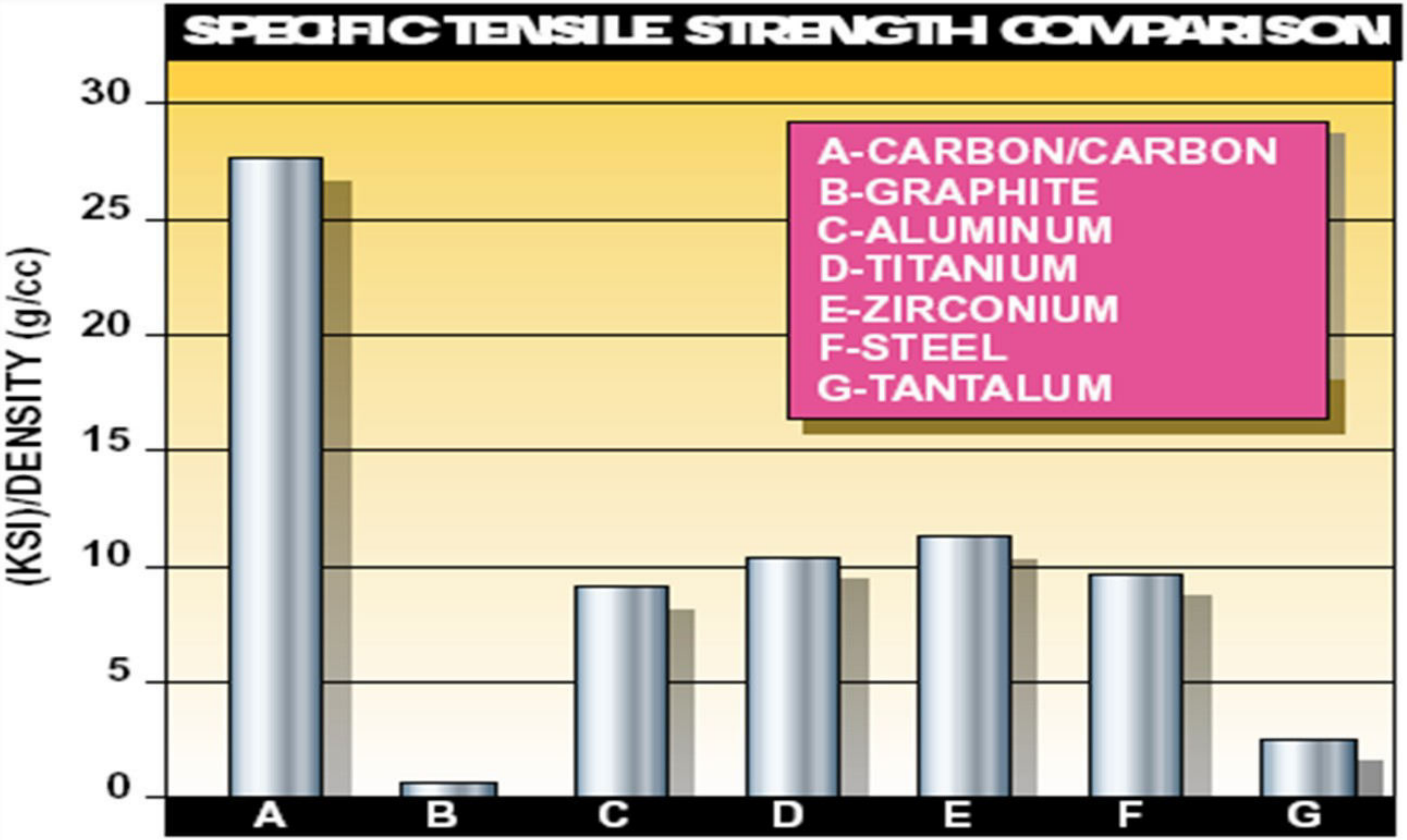
- Excellent Thermal Shock Resistance(Over 2000^{o}C)
- Low Coefficient of Thermal Expansion
- High Modulus of Elasticity (200 GPa)
- High Thermal Conductivity (100 W/m*K)
- Low Density (1830 Kg/m^3)
- High Strength
- Low Coefficient of Friction (in Fiber direction)
- Thermal Resistance in non-oxidizing atmosphere
- High Abrasion Resistance
- High Electrical Conductivity
- Non-Brittle Failure

Properties Of C–C Composites (CCC)



CHEMCARB composites retain their physical properties even at temperatures exceeding 3,700°F.

Properties Of C–C Composites (CCC)

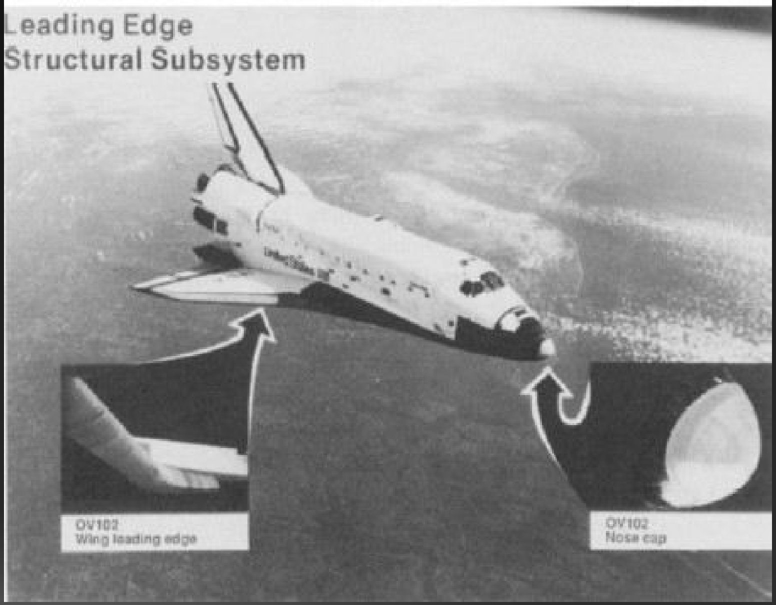


For its density, CHEMCARB composites offer outstanding tensile strength, exceeding that of many metals..

Uses of Carbon-Carbon Composites

- Aircraft, F-1 racing cars and train brakes
- Space shuttle nose tip and leading edges
- Rocket nozzles and tips

http://www.fibermaterialsinc.com/frSW.htm

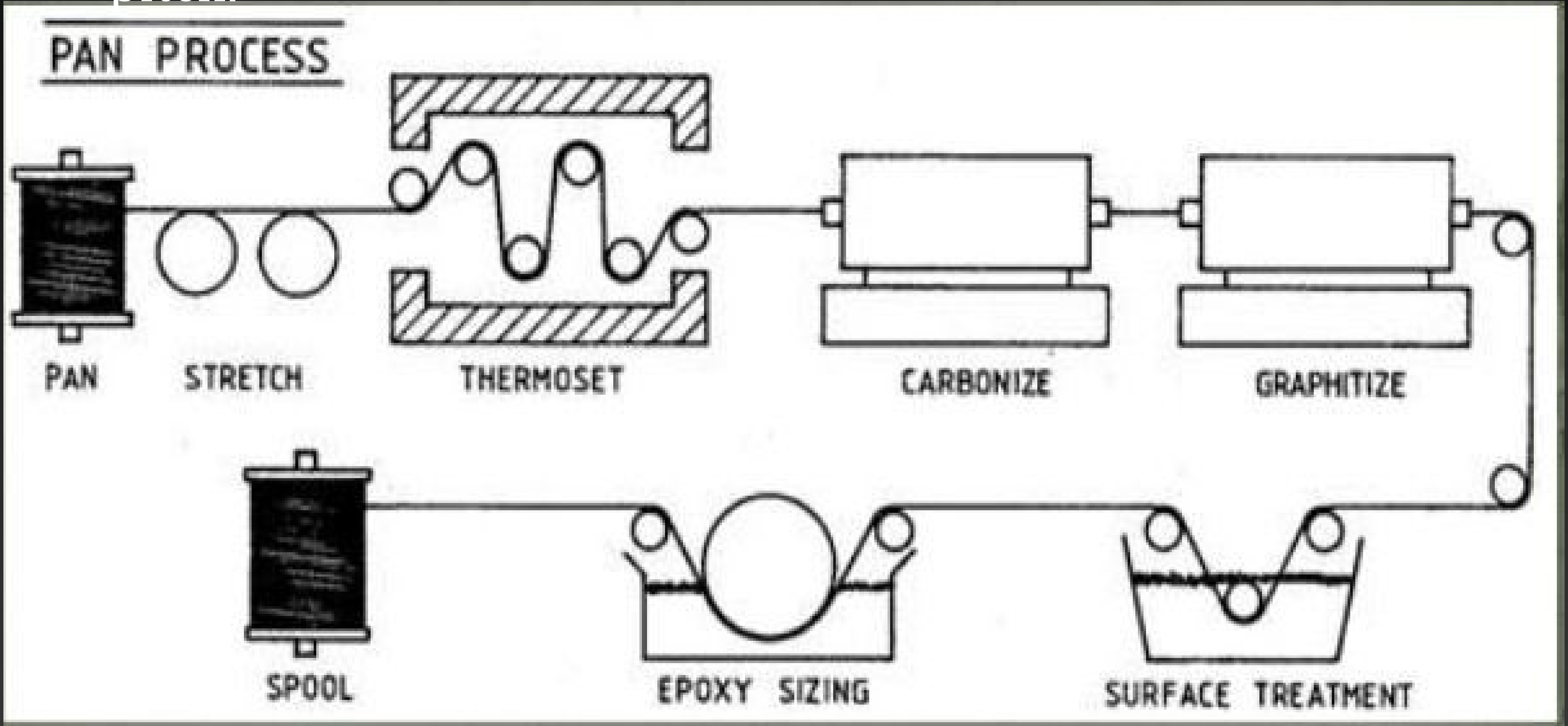


http://www.futureshuttle.com/conference/ThermalProtectionSystem/Curry_73099.pdf

http://www.fibermaterialsinc.com/frSW.htm

Processing Of Carbon Fiber

- About 90% of the **carbon fibers** produced are made from **polyacrylonitrile** (**PAN**) process.
- The remaining 10% are made from rayon or petroleum pitch.



Processing Of Carbon Fiber

PAN-PROSSES

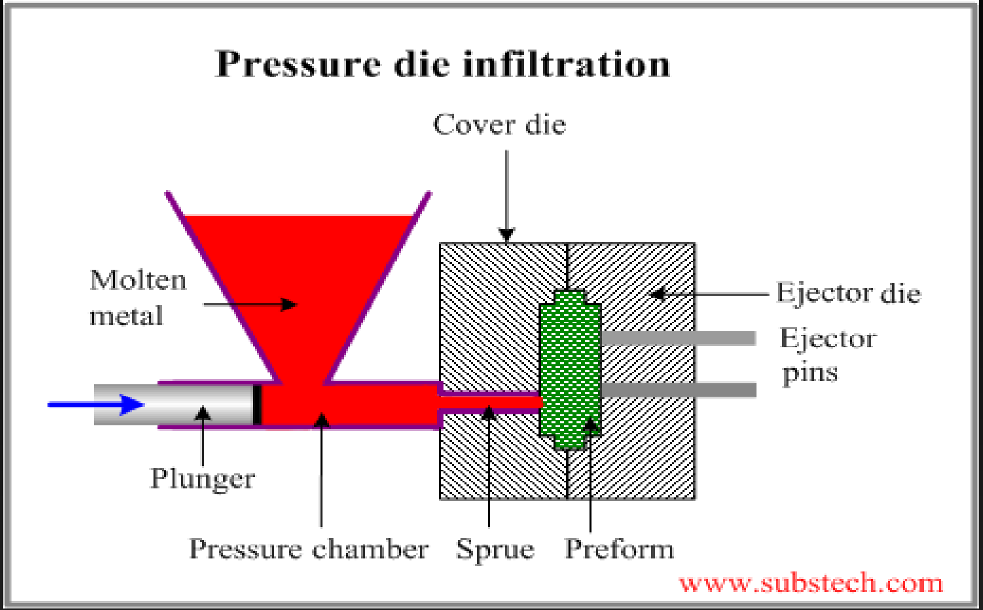
- In this method carbon fibers are produced by conversion of polyacrylonitrile (PAN) precursor through the following stages:
  Stretching filaments from polyacrylonitrile precursor and their thermal oxidation at 200°C.

- The filaments are held in tension. Carbonization in Nitrogen atmosphere at a temperature about 1200°C for several hours.

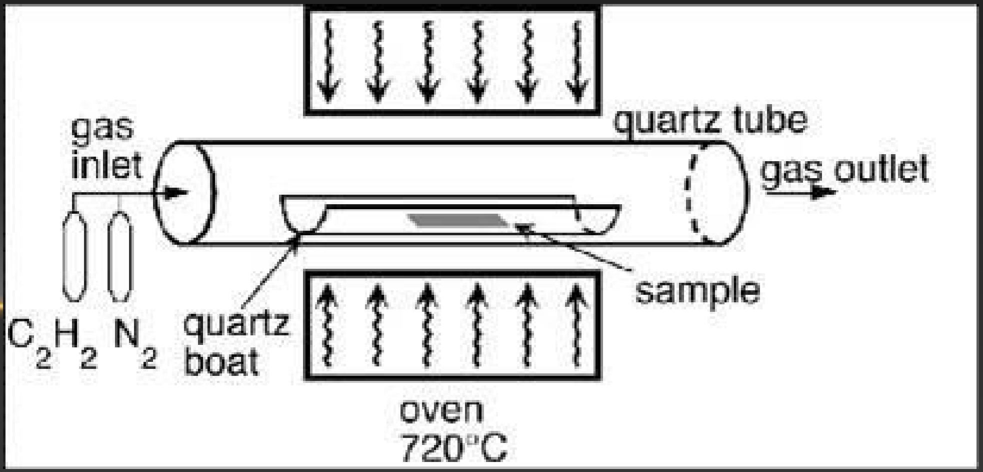
- During this stage non-carbon elements (O,N,H) volatilize resulting in enrichment of the fibers with carbon. Graphitization at about 2500°C.

Fabrication Of C-C Composite

- Liquid Phase Infiltration



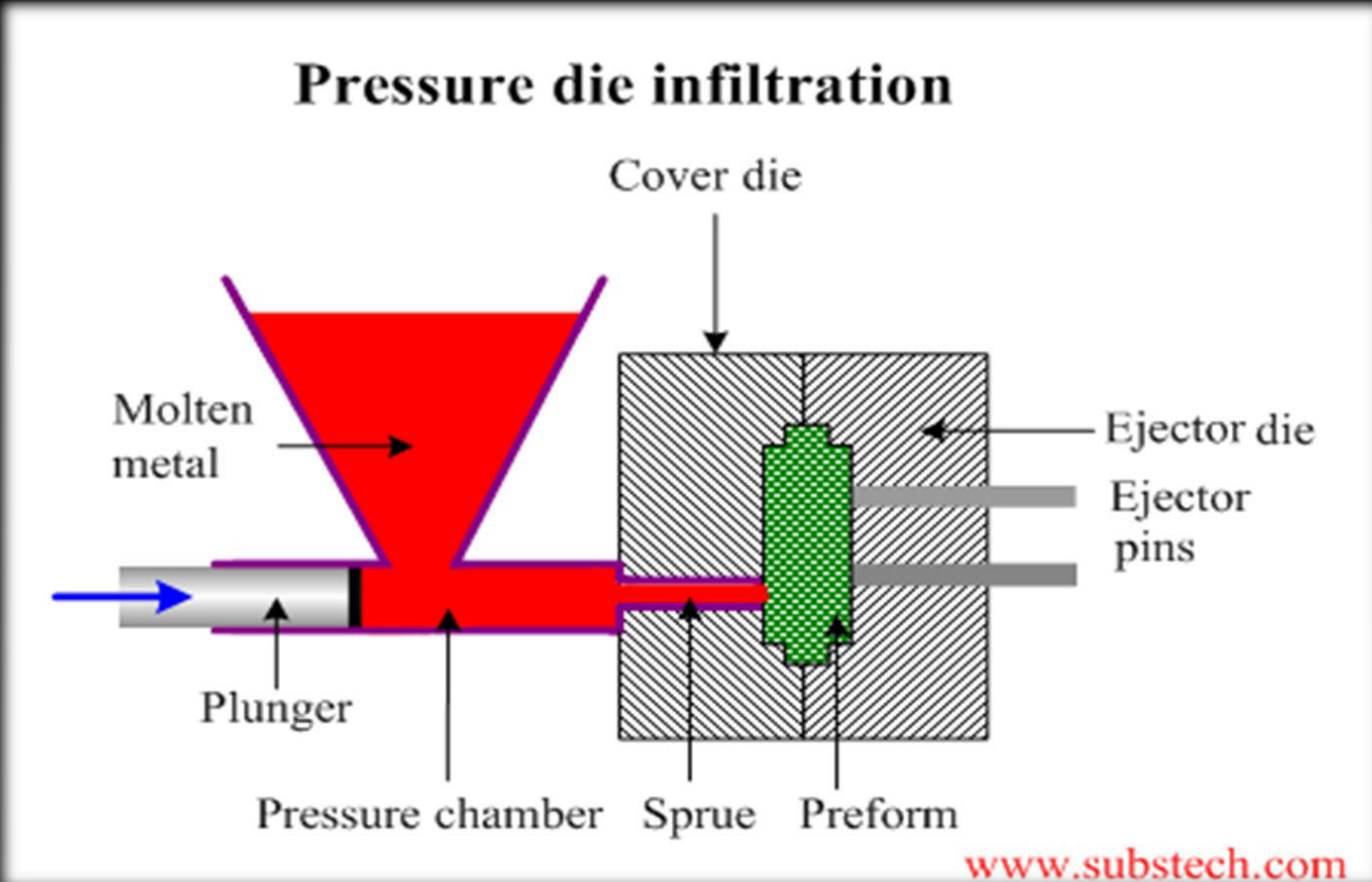
- Chemical Vapor Deposition



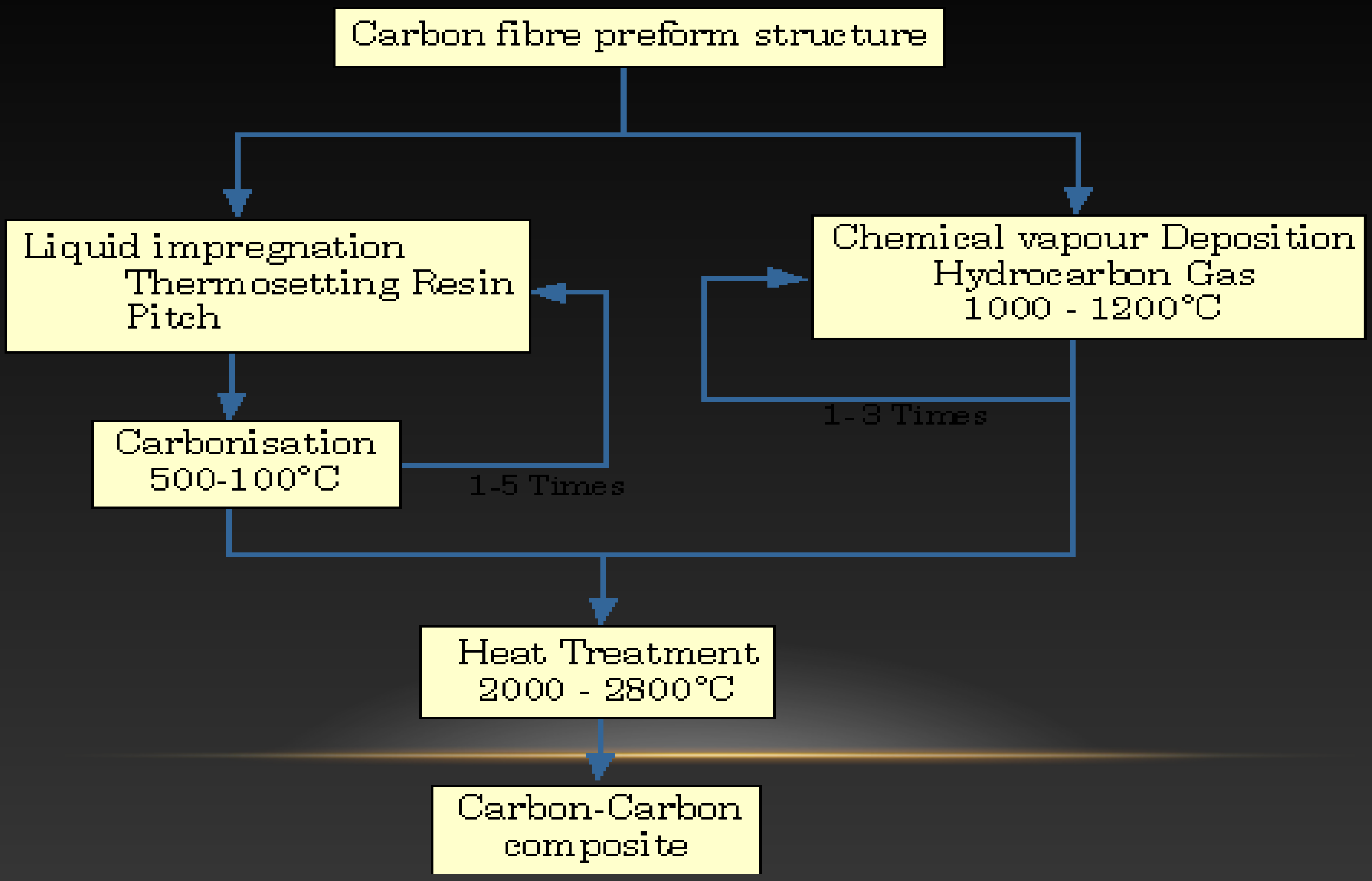
Liquid Phase Infiltration

- Preparation of C/C fiber pre-form of desired shape and structure.
- Liquid pre-cursor : Petroleum pitch/ Phenolic resin/ Coal tar.
- Pyrolysis (Chemical deposition by heat in absence of O2.
- It is processed at 540–1000°C under high pressure.
- Pyrolysis cycle is repeated 3 to 10 times for desired density.
- Heat Treatment converts amorphous C into crystalline C.
- Temperature range of treatment :1500-3000°C.
- Heat treatment increases Modulus of Elasticity and Strength.

Liquid Phase Infiltration



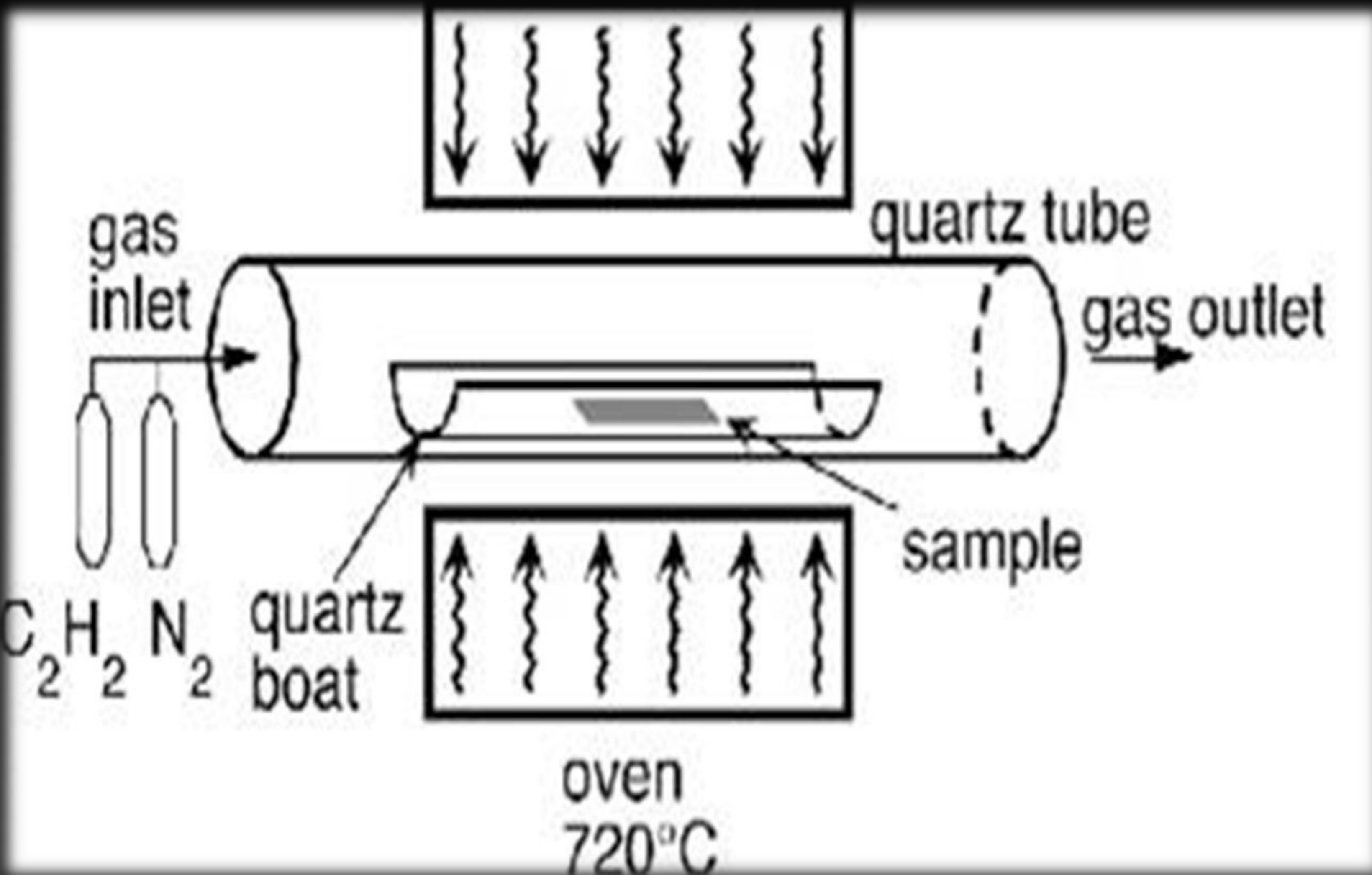
Flow Chart Of Manufacturing Process



Chemical Vapor Deposition

- Preparation of C/C fiber pre-form of desired shape and structure
- Densification of the composite by CVD technique
- Infiltration from pressurized hydrocarbon gases (Methane /Propane)at 990-1210°C
- Gas is pyrolyzed from deposition on fibre surface
- Process duration depends on thickness of pre-form
- Heat treatment increases Modulus of Elasticity and Strength
- This process gives higher strength and modulus of elasticity

Chemical Vapor Deposition



Limitation of CVD

- Hydrocarbon Gases Infiltrating into interfilament surfaces and cracks , sometimes these gases deposite on outer cracks and leave lot of pores.

- Reinfiltration and densification required.

- Month long process(for specific applications).

Application Of C-C Composite

- High Performance Braking System
- Refractory Material
- Hot-Pressed Dies(brake pads)
- Turbo-Jet Engine Components
- Heating Elements
- Missile Nose-Tips
- Rocket Motor Throats
- Leading Edges(Space Shuttle, Agni missile)
- Heat Shields
- X-Ray Targets
- Aircraft Brakes
- Reentry vehicles
- Biomedical implants
- Engine pistons
- Electronic heat sinks
- Automotive and motorcycle bodies

Carbon – Carbon Composites (CCC)

Advantages

- Light Weight (1.6-2.0g/cm^3)
- High Strength at High Temperature (up to 2000 °C) in non-oxidizing atm.
- Low Coefficient of thermal expansion.
- High thermal conductivity (>Cu & Ag).
- High thermal shock resistance.

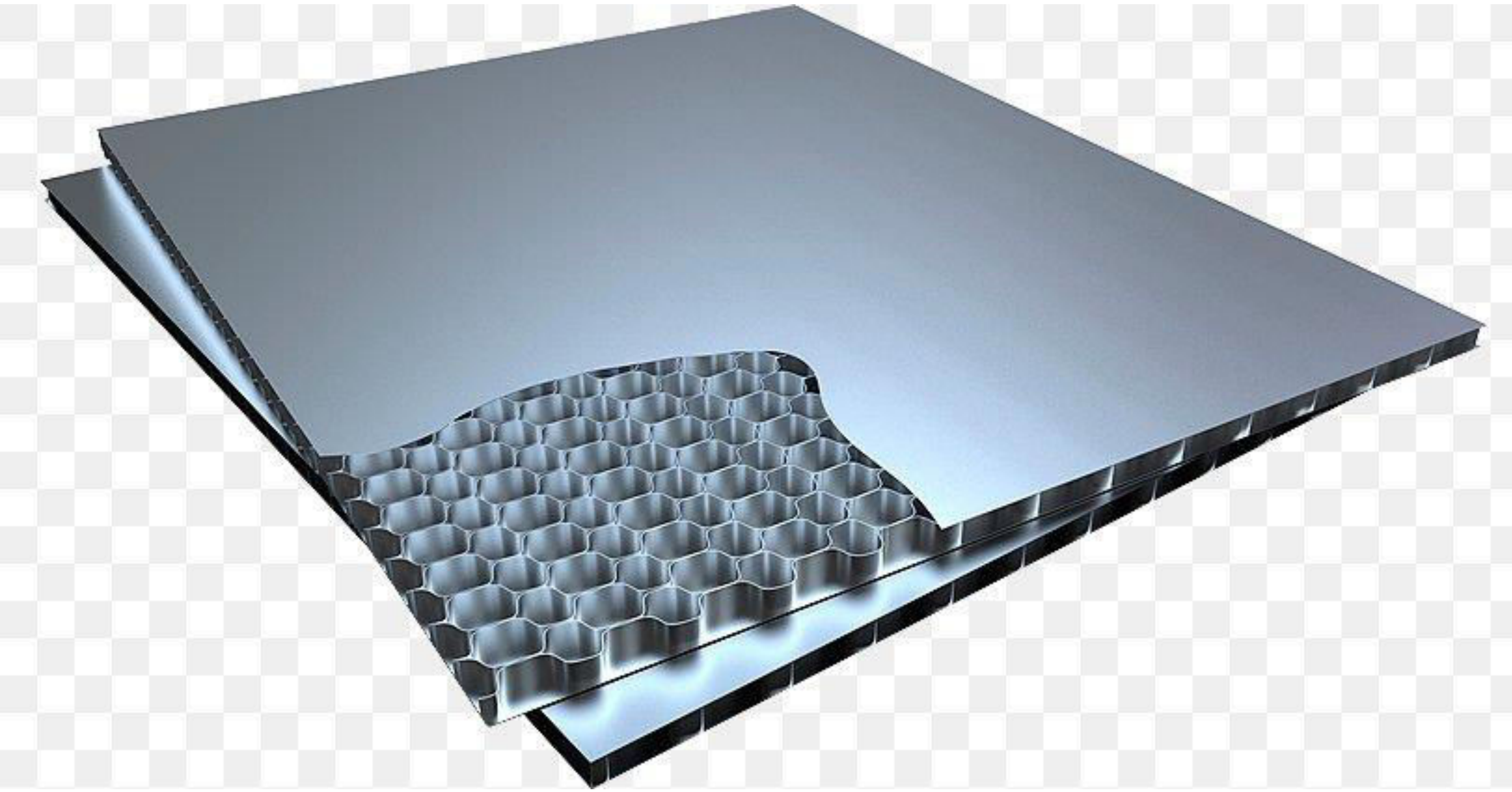
Carbon – Carbon Composites (CCC)

Disadvantages

- High fabrication cost.
- Porosity.
- Poor oxidation resistance – formation of gaseous oxides in oxygen atm.
- Poor inter-laminar properties.


Thank
You

Metal Matrix Composite
By-Jyotiprakash Das

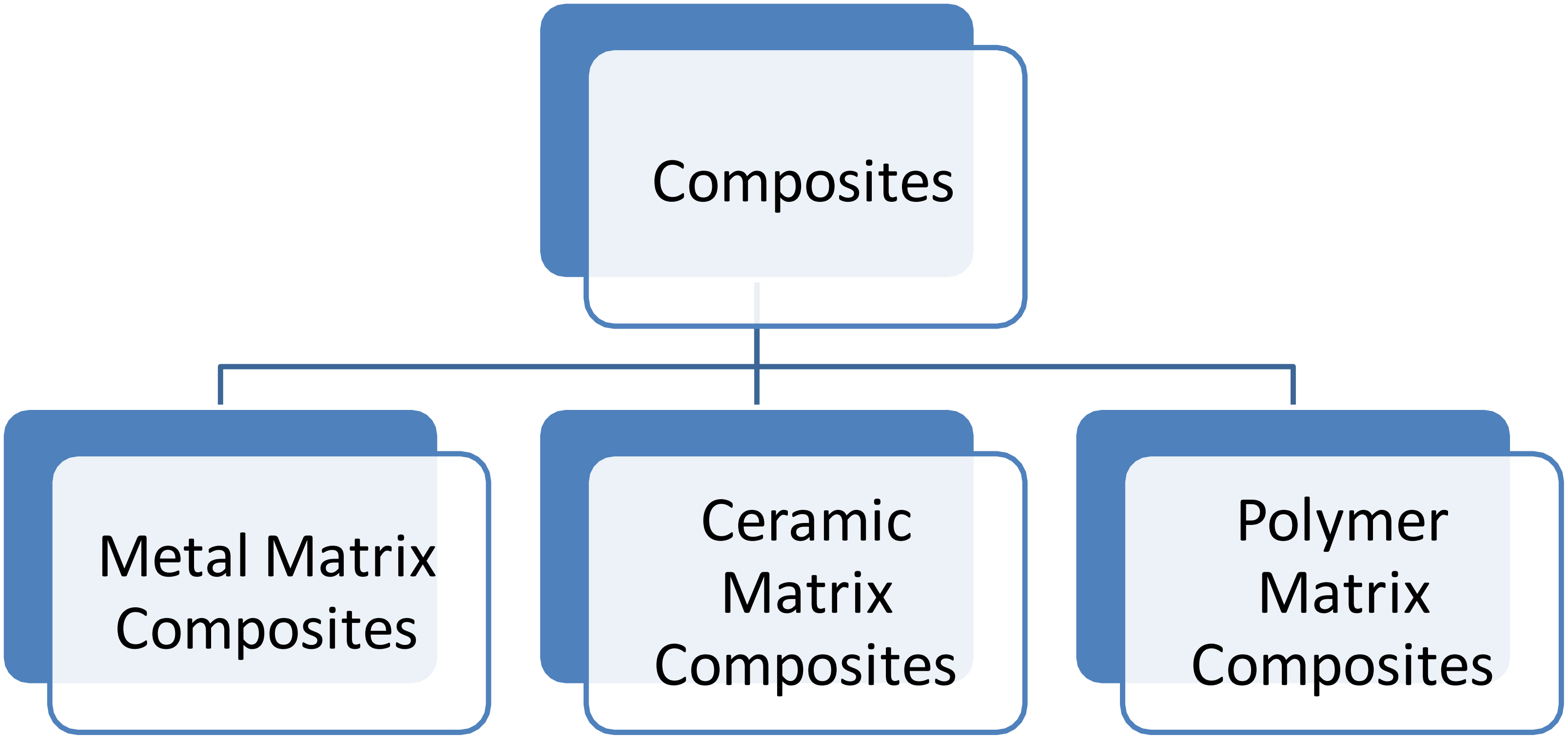


CONTENTS.

INTRODUCTION

- Composites are composed of two or more different materials to obtain a combination of properties not available in either of the materials.
- Usually one material forms a continuous matrix while the other provides the reinforcement.
- The two materials must be chemically inert with respect to each other so no interaction occurs on heating until one of the components melts.
- An exception to this condition is a small degree of interdiffusion at the reinforcement-matrix interface to increase bonding.

CLASSIFICATION



Functions of the Matrix Material

- Provides the bulk form of the part or product made of the composite material
- Holds the imbedded phase in place, usually enclosing and often concealing it
- When a load is applied, the matrix shares the load with the secondary phase, in some cases deforming so that the stress is essentially born by the reinforcing agent

Functions of the Reinforcing Phase

- Function is to reinforce the primary phase
- Imbedded phase is most commonly one of the following shapes:
  - Fibers
  - Particles
  - Flakes
- In addition, the secondary phase can take the form of an infiltrated phase in a skeletal or porous matrix – Example: a powder metallurgy part infiltrated with polymer

Metal Matrix Composites (MMCs)

- Materials consisting of metallic matrices, reinforced with ceramic particles or fibers, are known as metal matrix composites or MMCs
- The volume fraction of the reinforcement is typically in the range 10-70%.
- MMCs can offer a range of property enhancement over monolithic alloys.

Metal Matrix Composites (MMCs)

- A metal matrix reinforced by a second phase
- Reinforcing phases:
  - Particles of ceramic (these MMCs are commonly called cermets)
  - Fibers of various materials: other metals, ceramics, carbon, and boron

Metal Matrix Composites (MMCs)

- Metal matrix composite materials have found application in many areas of daily life for quite some time.
- Materials like cast iron with graphite or steel with a high carbide content, as well as tungsten carbides, consisting of carbides and metallic binders, also belong to this group of composite materials.
- Metal matrix composites become interesting for use as constructional and functional materials, if the property profile of conventional materials either does not reach the increased standards of specific demands, or is the solution of the problem.

Metal Matrix Composites (MMCs)

- The reinforcement of metals can have many different objectives;
  - Increase in yield strength and tensile strength at room temperature and above while maintaining the minimum ductility or rather toughness,
  - Increase in creep resistance at higher temperatures compared to that of conventional alloys,
  - Increase in fatigue strength, especially at higher temperatures,
  - Improvement of thermal shock resistance,
  - Improvement of corrosion resistance
  - Increase in Young's modulus,
  - Reduction of thermal elongation.

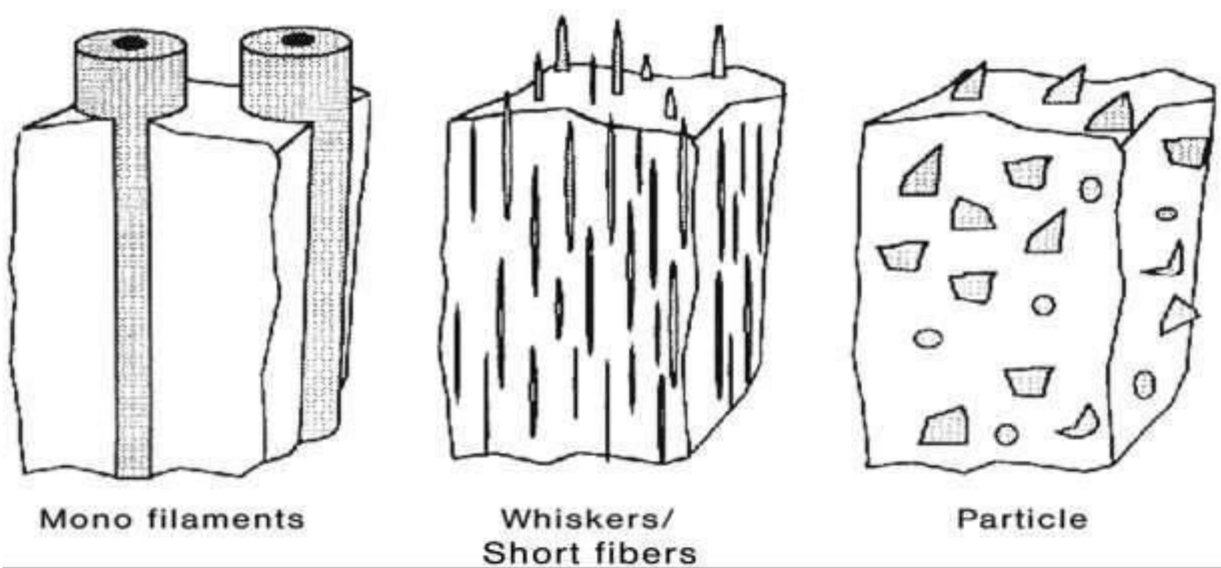
Advantages

- Light Weight
- Performance at higher temperatures
- High Strength
- Low Density, Better wear resistance

Classification of Metal Matrix Composites

Metal Matrix Composites(MMCs)

- Dispersion hardened and particles
- Layer composites
- Fiber composites
- Infiltration composites



Reinforcements for Metal Matrix Composites

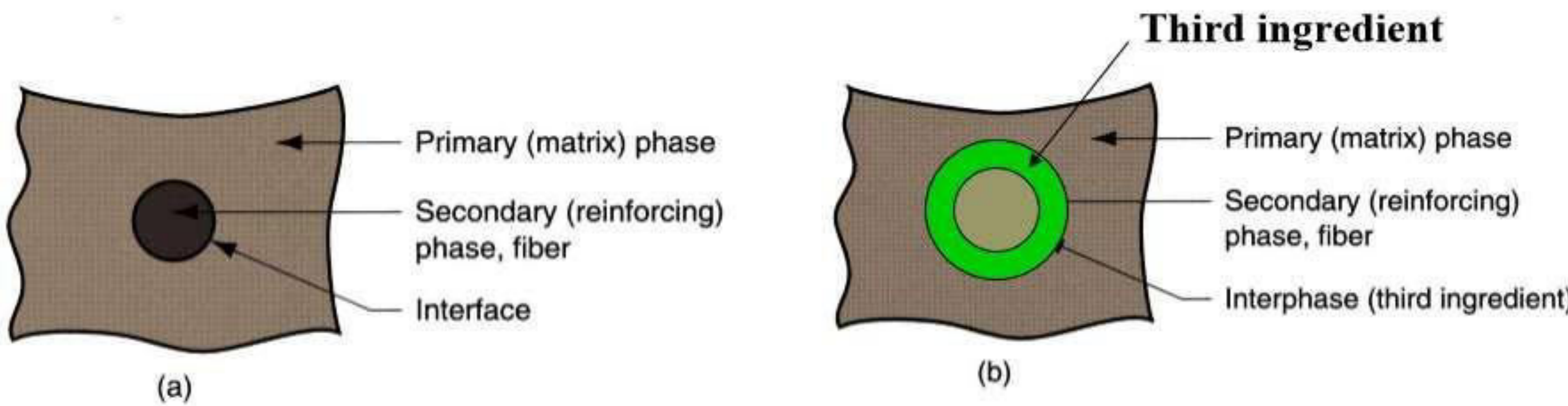
- These demands can be achieved only by using non-metal inorganic reinforcement components. For metal reinforcement ceramic particles or, rather, fibers or carbon fibers are often used.

Property potential of different metal matrix composites

MMC type	*Properties Strength*	*Young's modulus*	*High temperature properties*	*Wear*	*Expansion coefficient*	*Costs*
mineral wool: MMC	*	*	**	**	*	medium
discontinuous reinforced MMC	**	**	*	***	**	low
long fiber reinforced MMC: C fibers	**	**	**	*	***	high
other fibers	***	***	***	*	**	high

Interfaces (Bonding)

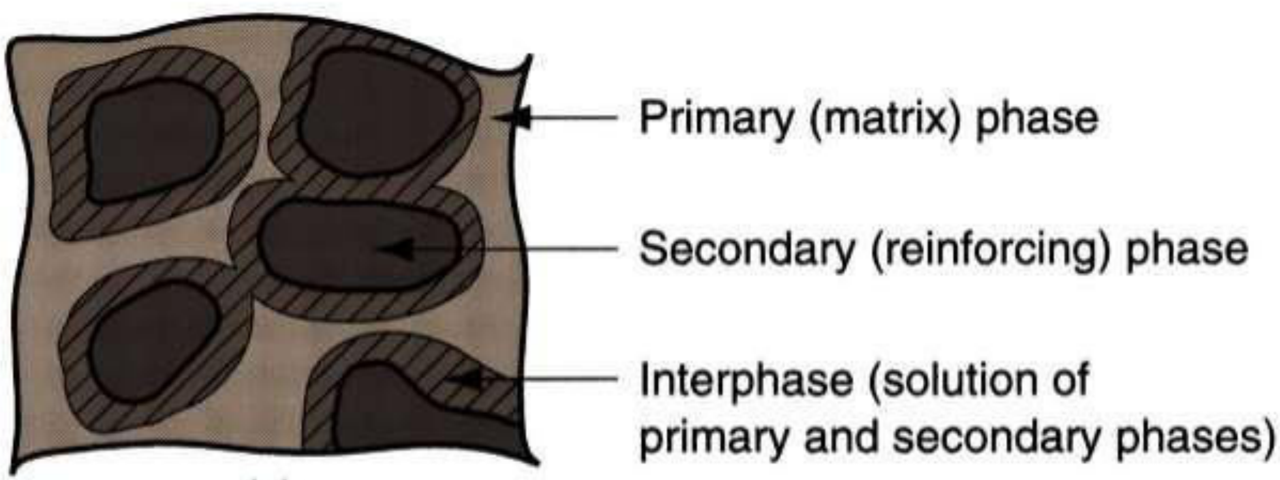
- There is always an interface between constituent phases in a composite material
- For the composite to operate effectively, the phases must bond where they join at the interface



- Interfaces between phases in a composite material: (a) direct bonding between primary and secondary phases; (b) addition of a third ingredient to bond the primary phases and form an interphase.

Interfaces (Bonding)

- Interphase consisting of a solution of primary and secondary phases



(c)

- Interfaces and interphases between phases in a composite material: (c) formation of an interphase by solution of the primary and secondary phases at their boundary.

Interfaces (Bonding)

Why are Reinforcement matrix interfaces important?

- Such large differences are shared through the interface. Stresses acting on the matrix are transmitted to the fiber across the interface.

- *The interfacial bond can influence*

  - Composite strength
  - Modes of failure
  - Young's modulus
  - Interlaminar shear strength
  - Compressive strength
  - Environmental resistance
  - Structural stability at elevate temperatures
  - Fracture and fatigue behavior

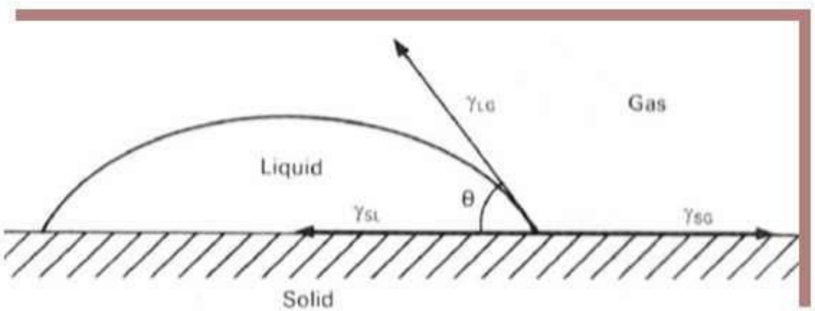
Interfaces (Bonding)

Wettability

- Is defined the extent where a liquid will spread over a solid surface
- During the manufacturing process, the matrix is often in the condition where it is capable of flowing or its behavior is like a liquid
- Good wettability means that the liquid (matrix) will flow over the reinforcement, covering every ‘bump’ and ‘dip’ of the rough surface of reinforcement and displacing all air.
- Wetting will only occur if the viscosity of the matrix is not too high.
- Interfacial bonding exists due to the adhesion between the reinforcement and the matrix (wetting is good)

Interfaces (Bonding)

- All surfaces have an associated energy and the free energy per unit area of the solid-gas, liquid-gas and solid-liquid are γSG, γLG and γSL,
- θ is called the contact angle. May be used as a measure of the degree of the wettability



$$\cos\theta = \frac{\gamma_{SG} - \gamma_{SL}}{\gamma_{LG}}$$

θ - is called a contact angle

$\theta = 180^0$ - No wetting takes place

$\theta = 0^0$ - Perfect wetting

$0^0 < \theta < 180^0$ - The degree of wetting increases as θ decreases

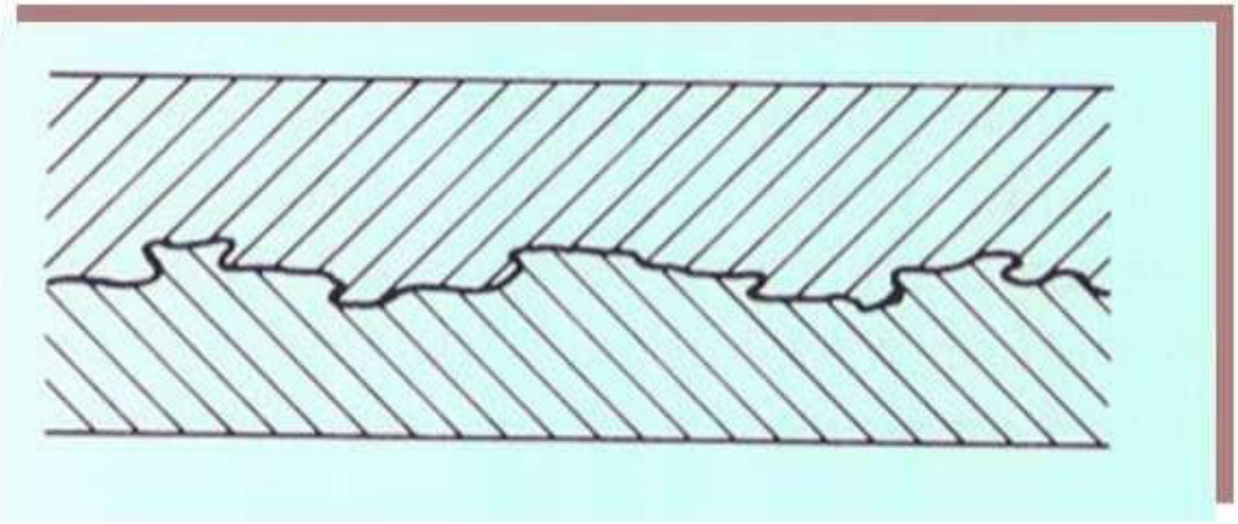
Interfaces (Bonding)

- Types of interfacial bonding at interface
  - Mechanical bonding
  - Electrostatic bonding
  - Chemical bonding
  - Reaction or inter-diffusion bonding

Interfaces (Bonding)

Mechanical bonding

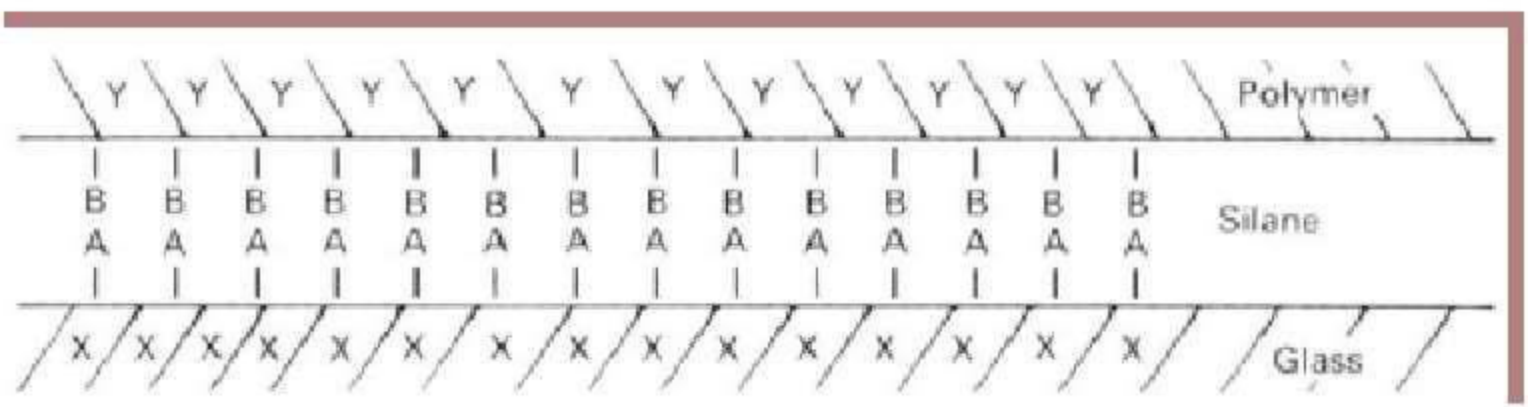
- Depending on degree of roughness of fiber surface
- Larger surface area may also increase strength of chemical bond.



Interfaces (Bonding)

Chemical bonding

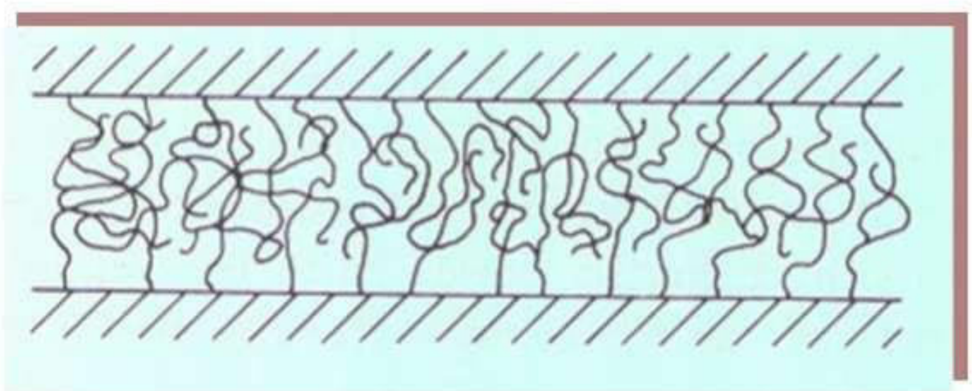
- The bond formed between chemical groups on the reinforcement surfaces and compatible groups in the matrix
- Strength of chemical bonding depends on the number of bonds per unit area and the type of bond



Interfaces (Bonding)

Reaction or interdiffusion bonding

- Diffusion and entanglement of molecules



$$D_d = D_0 \exp(-Q_d / RT)$$

D_d- the diffusion coefficient

Q_0- is the activation energy for diffusion

D_0- is constant

R- is the gas constant

T- is the temperature

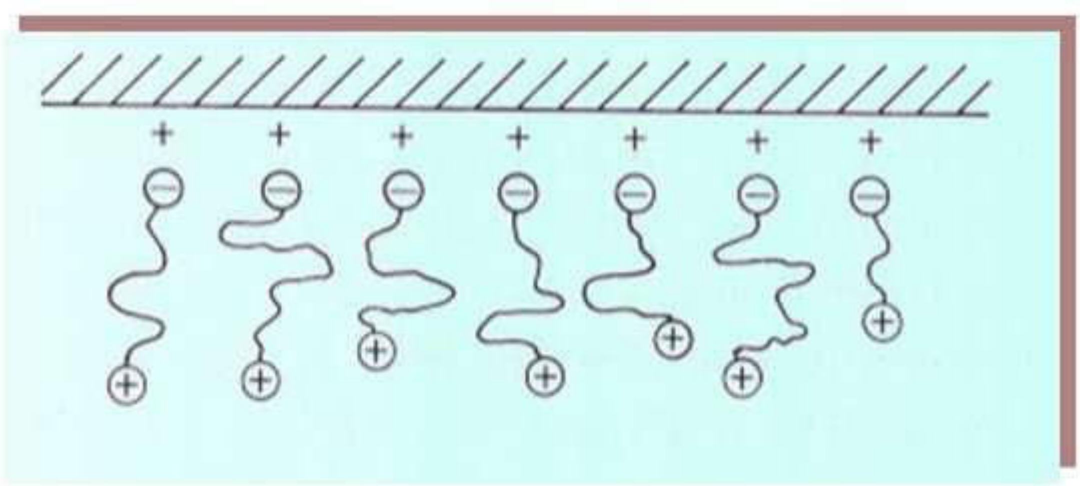
Interfaces (Bonding)

- **Electrostatic bonding**

➢ Occur when one surface is positively charged and the other is negatively charge (refer to the figure)

➢ Interactions are short range and only effective over small distances of the order of atomic dimensions

➢ Surface contamination and entrapped gases will decrease the effectiveness of this bonding



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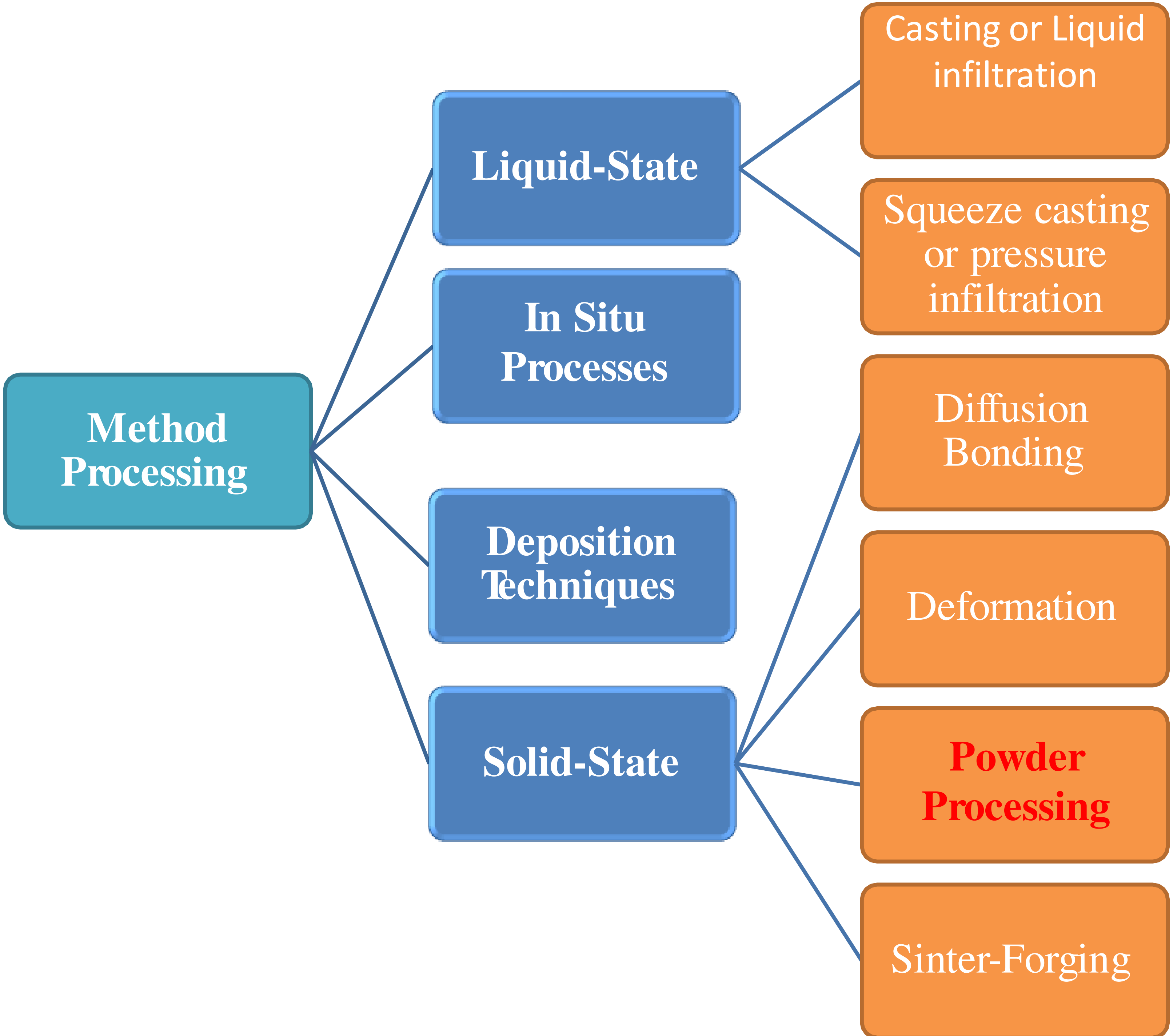
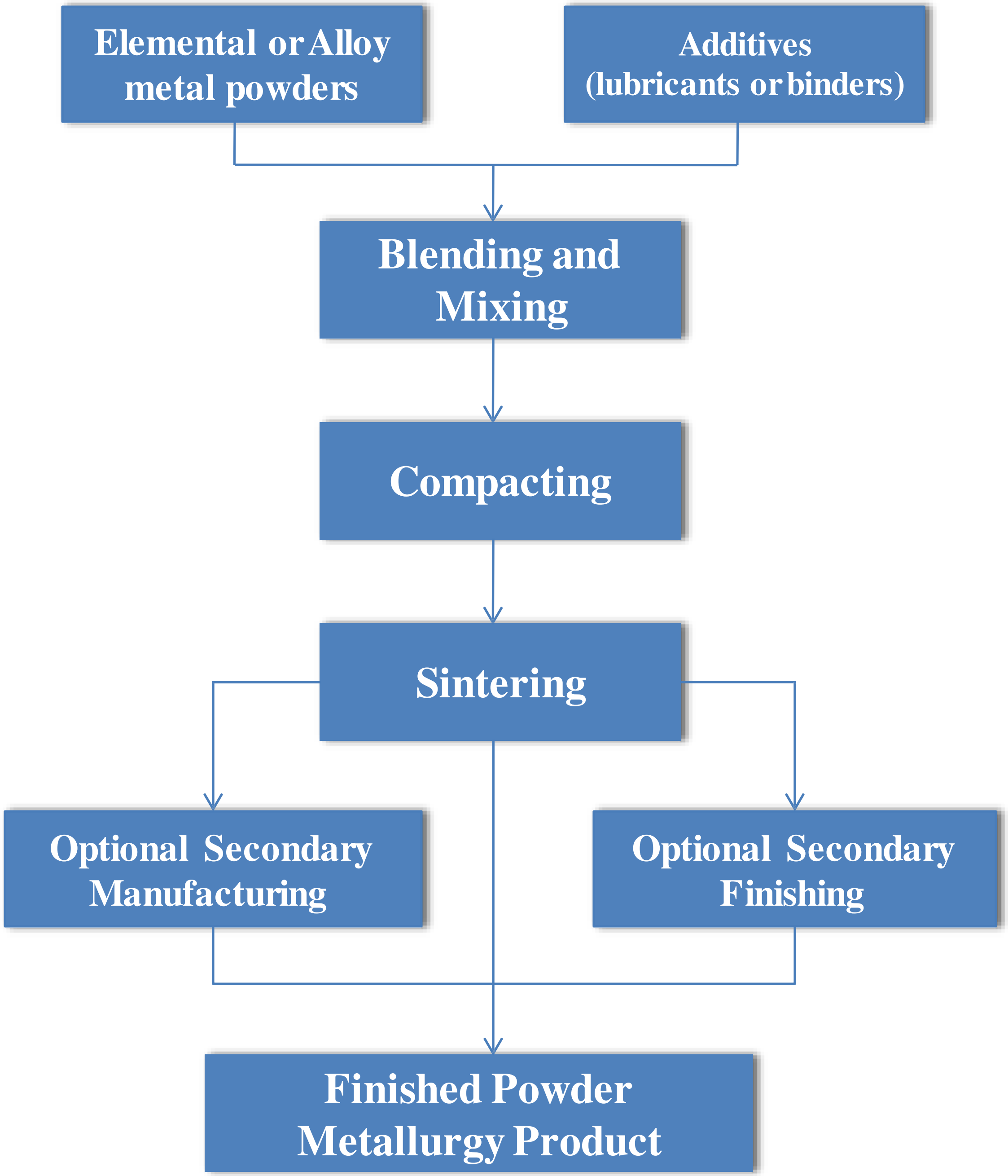
Processing of Metal Matrix Composites

- Metal matrix composites materials can be produced by many different techniques.
- The focus of the selection of suitable process engineering is the desired kind, quantity and distribution of the reinforcement components (particles and fibers), the matrix alloy and the application.
- By altering the manufacturing method, the processing and the finishing, as well as by the form of the reinforcement components it is possible to obtain different characteristic profiles, although the same composition and amounts of the components are involved.

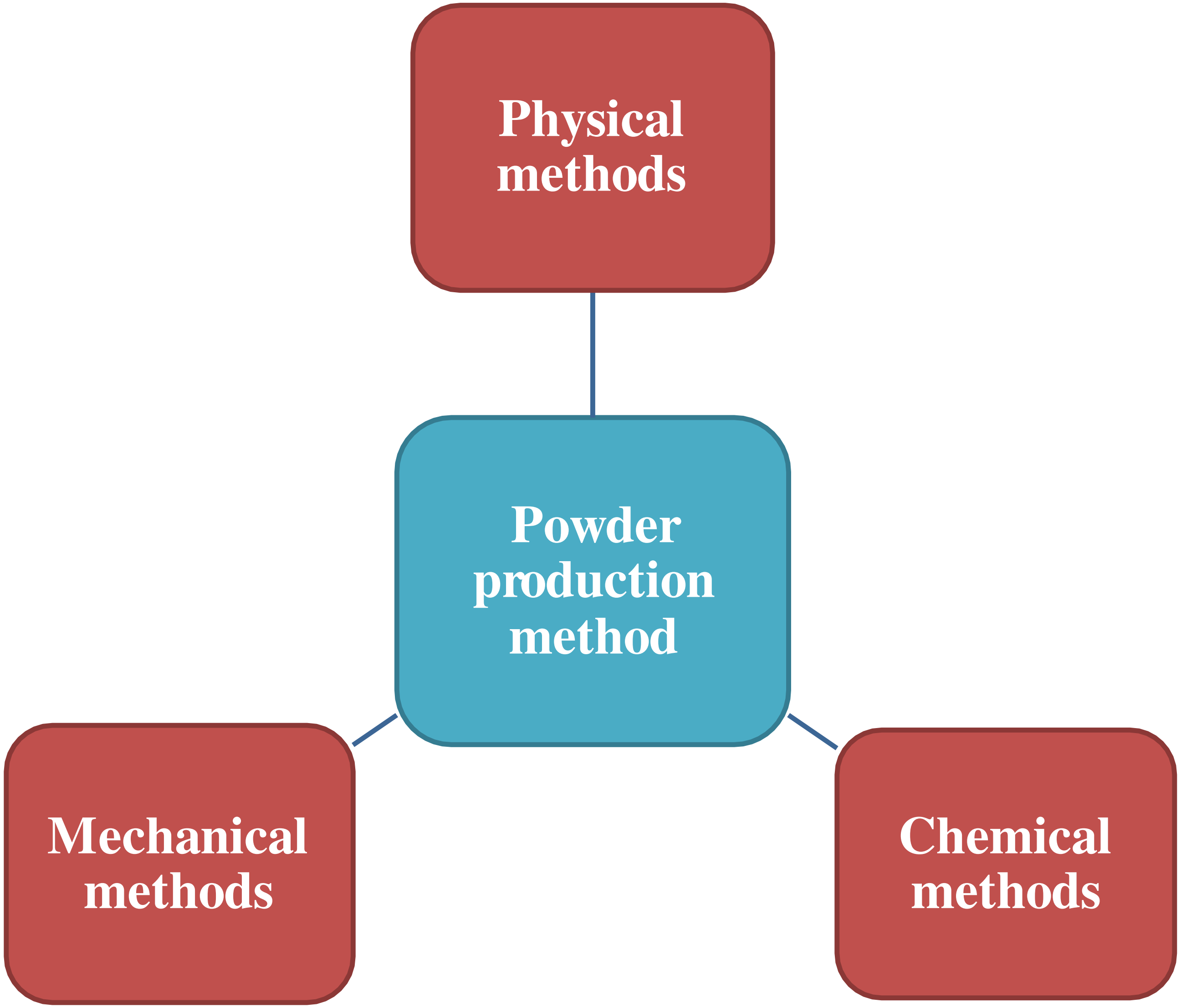

Method Processing
Liquid-State
In Situ Processes
Deposition Techniques
Solid-State
Casting or Liquid infiltration
Squeeze casting or pressure infiltration
Diffusion Bonding
Deformation
Powder Processing
Sinter-Forging

Solid-State Processes
Powder Processing

- **Powder metallurgy**: Science of producing metal powders and making finished /semifinished objects from mixed or alloyed powders with or without the addition of nonmetallic constituents
- Steps in powder metallurgy : Powder production, Compaction, Sintering, Secondary operations


Elemental or Alloy metal powders
Additives (lubricants or binders)
Blending and Mixing
Compacting
Sintering
Optional Secondary Manufacturing
Optional Secondary Finishing
Finished Powder Metallurgy Product

Production of powders



Production of powders

Mechanical methods

- Cheapest of the powder production methods.
- These methods involve using mechanical forces such as compressive forces, shear or impact to facilitate particle size reduction of bulk materials. *Ex: Milling*
- **Milling:** During milling, impact, attrition, shear and compression forces are acted upon particles
- **Impact** : Striking of one powder particle against another occurs.
- **Attrition** : The production of wear debris due to the rubbing action between two particles.
- **Shear**: Cutting of particles resulting in fracture.
- **Compression** :The particles are broken into fine particles by squeezing action in compression

Production of powders

- **Main objective of milling**: Particle size reduction (main purpose), Particle size growth, shape change, agglomeration (joining of particles together), solid state alloying, mechanical or solid state mixing, modification of material properties.
- **Mechanism of milling**: Changes in the morphology of powder particles during milling results in the following events.
  - Micro forging
  - Fracture
  - Agglomeration
  - Deagglomeration

Production of powders

- **Micro forging**: Individual particles or group of particles are impacted repeatedly so that they flatten with very less change in mass
- **Fracture** : Individual particles deform and cracks initiate and propagate resulting in fracture
- **Agglomeration** : Mechanical interlocking due to atomic bonding or vande Waals forces
- **Deagglomeration** : Breaking of agglomerates
- The different powder characteristics influenced by milling are shape, size, texture, particle size distribution, crystalline size, chemical composition, hardness, density, flowability, compressibility, sinterability, sintered density

Production of powders

Micro forging

The start power are soft, easy flattened as flake

Agglomeration

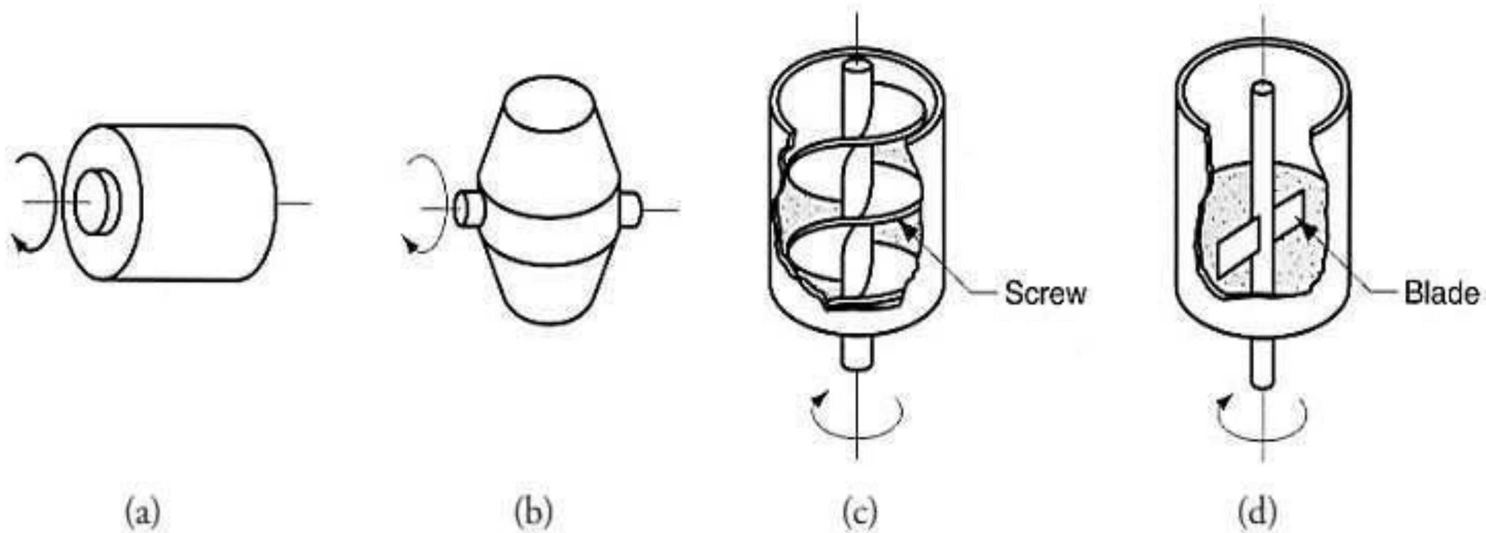
the particles weld together due to the impacts of grinding balls to form larger particle

Fracture

The particle are work hardened, the fracture mechanism are predominate the cold weld, thus particles size decreased

Blending and Mixing

- **Blending** : mixing powder of the same chemical composition but different sizes.
- **Mixing** : combining powders of different chemistries.
- Blending and mixing are accomplished by mechanical means:



Several blending and mixing devices: (a) rotating drum, (b) rotating double cone, (c) screw mixer, (d) blade mixer

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Blending and Mixing

- Except for powders, some other ingredients are usually added:

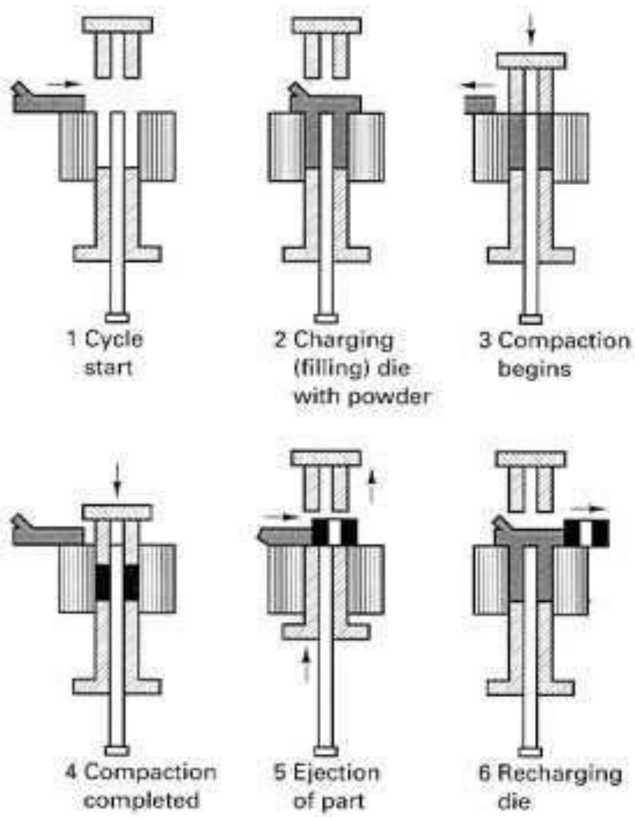
❖ Lubricants: to reduce the particles-die friction

❖ Binders: to achieve enough strength before sintering

❖ Deflocculants : to improve the flow characteristics during feeding

Compaction

- Blended powers are pressed in dies under high pressure to form them into the required shape. The work part after compaction is called a green compact or simply a green.

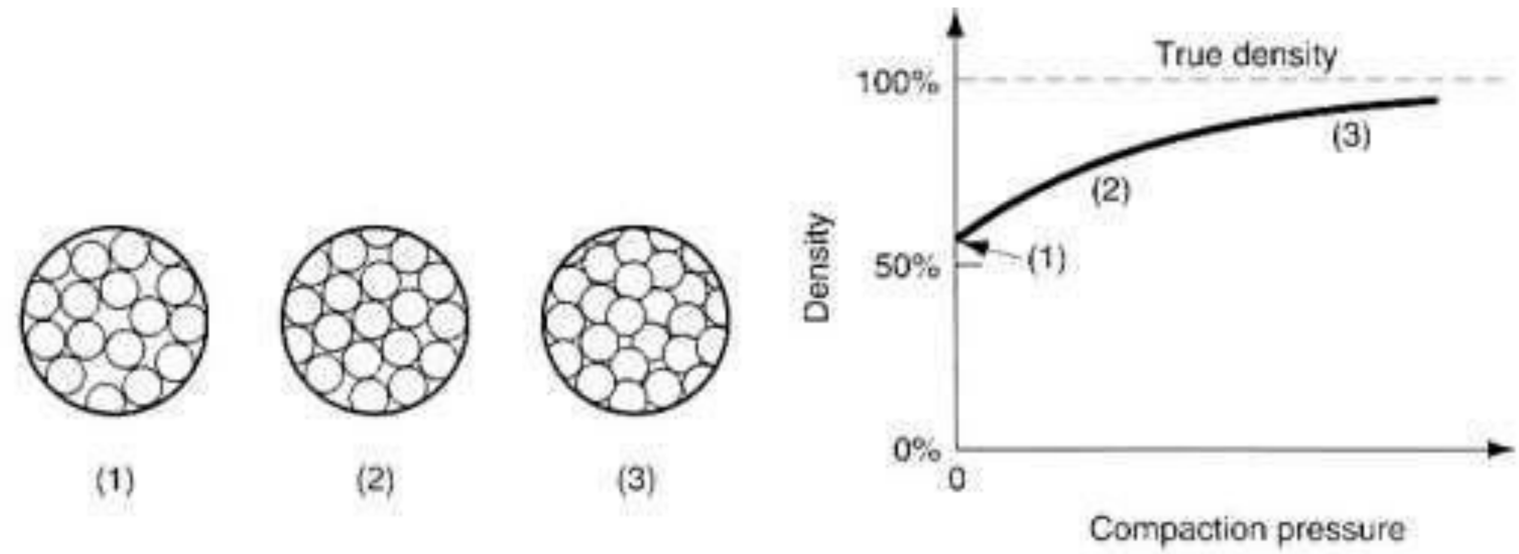


Typical steps in compaction

Typical press for the compaction of metallic powders. The removable die set (*right*) allows the machine to be producing parts with one die set while another is being fitted to produce a second part

Compaction

- As a result of compaction, the density of the part, called the green density is much greater than the starting material density, but is not uniform in the green. The density and therefore mechanical properties vary across the part volume and depend on pressure in compaction.



Effect of applied pressure during compaction: (1) initial loose powders after filling, (2) repacking, and (3) deformation of particles.

Sintering

- Compressed metal powder is heated in a controlled-atmosphere furnace to a temperature below its melting point, but high enough to allow bounding of the particles:
- **Purpose** : to increase strength & hardness of a green compact
- **Principal variables** : temperature (generally within 70 – 90% of the melting point of metal or alloy), time (10 min. – 8 hours) & furnace atmosphere
- **Sintering process is concerned with**
  - <u>diffusion</u> (surface of particles as temperature rises)
  - <u>densification</u> (decreases porosity, increases particle contact area)
  - <u>recrystallization & grain growth</u> (between particles at the contact area)

Sintering

- The primary driving force for sintering is not the fusion of material, but formation and growth of bonds between the particles, as illustrated in a series of sketches showing on a microscopic scale the changes that occur during sintering of metallic powders.

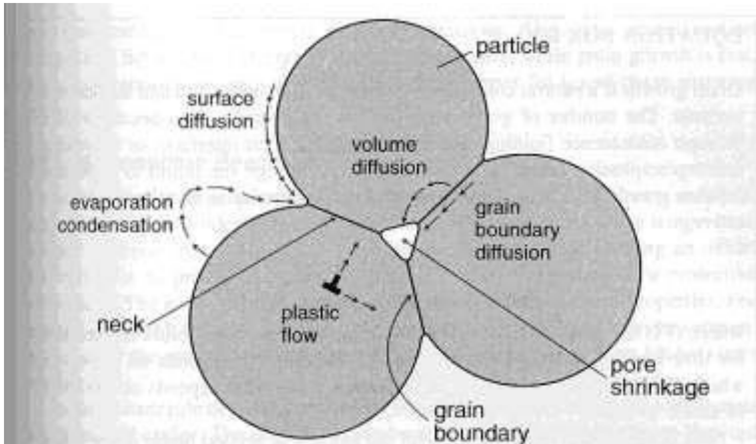
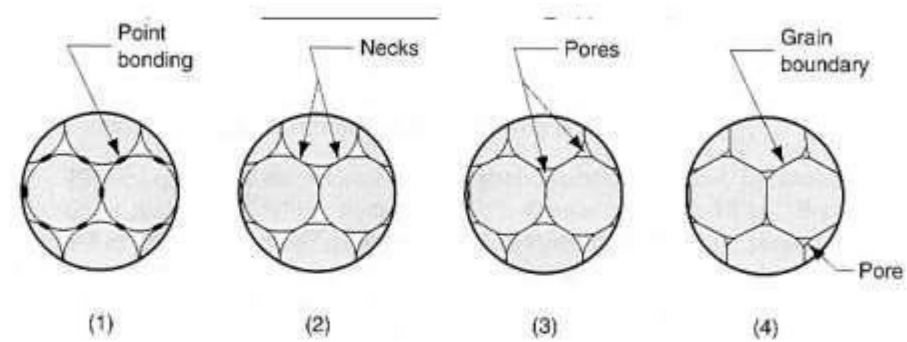
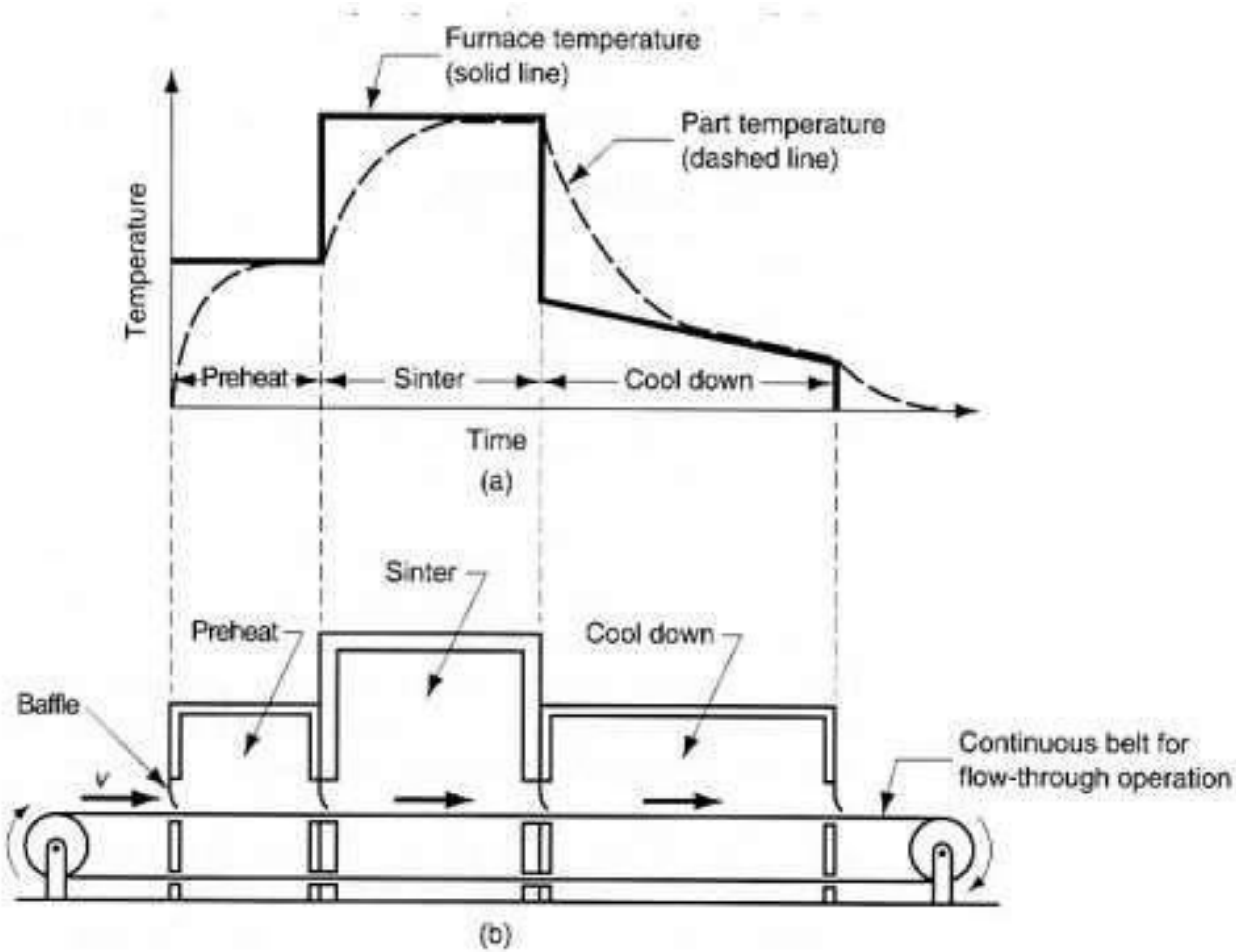


Figure 6.4. A three-particle sketch of sintering, showing the several possible paths of atomic motion involved with particle bonding (neck growth) and pore shrinkage (densification).



Sintering on a microscopic scale. The illustration shows different stages in development of grain boundaries between particles.

Sintering



(a) Typical heat treatment cycle in sintering; and (b) schematic cross-section of a continuous sintering furnace

FINISHING / SECONDARY OPERATIONS

1.Sizing : cold pressing to improve dimensional accuracy

2.Coining or pressing :

- cold working process, to press details into surface
- condensation of sintered product

3.Impregnation:

- impregnation with heated oil (self lubricated bearings)
- oil fills the pores of the part

4.Infiltration:

- placement of slug of a lower melting point metal against the sintered part
- infiltration of molten metal by capillary action
- pores are filled with a molten metal

1.Heat treatment , Plating, Painting

Advantages

- Elimination/reduction of machining
- High production rates
- Complex shapes can be produced
- Wide composition variations are possible
- Wide property variations are possible
- Scrap is eliminated or reduced

Disadvantages

- High cost of powder material & tooling
- Less strong parts than wrought ones
- Less well known process

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Thank You