الجامعة التكنولوجية

قسم هندسة المواد

فرع المواد العام

Basics of composite materials

first Semester

Fourth class

2019-2018

· **Learning References**	1) Willian D. Calister, jr. & David G. Rethwisch, "Materials Science and Engineering An Introduction", eight edition, John Wiley & sons, inc., (2009). 2) Autar K. Kaw, "Mechanics of Composite Materials", second edition, New York, (2006). 3) Derek. Hull," An Introduction to Composite Materials", Cambrige University, (1995). 4) Deborch D.L. Chung, "Composite Materials, Science and Applications", Second edition, Springer, (2010). 5) W. Bolton, "Engineering Materials Technology", Third edition, Oxford (1998). 6) R.M. Jones, "Mechanics of composite Materials", McGraw-Hill, New york (1975).

1-Introduction to Composite Materials:

1.1- Definitions ,Properties and Applications

A Composite material is formed when two or more materials are combined on a macroscopic scale, So that the properties of composite are different (usually better) from those of the individual constituents.

Properties that can be improved by composite materials

- Strength	- thermal insulation
- stiffness	-thermal conductivity
- fatigue life	- acoustical insulation
- corrosion resistance	- weight
- high temperature performance	- hardness
- wear resistance	- etc

<u>Composite materials have a wide range of practical application in the industry like:</u>

- Car body manufacturing
- Air plane structure
- Space land and space satellite
- Boats manufacturing
- Storage containers
- House appliances

The important property that recognizes the composite material on metal is the <u>strength</u> to the <u>density</u> ratio or <u>strength</u> to <u>weight</u> ratio.

Composite are made of

- Continuous medium “matrix”
- Discontinuous medium “Reinforcement “ (which is usually harder and stronger one)

Therefore the properties of composite are depend on the properties of the matrix and reinforcement materials, their distribution and interaction.

Matrix :- It is the material that work to bind the reinforcing material together in order to make a composite material that can carry loads or stresses .

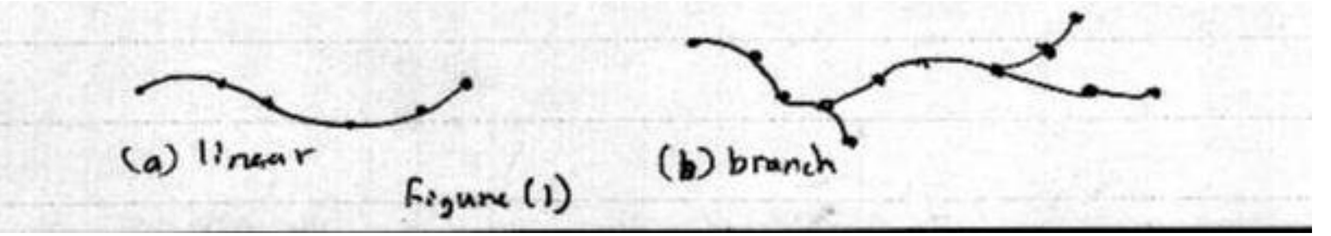
It is also called “**medium** “, it is may be **metal , polymer or ceramic**.

The polymers are most widely used as a “matrix”. And are also called resins .

Polymers are very complex organic compounds whose molecular weight exceed 5000

Polymers have low electrical and thermal conductivity ,therefore use for electrical and thermal insulation .

The molecules of polymers may have the linear ,branch (fig 1) or three dimensional (spatial) structure repeated many times .



Polymers may be classified as :-

1- Thermoplastic resins: - for examples “nylon “, “polyethylene “.

Soften when heated and become hard again when the heat is removed. And have linear chains or branch chains for their structure.

2- Thermosetting resins :- for example “ epoxy” , “ polyester”.

Do not soften when heated, but char and decompose and have cross linked

structure.

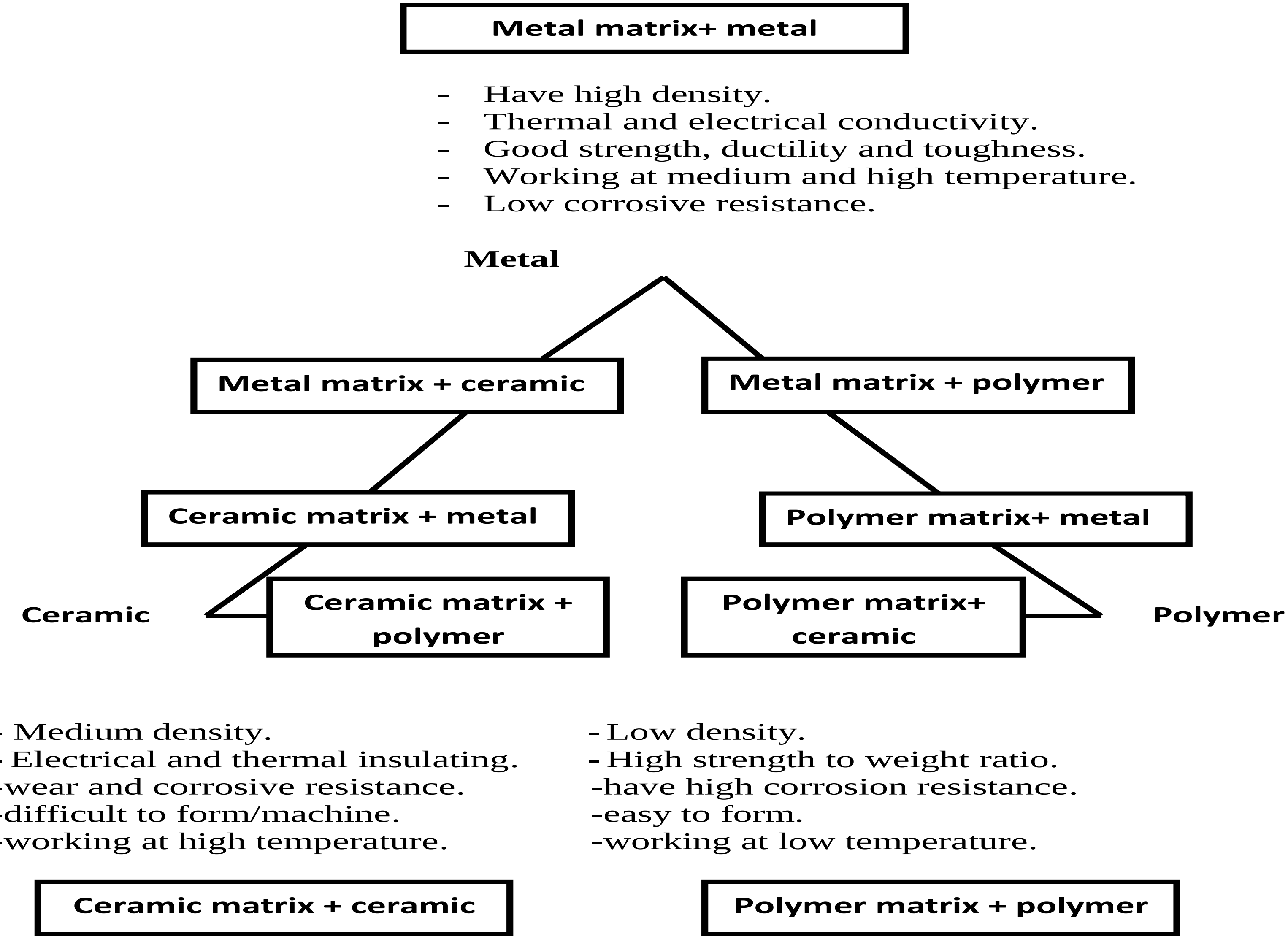
3- Elastomers resin :- for example “ rubber”.

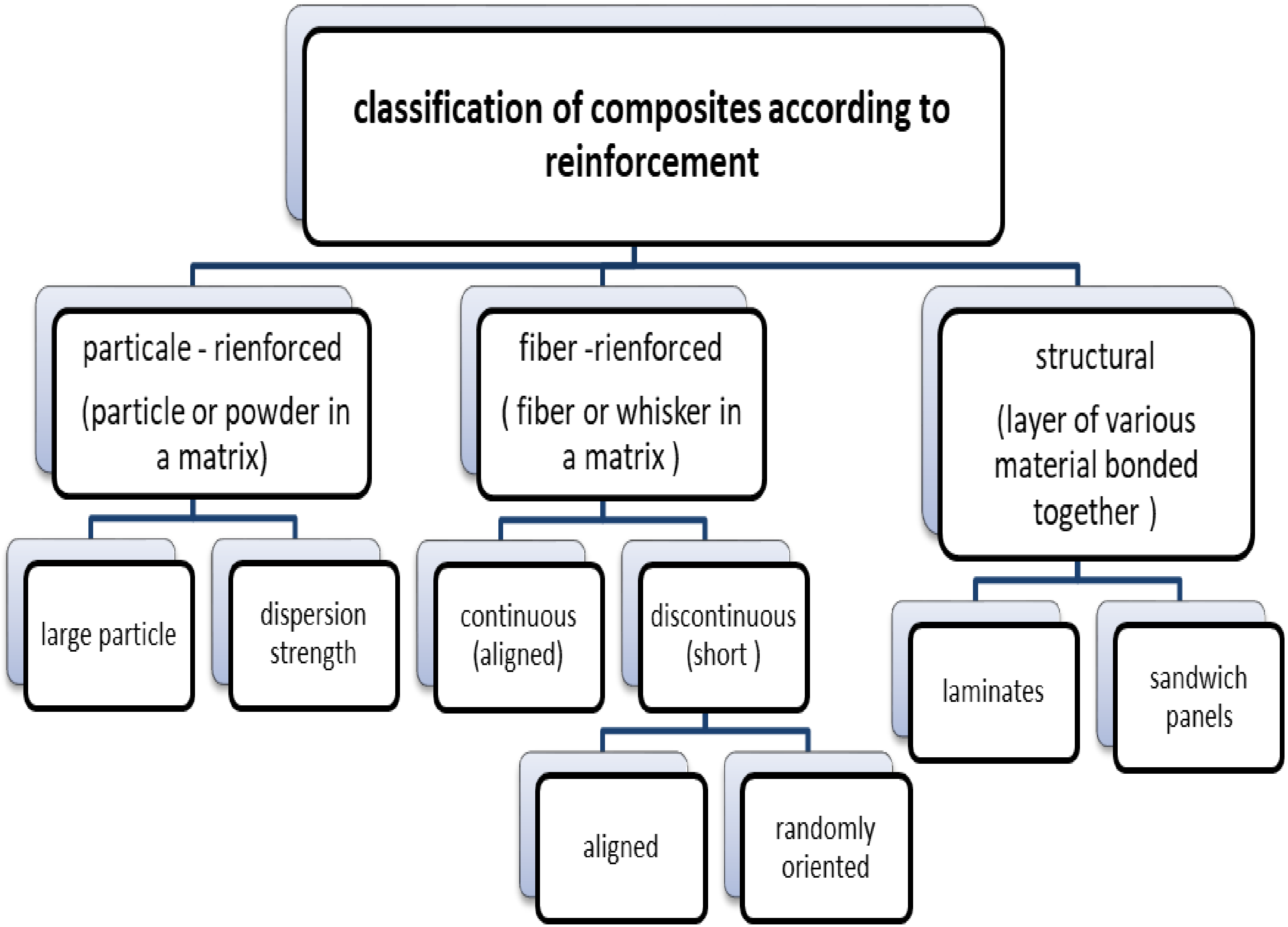
Is a polymer having considerable extensions and reversible. It is chains have some degree of cross- linking.

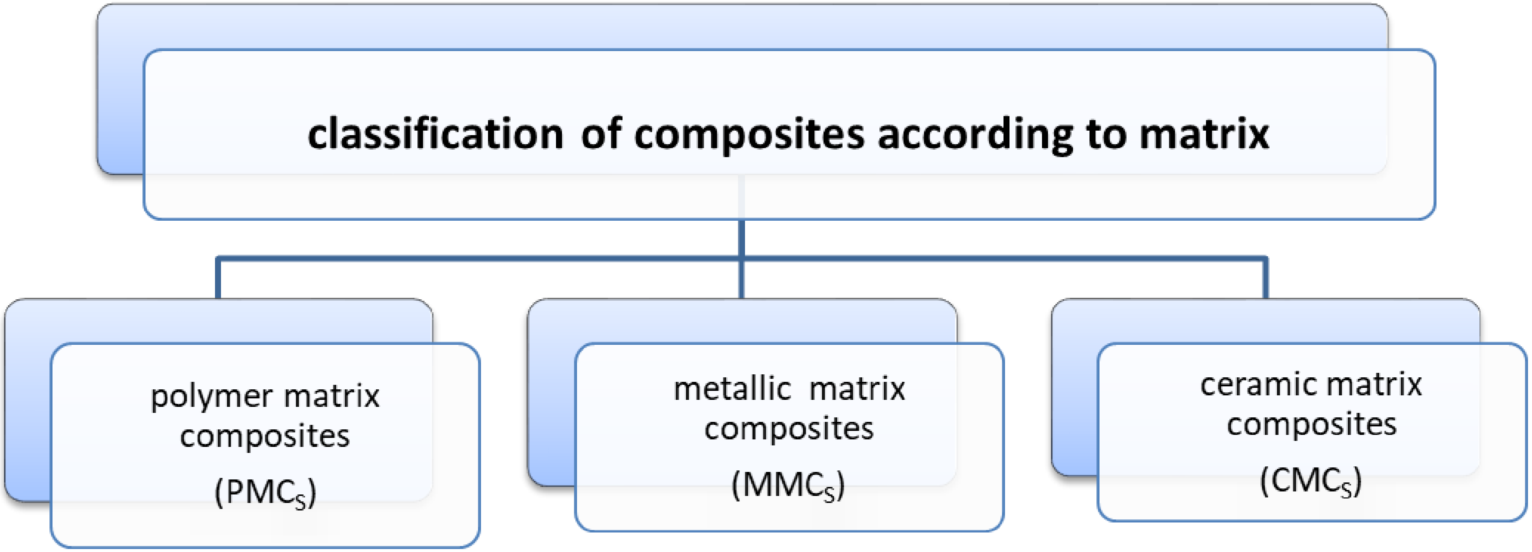
Reinforcing materials:- It is the materials that make the reinforcing to the matrix. It is have different form may be fibers, particles, flakes, fillers and woven made from glass, carbon , Kevlar or steel…….etc.

1.2- Classification of Composite Materials

The diagram of the composite materials illustrated as following:-




classification of composites according to reinforcement
particale - rienforced
(particle or powder in a matrix)
fiber -rienforced
(fiber or whisker in a matrix)
structural
(layer of various material bonded together)
large particle
dispersion strength
continuous (aligned)
discontinuous (short)
aligned
randomly oriented
laminates
sandwich panels


classification of composites according to matrix
polymer matrix composites
(PMCs)
metallic matrix composites
(MMCs)
ceramic matrix composites
(CMCs)

2.1- Composite Strengthened

2.1.1- Particulate composite:- Consist of one or more materials suspended in a matrix of another material .The particles can be either metallic or non-metallic .

Large particles reinforced composite

Particulate composite classified as

Dispersion strength composite

A classic example of polymers as a particulate composite material is carbon black in rubber (in manufacturing of tires).A carbon black improves strength, stiffness, wears resistance.

2.1.1.1- Large particle reinforced composite :- Have particles with diameter of (1μm)or more and volume concentration (25-50) % or more of the composite .

One of their applications cermet or (cemented carbides), composite involving ceramic particles in a metal matrix which are widely used for the tips of cutting tools.

(e.g.)

Ceramic (Tungsten carbides)
[hard, brittle]

Metal
[soft, ductile]

Composite
[strong, hard, tough]

2.1.1.2- Dispersion strengthened composite :- The strength of a metal can be increased by small particles dispersed throughout the matrix .The diameter of particle (0.1μm)and volume concentration (1-15)% of the composite . For example the dispersion of aluminum – copper compound throughout of alloy. To product composite for general application, like piston, connecting rod for automotive application.

Also one way of introducing a dispersion of small particles throughout a metal uses sintering .Like dispersion of aluminum oxide (AL_2O_3) about (14%) throughout an aluminum matrix .

Where the tensile strength is { 400 MPa for sintered aluminum powder; 90 MPa for aluminum }

The following table give an example and applications of selected dispersion strengthened composites:

Composite	Applications
Ag-CdO	electrical contact material
Al-Al_2O_3	nuclear reaction
Pb- PbS	battery grids

The General Applications of Particulate Composite Materials

1- Non-metallic in non-metallic

- *Concrete*
- *Flakes glass in plastic matrix – for electrical insulating*

2- Metallic in non-metallic

- *Silver flakes in paint – for good conductivity*
- *Aluminum flakes in paint – aluminum paint for surface protection*

3- Non-metallic in metallic composites

- *Cermets are examples of ceramic and metallic*

4- Metallic in metallic composites

Lead particles in copper alloys to improve machineability

2.1.1.4- Rule of mixture

The rule of mixtures can predict the properties of the particulate composite material because the particulate composite materials depend only on relative amount and properties of the individual constituents . e.g.

$$\rho_c = \sum V_i * \rho_i = V_1 * \rho_1 + V_2 * \rho_2 + V_3 * \rho_3 + \cdots V_n * \rho_n$$

Where :

ρ_c = density of the composite

ρ_1 , ρ_2 , ... , ρ_n = are the density of each constituent

V_1 , V_2 , ..., V_n = are the volume of fractions of each constituent

$$V_i = \frac{v_i}{v_c}$$

where v_i volume of the item (matrix or reinforcement)

v_c total volume of the composite

$$v_i = \frac{m_i}{\rho_i}$$

where m_i mass

ρ_i density

$$v_c = \frac{m_c}{\rho_c}$$

Or $$v_c = \frac{m_c}{\rho_c} = \frac{m_1}{\rho_1} + \frac{m_2}{\rho_2} + \frac{m_3}{\rho_3} \ldots \ldots + \frac{m_n}{\rho_n}$$

Example :-

A cemented carbide cutting tool used for machining contains (54.7 vol.%) of WC (Tungsten carbide) , (34.9 vol.%) of TiC (Titanium carbide), (4 vol.%) TaC (Tantalum carbide), and (6.4 vol.%) Co (Cobalt) . Estimate the desity of the composite . where the densities are ($\rho_{WC} = 15.77\ \mathrm{g/cm^3}$, $\rho_{TiC} = 4.94\ \mathrm{g/cm^3}$, $\rho_{TaC} = 14.5\ \mathrm{g/cm^3}$, $\rho_{CO} = 8.90\ \mathrm{g/cm^3}$)

Solution :-

$\rho_c = \sum V_i * \rho_i = 0.547*15.77+0.349*4.94+0.04*14.5+0.064*8.9 = 11.5\ \mathrm{g/cm^3}$

2.1.1.5 - Upper and Lower bound

Lower bound on apparent Young,s modulus

The basic for the determination of a lower bound on the apparent Young' s modulus is application of the principle of minimum complementary energy.

$$E_{(L)} = \frac{E_m * E_p}{V_m * E_p + V_p * E_m}$$

Where, E= modulus of composite material

E_m= modulus of basic matrix

E_p= modulus of dispersed material (particles)

V_m = volume fraction of matrix

V_p = volume fraction of dispersed material

Upper bound on apparent Young's modulus :-

The basic of determination of an upper bound on the apparent Young's modulus is application of the principle of minimum potential energy.

$$E_{(U)} = E_p * V_p + E_m * V_m$$

There are many considerations must be taken in the account of choosing of dispersed material (particles) which are :-

1- No chemical reaction with the matrix.
2- Hard and solid to obstacle the slip (dislocation movement).
3- Stable at high temperature and insoluble in matrix.

The following formula is used to determine the activity of dispersed particles as obstacle to dislocation movement as following:

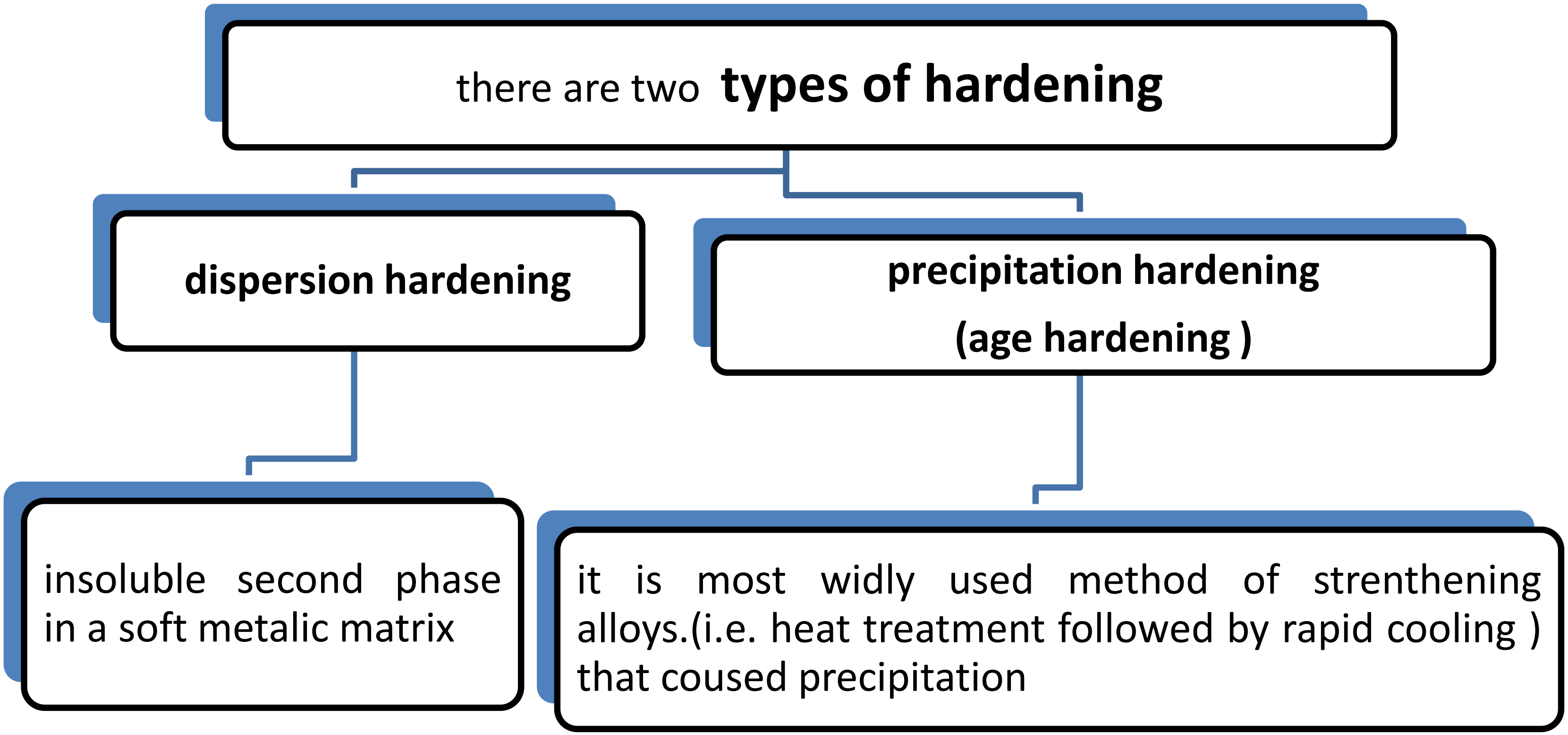
$$D_p = \frac{2*d^2}{3*v_p}(1 - v_p)$$

Where - $v_p =$ volume fraction of particles

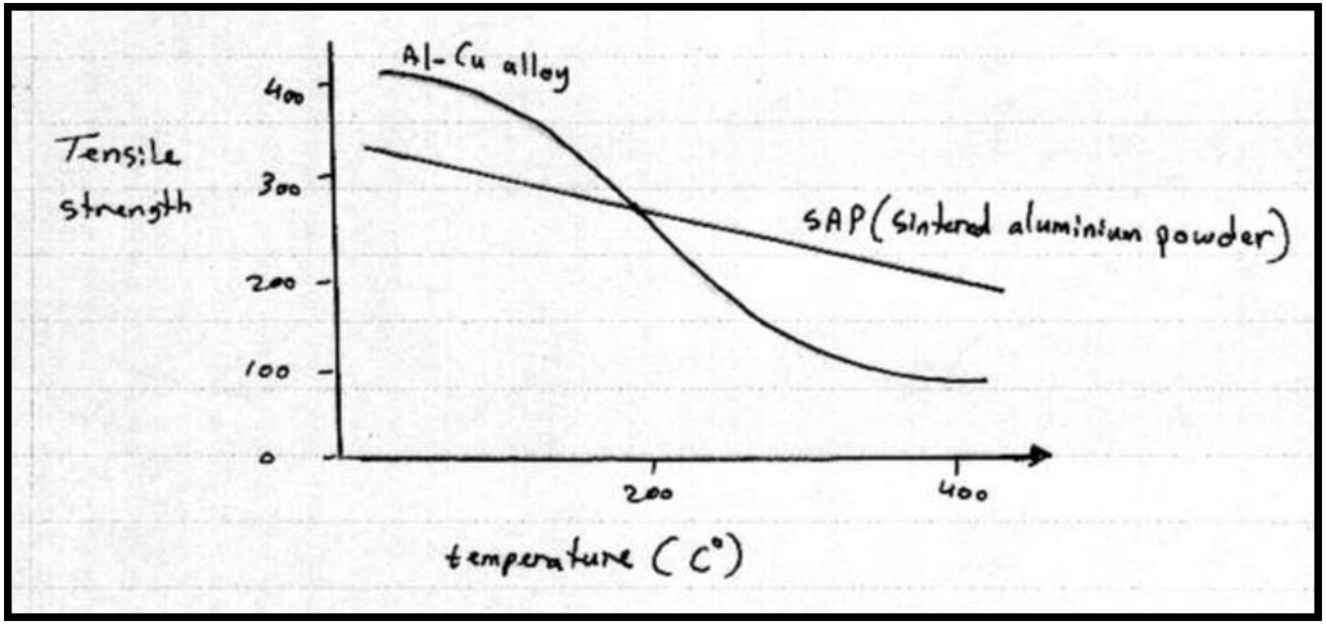
$d =$ particle diameter

$D_p =$ the distance between particles

2.1.3- Type of Hardening



The (dispersion) sintered aluminum has advantage over precipitation hardened aluminum alloys in that it retains it strength better at high temperature as showing:-



This is because at the higher temperatures, the precipitate particles in precipitation hardened alloys tend to coalesce or go into solution in the metal. While in dispersion composite material the particle remain (insoluble) to obstacle the dislocation movement.

2.2 – Natural Particulate Composite

There are some examples of naturally composite

Wood - Matrix (lignin)

Reinforcement (cellulose fiber)

Bone and teeth - Matrix (collagen)

Reinforcement

(Calcium and phosphate ions and hydroxyapatite)

2.3 - Nano Composite :-

Is a multiphase material in which at least one of the phases has at least one dimension in order of nanometers (less than 100nm, i.e. 0.1 μm)

Bone – natural nano composite.

3- Principles of Fiber Reinforcement

3.1- Type , Classification and Properties

The fibers may be continuous throughout the matrix or short fibers, and aligned in all the same direction or randomly arranged as shown in figure (1).Like glass or carbon fibers in polymers and ceramic fiber in metal.

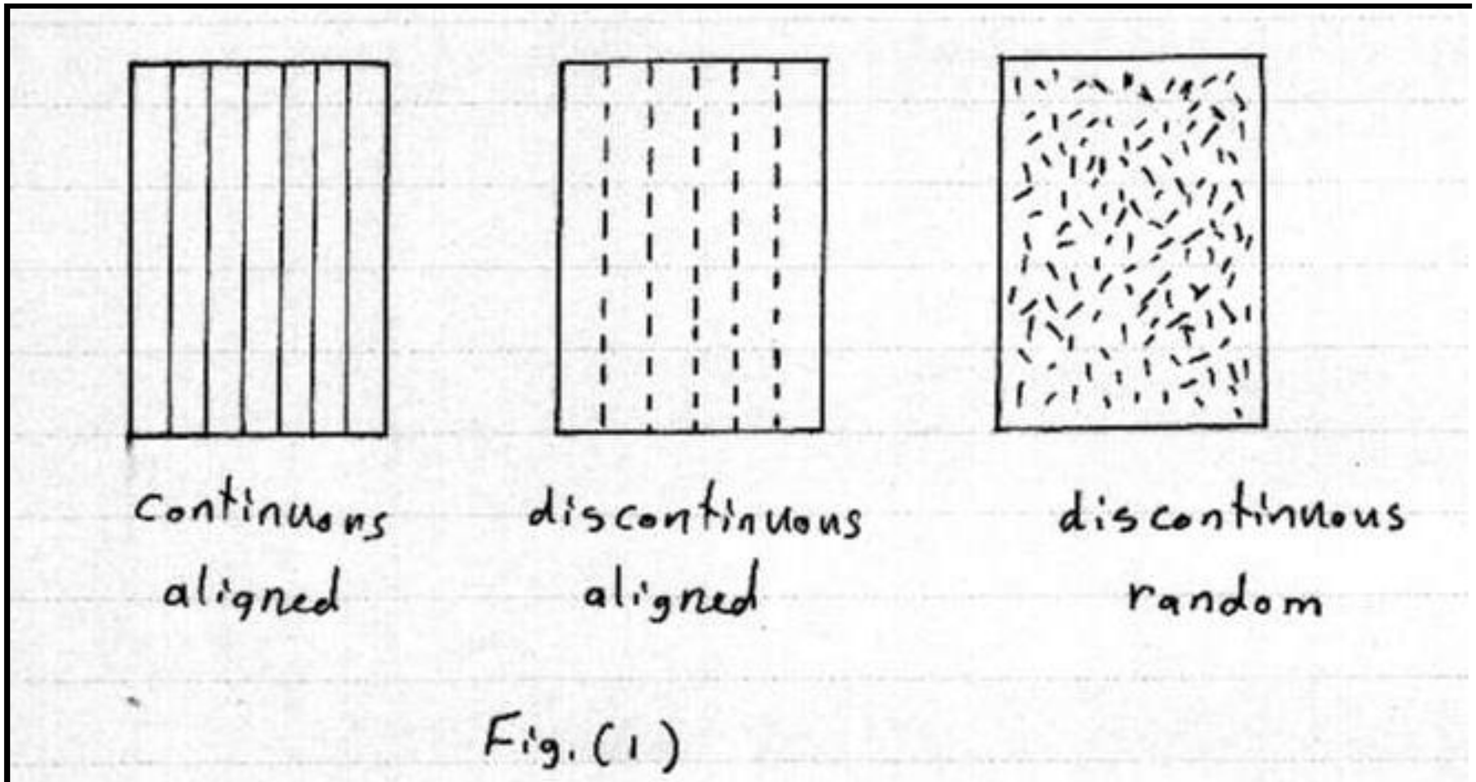


Fig. (1)

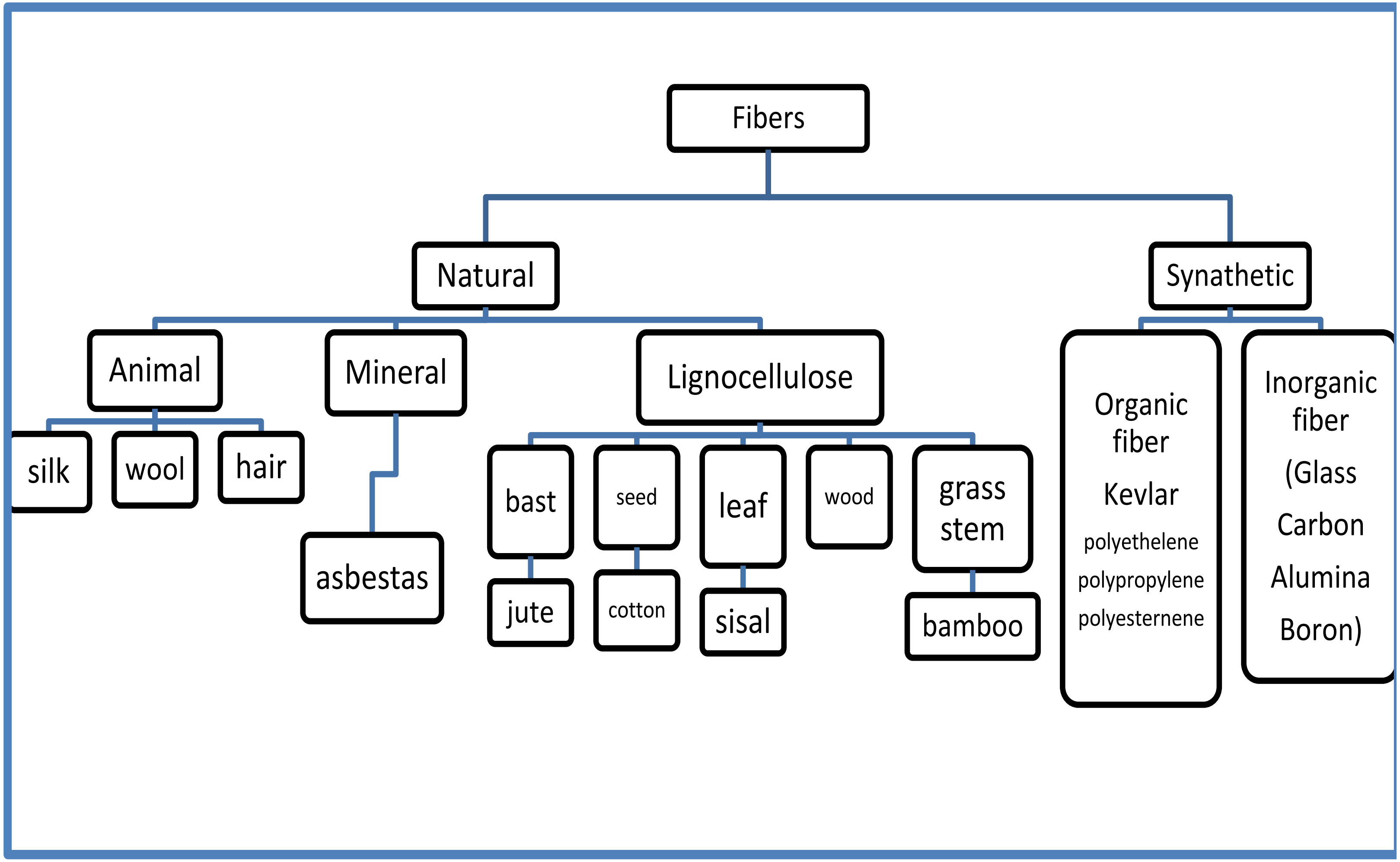
Fibrous form give the rigidity and strength of the composite

Continuous fiber composite: - A composite whose reinforcement is made by fibers of indefinite length .

Discontinuous fiber composite:- A composite whose fibers have a limited length, typically (3-50) mm.

Unidirectional composite:- A composite in which the fibers are aligned according to the principal orientation .

Fibers may be classified according to its nature as folowing:-



3.2- Common fiber used in composite materials

The most **common fibers used for engineering applications** one :-

- Glass
- Carbon (graphite)
- Kevlar (aramid)
- Boron

While the most widely used as a matrix for fibrous composites are epoxy ,polyester and organic " supper polymer " material commonly called plastics.

Properties of fiber

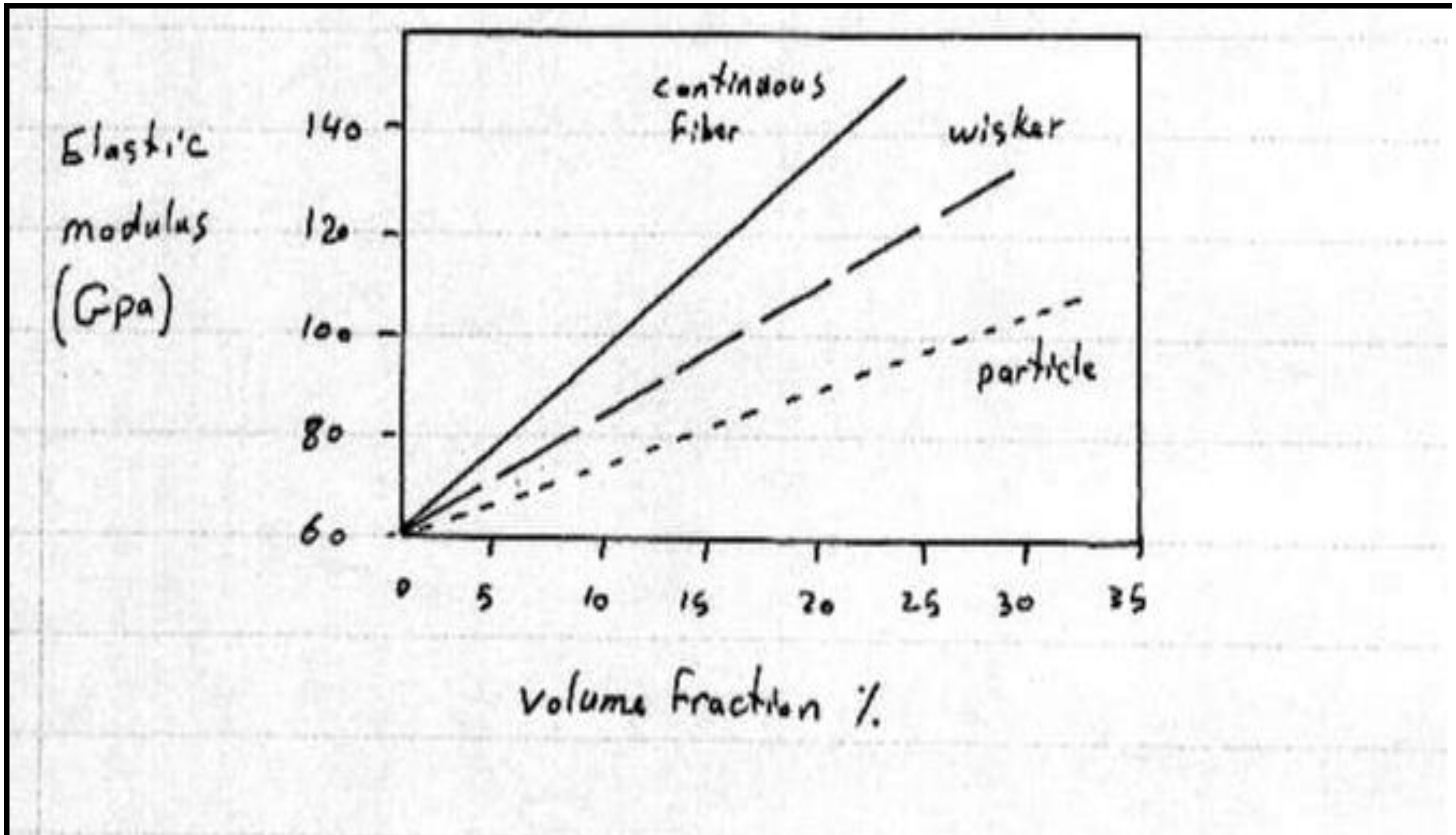
1- High modulus of elasticity.
2- High ultimate strength.
3- Low variation of strength between individual fibers.
4- Uniform fiber cross- section.
5- Stability and retention of strength during fabrication.

Properties of matrix

1- Low density.
2- Low strength.
3- Bind the fibers together.
4- Transfer the load to the fiber.
5- Stop, to some extent, a crack from propagation.
6- Protect the fibers surfaces from damage in service.
7- Be chemically and thermally compatible with fiber.

Fibers may be wires or wisker (**wiskers** are very fine fibers have short length to diameter ratio).

The following figure shows the increase modulus with increase the volume fraction for the same reinforcement but different shape (continuous fiber, wisker or particle). This schematic shows the loss of reinforcement efficiency as one goes from continuous fiber to particle.



The most fibers used in composite material are :-

1) **Glass fiber**

- The most common and inexpensive fiber, usually used for the reinforcement of polymer matrices.
- Typical composition is (50-60% SiO_2), and other oxides of (Al, Ca, Mg, Na,…….etc.).
- Glass fibers are available as:-

a) Chopped strands.

b) Continuous yarn.

c) Roving.

d) Fabric sheet.

- Properties of Glass fiber

- Good dimensional stability.
- Resistant to heat.
- Strength - to – density is high.

2) **Carbon fibers**

a) Carbon is very light element, with density about (2.39 gm/cm^3).

b) Carbon has excellent compression properties.

c) Good thermal properties.

Carbon fiber adds electrical conductive properties to composite.

1) **Ceramic fiber**

- Such as
  - Alumina (Al_2O_3)
  - Silicon carbide (SiC)
- It is used in very high temperature applications.
- It has poor properties in tension and shear.

2) **Metallic fiber**

- Such as steel and tungsten.
- Have high strength.
- Density is very high for these fibers.

3) **Natural fibers**

- Cotton
- Flax
- Jute
- Hemp
- Ramie
- Wood
- Straw
- Hair
- Wool
- Silk

3.3- Rule of Mixture in Fibrous Composite

As for particulate composites, the rule of mixtures always predicts the density of fiber – reinforced composites.

The mass (m_c) of a composite is made up of masses of the matrix (m_m) and the fiber (m_f) i.e.

$$m_c = m_m + m_f \qquad \text{........................(1)}$$

since mass is volume (v) time density (ρ) then equation (1) can be written as :-

$$v_c * \rho_c = v_m * \rho_m + v_f * \rho_f$$

And so :-

$$\rho_c = \frac{v_m}{v_c}\rho_m + \frac{v_f}{v_c}\rho_f$$

$\frac{v_m}{v_c}$ is the matrix volume fraction (V_m)

$\frac{v_f}{v_c}$ is the fiber volume fraction (V_f)

Thus ,

Thus ,

$$\rho_c = V_m * \rho_m + V_f * \rho_f \dots\dots\dots\dots\dots\dots (2)$$

And $V_m = 1 - V_f$

Therefore equation (2) can be termed a law of mixtures.

In addition, the rule of mixtures accurately predicts the electrical and thermal conductivity of fiber –reinforced composites along the fiber direction

$$K_c = V_m * K_m + V_f * K_f$$

$$\sigma_c = V_m * \sigma_m + V_f * \sigma_f$$

where :- K- is the thermal conductivity

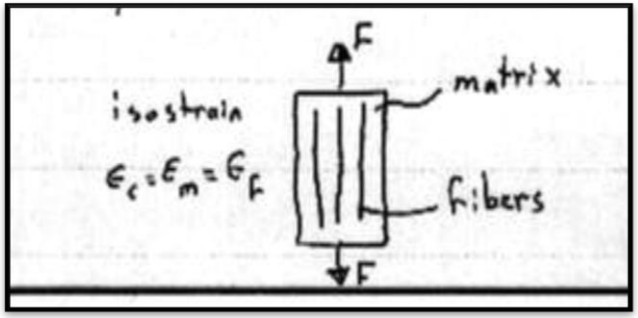
σ - is the electrical conductivity

Modulus of elasticity

The rule of mixtures is used to predict the modulus of elasticity

Parallel to the fiber (along the axis of fibers)

The total force acting on the composite is the sum of the forces carried by each constituent



$$F_c = F_m + F_f$$

Scine, $F = \sigma * A$

$$\sigma_c * A_c = \sigma_m * A_m + \sigma_f * A_f$$

$$\sigma_c = \sigma_m \left(\frac{A_m}{A_c}\right) + \sigma_f \left(\frac{A_f}{A_c}\right)$$

The area fraction (A) equal to the volume fraction (V)

$$\sigma_c = \sigma_m * V_m + \sigma_f * V_f$$

from Hooke's law , $\boldsymbol{\sigma = E * \varepsilon}$, therefore

$$E_c * \varepsilon_c = E_m * \varepsilon_m * V_m + E_f * \varepsilon_f * V_f$$

If the fibers are rigidly bonded to the matrix, both the fibers and matrix must stretch equal a mounts (iso-strain conditions)

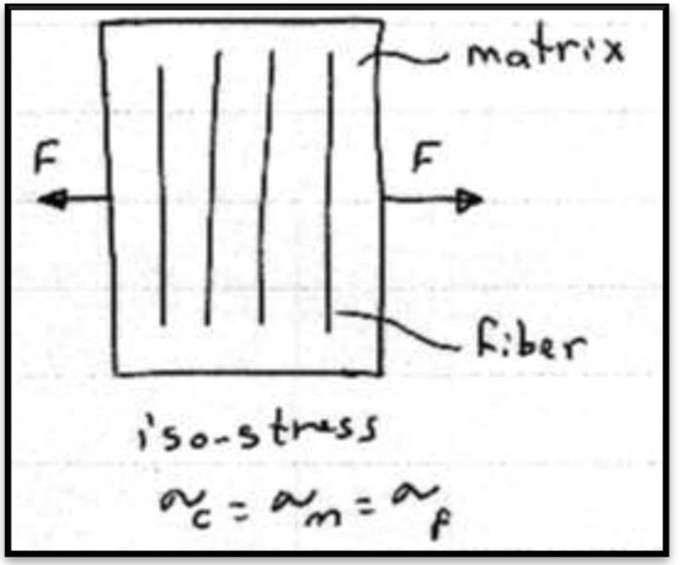
$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

so, $E_{c,II} = E_m * V_m + E_f * V_f$ *(upper bound)*

The modulus of elasticity may be high .

while in perpendicular direction (at right angle to fiber)

The sum of strains in each component equals to the total strain in the composite, where as the stresses in each component are equal (iso- stress condition).



$$\varepsilon_c=\varepsilon_m*V_m+\varepsilon_f*V_f$$

$$\frac{\sigma_c}{E_c} = \frac{\sigma_m}{E_m} * V_m + \frac{\sigma_f}{E_f} * V_f$$

Science $\sigma_c=\sigma_m=\sigma_f$

$$\therefore \frac{1}{E_{c,\perp}} = \frac{V_m}{E_m} + \frac{V_f}{E_f} \Longrightarrow$$

$$E_{c,\perp} = \frac{E_m * E_f}{E_m * V_f + E_f V_m} \quad (lower\ bound)$$

It can also be shown, for longitudinal loading that the ratio of load carried by the fibers to that carried by the matrix is:

$$\frac{F_f}{F_m} = \frac{E_f * V_f}{E_m * V_m}$$

This can be proved as following :-

In the longitudinal direction both matrix and fiber have equal strain if bonding is good, so :

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

$$\varepsilon_m = \frac{\sigma_m}{E_m} \quad , \quad \varepsilon_f = \frac{\sigma_f}{E_f}$$

$$\therefore \frac{\sigma_m}{E_m} = \frac{\sigma_f}{E_f} \quad , \quad \sigma = \frac{F}{A}$$

$$\frac{F_m}{E_m * A_m} = \frac{F_f}{E_f * A_f}$$

$$\therefore \frac{F_f}{F_m} = \frac{E_f * A_f}{E_m * A_m}$$

Dividing the right side by A_c

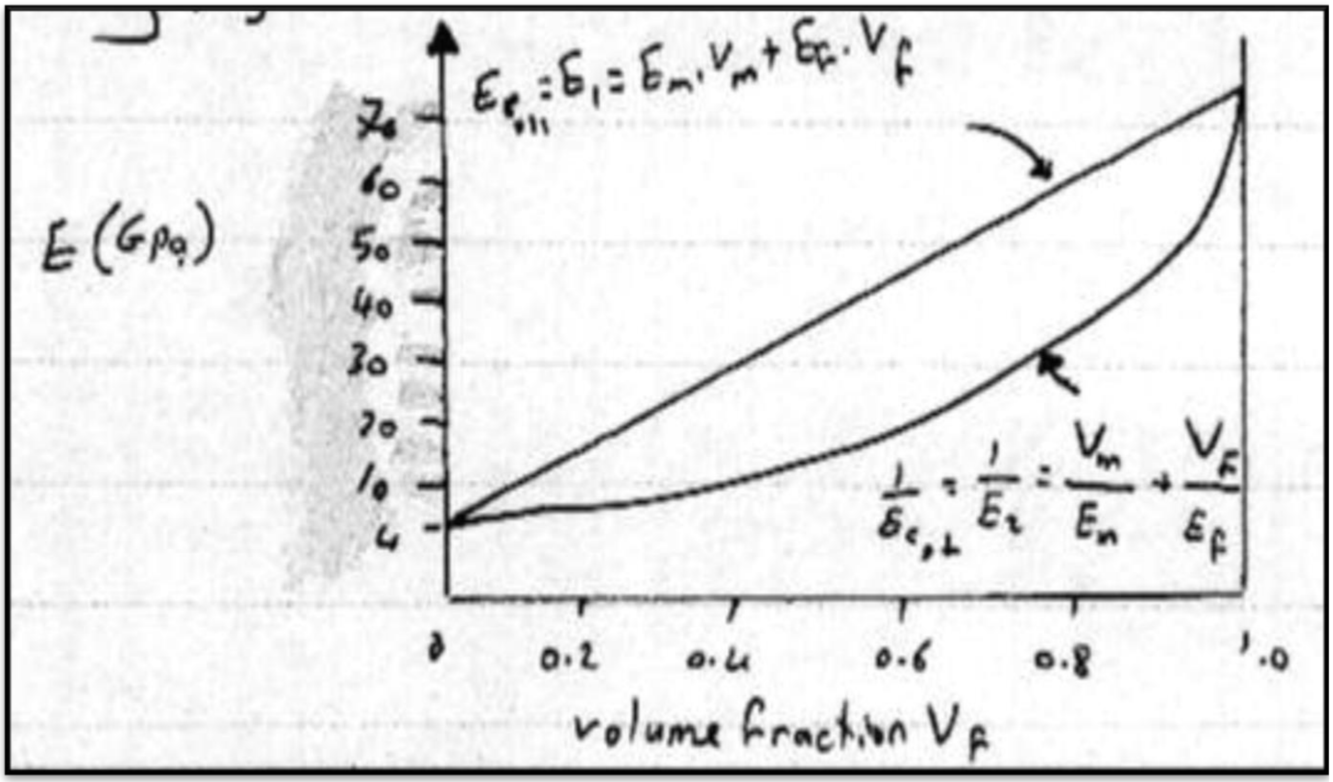
$$\frac{F_f}{F_m} = \frac{E_f * \frac{A_f}{A_c}}{E_m * \frac{A_m}{A_c}}$$

$$V_f = \frac{A_f}{A_c} \quad , \quad V_m = \frac{A_m}{A_c} \quad for\ the\ same\ length\ (L)$$

$$\therefore \frac{F_f}{F_m} = \frac{E_f * V_f}{E_m * V_m}$$

It is represent the ratio of the load carried by the fibers to that carried by the matrix.

According to the formula, the volume fraction has effect on the modulus of elasticity in both directions .For example Rule- of –mixtures Prediction for longitudinal (E_1) and transverse (E_2) modulus for glass-polyester composite (E_f = 73.7 G pa),(Em = 4 G pa) as shown in the following figures .



Note: To calculate the volume fraction of fiber and matrix

3.4 – Relationship between Volume Fraction and Weight Fraction

1. **In term of weight fraction**

$$V_f = \frac{\rho_c}{\rho_f} . w_f \quad , \quad V_m = \frac{\rho_c}{\rho_m} . W_m$$

(w_f) is the **weight fraction of fiber** = $\frac{W_f}{W_c}$

(W_f)means **fiber weight , (**W_c)means **composite weight**

(w_m) is the **weight fraction of matrix** = $\frac{W_m}{W_c}$

(W_m)**means matrix weight**

2. **In term of volume fraction**

$$V_f + v_m = 1$$

$$v_f = \frac{\nu_f}{\nu_c}$$

$$v_m = \frac{\nu_m}{\nu_c}$$

Example :-_borsic (boron coated with Sic) reinforced aluminum 40 % volume fibers is an important high - temperature .Estimate the density, modulus of elasticity ,and tensile strength parallel to the fiber axis. Also estimate the modulus of elasticity perpendicular to the fibers.

Material	Density g/cm^2	Modulus of elasticity (Gpa.)	Tensile strength Mpa.
Fibers (Borosic)	2.36	380	2760
Matrix(aluminum)	2.7	69	34.5

Solution : $V_{f=0.4}$ ⇨ $V_{m=0.6}$

From the rule of mixtures

$$\rho_c = \rho_m * V_m + \rho_f * V_f \quad =2.7*0.6+2.36*0.4=2.56\ g/cm^3$$

$$E_{c,11}=E_m*V_m+E_f*V_f = 69*0.6+380*0.4=193.4\ GPa$$

$$T_{Sc} = T_{Sm}*V_m+T_{Sf}*V_f$$

$$=34.5*0.6+2760*0.4=1124.7\ MPa$$

Perpendicular to the fibers

$$\frac{1}{E_{c,\perp}} = \frac{V_m}{E_m} + \frac{V_f}{E_f} = \frac{0.6}{69} + \frac{0.4}{380} = 9.75 * 10^{-3}$$

$$\therefore E_{c,\perp} = 102.56\ GPa$$

Example: - A continuous and aligned glass fiber – reinforced composite consist of (40%) volume fraction of glass fibers having a modulus of elasticity of (69Gpa). ,and (60%) volume fraction of polyester resin , when hardened , displays a modulus of (3.4 GPa).

a) Compute the modulus of elasticity of this composite in the longitudinal direction.
b) If the cross- sectional area is (250 mm^2) and a stress of (50 MPa). Is applied in this longitudinal direction, compute the magnitude of the load carried by each of the fiber and matrix phases.
c) Determine the strain that is sustained by each phase when the stress in part (b) is applied.

d) Compute the modulus of elasticity of this composite in the perpendicular direction.

Solution:-

a) $E_{c,11}=E_m*V_m+E_f*V_f = 3.4*0.6+69*0.4 = 30$ GPa

b) $\frac{F_f}{F_m} = \frac{E_f*V_f}{E_m*V_m} = \frac{69*0.4}{3.4*0.6} = 13.5$

or $F_f = 13.5\ F_m$

$F_c=A_c*\sigma = 250*50=12500$ N

This total load is just the sum of load carried by fiber and matrix

$F_c=F_f+F_m$

$13.5\ F_m+ F_m=12500$

$F_m=860$ N

Where , $F_f = F_c - F_m = 12500-860=11640$ N

The fibers support the majority of the load.

c) $A_m=V_m*A_c=0.6*250 = 150\ mm^2$

$A_f=V_f*A_c = 0.4*250 = 100\ mm^2$

$$\sigma_m = \frac{F_m}{A_m} = \frac{860}{150} = 5.73\ MPa$$

$$\sigma_f = \frac{F_f}{A_f} = \frac{11640}{100} = 116.4\ MPa$$

Finally the strain are computed as :

$$\varepsilon_m = \frac{\sigma_m}{E_m} = \frac{5.73}{3.4 * 10^3} = 1.69 * 10^{-3}$$

And $\quad , \varepsilon_f = \frac{\sigma_f}{E_f} = \frac{116.4}{69 * 10^3} = 1.69 * 10^{-3}$

$$\varepsilon_c = \frac{\sigma_c}{E_c} = \frac{50}{30 * 10^3} = 1.69 * 10^{-3}$$

a) $E_{c,\perp} = \frac{E_m * E_f}{V_m * E_f + V_f * E_m} = \frac{3.4 * 69}{0.6 * 69 + 0.4 * 3.4}$

$E_{c,\perp}$ = 5.5 GPa

Example :- For an glass fiber- epoxy matrix composite with the volume fraction of fiber as (65%). Estimate the modulus of elasticity when the load is at (0^o) with the fibers and the modulus of elasticity when the load is at (90^o) with the fiber.

Note:- modulus of elasticity for epoxy = 3.5 GPa.

modulus of elasticity for glass fiber = 70 GPa.

H.W.

SOLUTION

Example :- Consider a uniaxial fiber reinforced composite of aramid fibers in an epoxy matrix. The volume fraction of fibers is (60 %) .The composite is subjected to an axial strain of (0.1 %) .Compute the modulus and strength along the axial direction of the composite, E_f=140 GPa (aramid fiber), E_m=5 GPa (epoxy)

Solution:-

$E_{c,II} = E_f * V_f + E_m * (1 - V_f)$

$= 140*0.6+5*0.5 = 86$ GPa

$$\sigma_{c1} = \varepsilon * E$$

$$= 0.001 * 86 = 86 \quad MPa$$

Example :-what is the ratio of the longitudinal modulus of elasticity to the transverse modulus for a composite with continuous aligned fiber constituting (50 %) of the volume if the tensile modulus of the fiber (50 times) that of the matrix .

Solution :-

$E_{c,11}=E_m*V_m+E_f*V_f$

$= E_m*0.5+50\ E_m*0.5= 25.5\ E_m$

a) $$E_{c,\perp} = \frac{E_f*E_m}{E_m*V_f+E_f*V_m}$$

$$= \frac{50\ \mathrm{Em}*\ \mathrm{Em}}{\mathrm{Em}*0.5+50\ \mathrm{Em}*0.5} = \frac{50\ \mathrm{Em}}{25.5} = 1.961Em$$

$$\therefore \frac{\mathrm{Ec,II}}{E_{c,\perp}} = \frac{25.5\ \mathrm{Em}}{1.961\mathrm{Em}} = 13.005$$

Example :- A composite material has a longitudinal modulus of elasticity of (18.2 GPa). Containing unidirectional S – glass fibers in on epoxy matrix. Determine,

a) Volume fraction of glass fiber and the epoxy matrix.
b) The density of the composite.
c) The ratio of load carried by the fibers to that carried by the matrix.

Note :- Density of epoxy = 1.3 gm/cm^3

Density of glass = 2.2 gm/cm^3

Modulus of epoxy = 2.75 GPa.

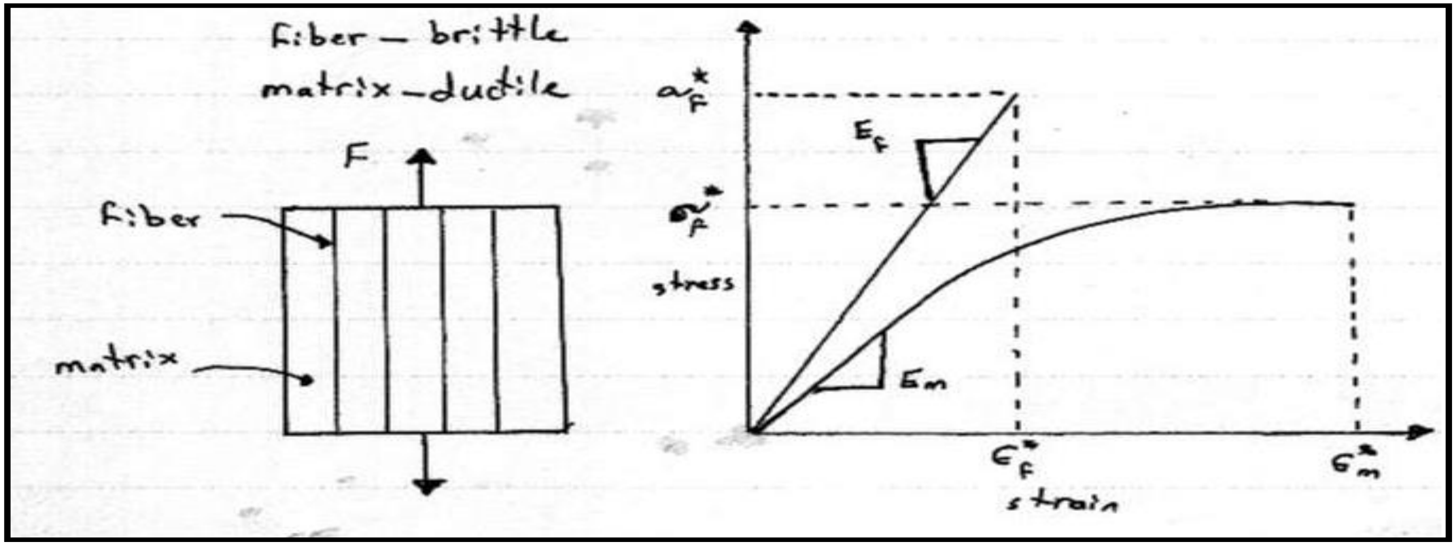
Modulus of glass =380 GPa.

H.W.

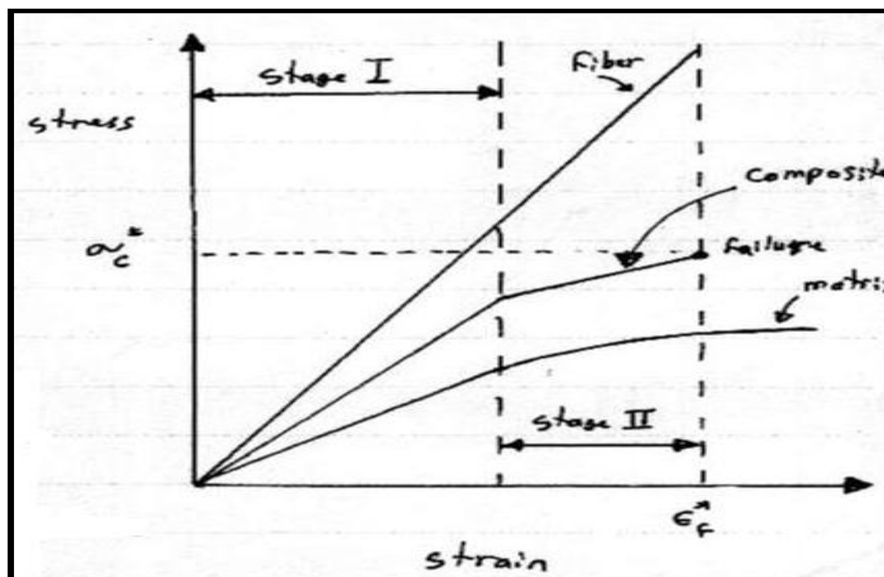
Solution :-

4.1 - Stress-Strain Behavior of Aligned Fiber Composite

The following figure represented schematically stress-strain behaviors for the fiber and matrix (loaded in the longitudinal direction).



- In the stage I region,
  Both fibers and matrix deform elastically.
- In stage II
  The matrix starts to yield as the fibers continue to deform elasticity.
- The onset of composite failure begins as fibers start to fracture.



4.2 – Causes of Failure

Therefore in composites the main causes of failure can be:

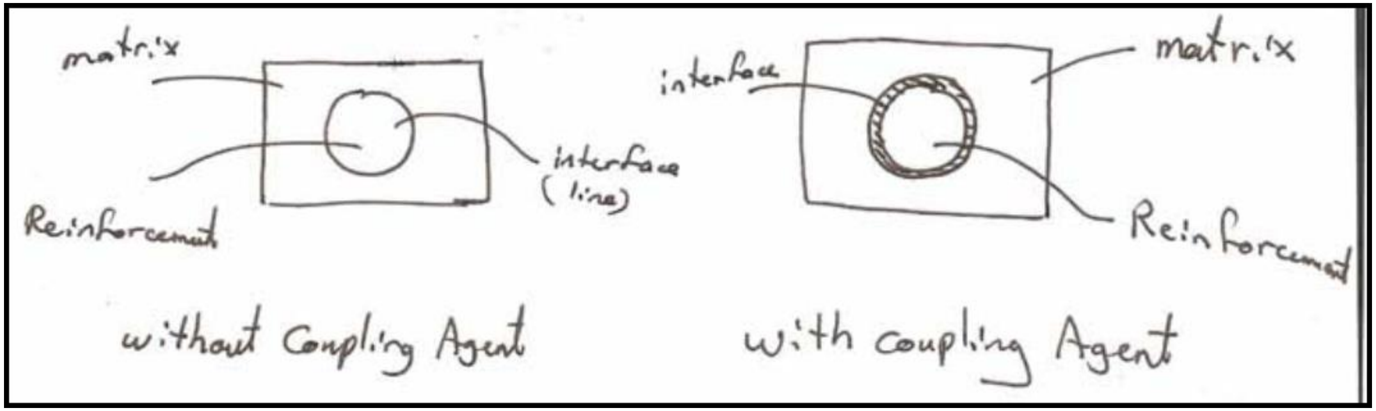
a) Breaking of fibers.
b) Deboning (separation of fibers and matrix).
c) Micro cracking of the matrix.
d) Delamination.

4.3 - Components of Composite Materials

1. Matrix
2. Reinforcement
3. Interface

5.1 – Definition of Interface

The interface is a bonding surface or zone between the reinforcement and matrix.

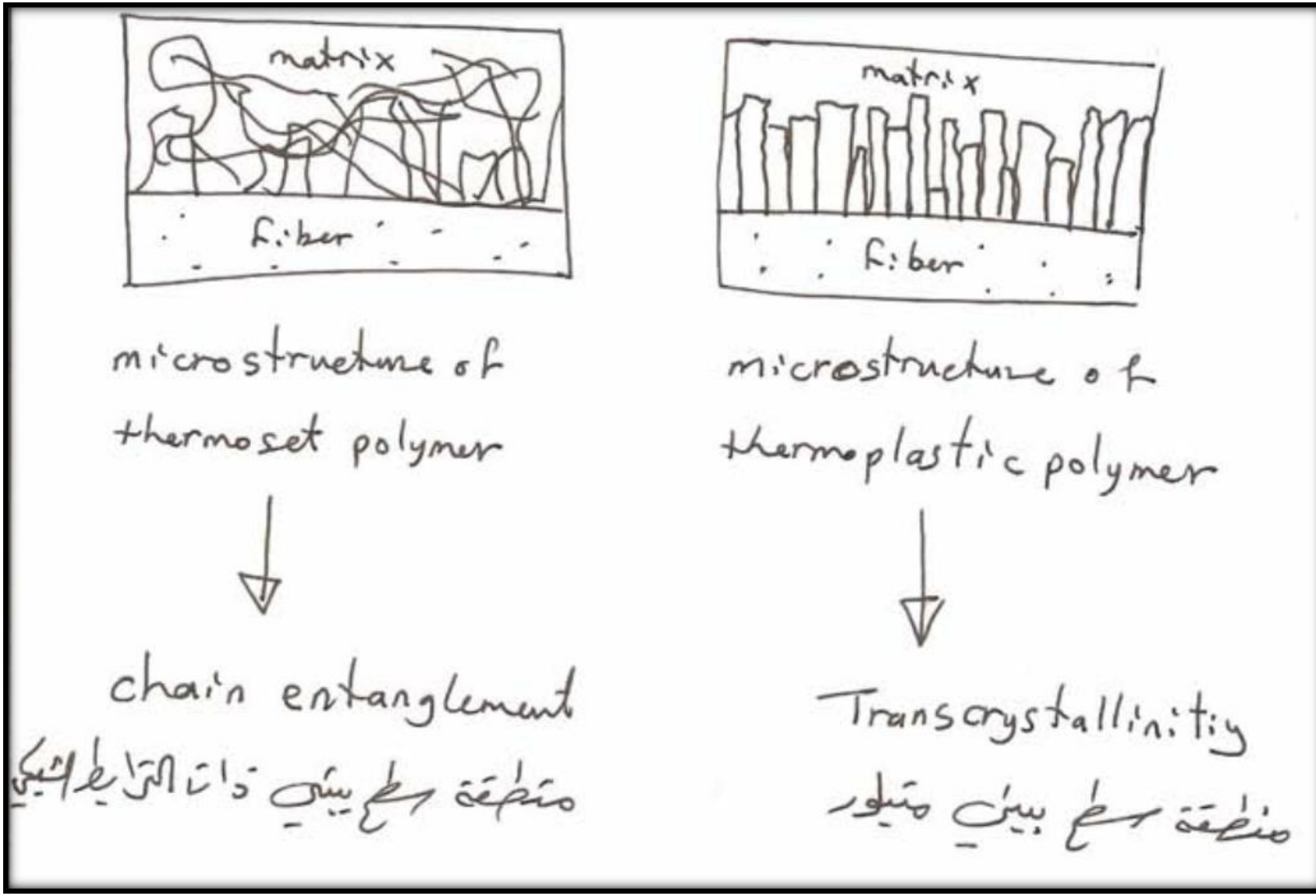


- The matrix material must "wet " the reinforcement. Coupling agents are frequently used to improve wettability.

(Wetted reinforcement increase the interface surface area and bonding).

- The applied load is transfer from matrix to the reinforcement via the interface. This means that the interface must be larger and exhibit strong adhesion between the reinforcement and matrix.
- Coupling Agents form the interphase which has different mechanical properties from that of matrix and reinforcement.

There for the mechanical properties depend on the properties of the interphase also .


matrix
fiber
microstructure of thermoset polymer
chain entanglement
منطقة سطح بيني ذات الترابط الشبكي
matrix
fiber
microstructure of thermoplastic polymer
Transcrystallinitiy
منطقة سطح بيني متبلور

5.2 – Requirement

The General Requirement of the interphase

- Big bond
- chemical stability

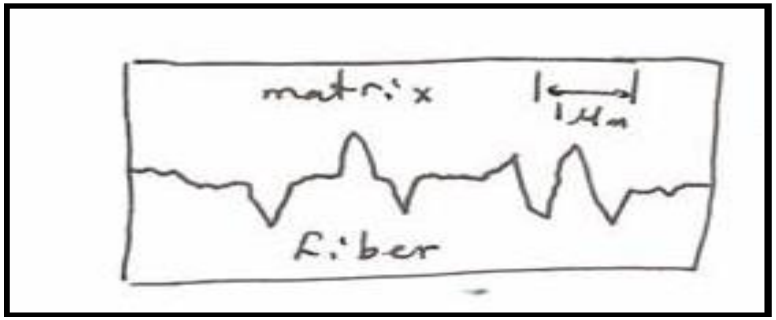
} In order to carry the load from the matrix to reinforcement

Therefore the interphase depend on

1) Reinforcement shape.
2) Surface roughness of the reinforcement.
3) Treated the surface by coupling agent (wettability).

5.3 – Type of Bond

5.3.1 - Mechanical Bond



That depends on surface roughness

5.3.2 - Chemical Bond

عن طريق الترابط بأواصر تساهمية أو أيونية أو معدنية

n the wettability increase → increase chemical bonding.

- ➢ Failure at the interface (called deboning)
- ➢ The interfacial strength (max. shear stress)

Adhesion failure between the reinforcement and matrix is measured by three - point bending test by founding max. Shear stress (τ_{max}).

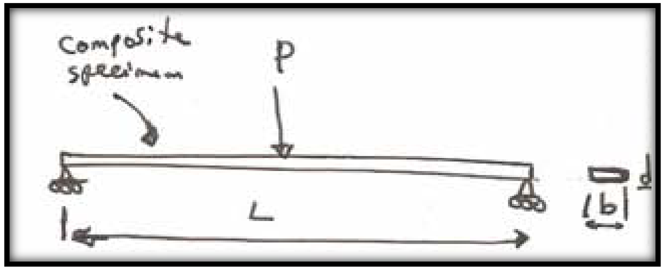
$$\tau_{max} = \frac{3P}{4bd} \qquad (MPa)$$

Where:-

P= force at the fracture (N).

b = width of the composite specimen (mm).

d = thickness of the composite specimen (mm).



5.4 - Advantages of Composite Materials

1) High resistance to fatigue and corrosion degradation.
2) High strength - to - weight ratio, as shown in the following table.

Material	Strength (lb/in^2)	Density (lb/in^3)	Strength-to-weight ratio (in)
Poly ethylene	1000	0.030	$0.03*10^6$
Pure aluminum	6500	0.098	$0.07*10^6$
Epoxy	1500	0.050	$0.3 *10^6$
Alloy steel	240000	0.28	$0.86 *10^6$
Aluminum alloy	86000	0.098	$0.88*10^6$
Titanium alloy	170000	0.16	$1.06 *10^6$
Carbon-carbon composite	60000	0.065	$0.92 *10^6$
Carbon-epoxy composite	80000	0.050	$1.6*10^6$

3) Due to greater reliability, there are fewer structural repair.
4) Composite are dimensionally stable, i.e. they have low thermal conductivity and low coefficient of thermal expansion.
5) Manufacture and assembly are simplified.

5.5 - Disadvantages of Polymers in Construction are

1) High cost of materials.
2) Low stiffness and strength.
3) Poor scratch resistance.
4) Degradation under UV light (stabilizers used)
5) Low resistance to fire and high temperature (additive used).

6.1 - Limitation of Composite Materials

1) High cost of raw materials and fabrication.
2) Composites are more brittle than metals and thus are more easily damaged.
3) Transverse properties may be weak.
4) Reuse may be difficult.
5) Difficult to attach.
6) Analysis is difficult.

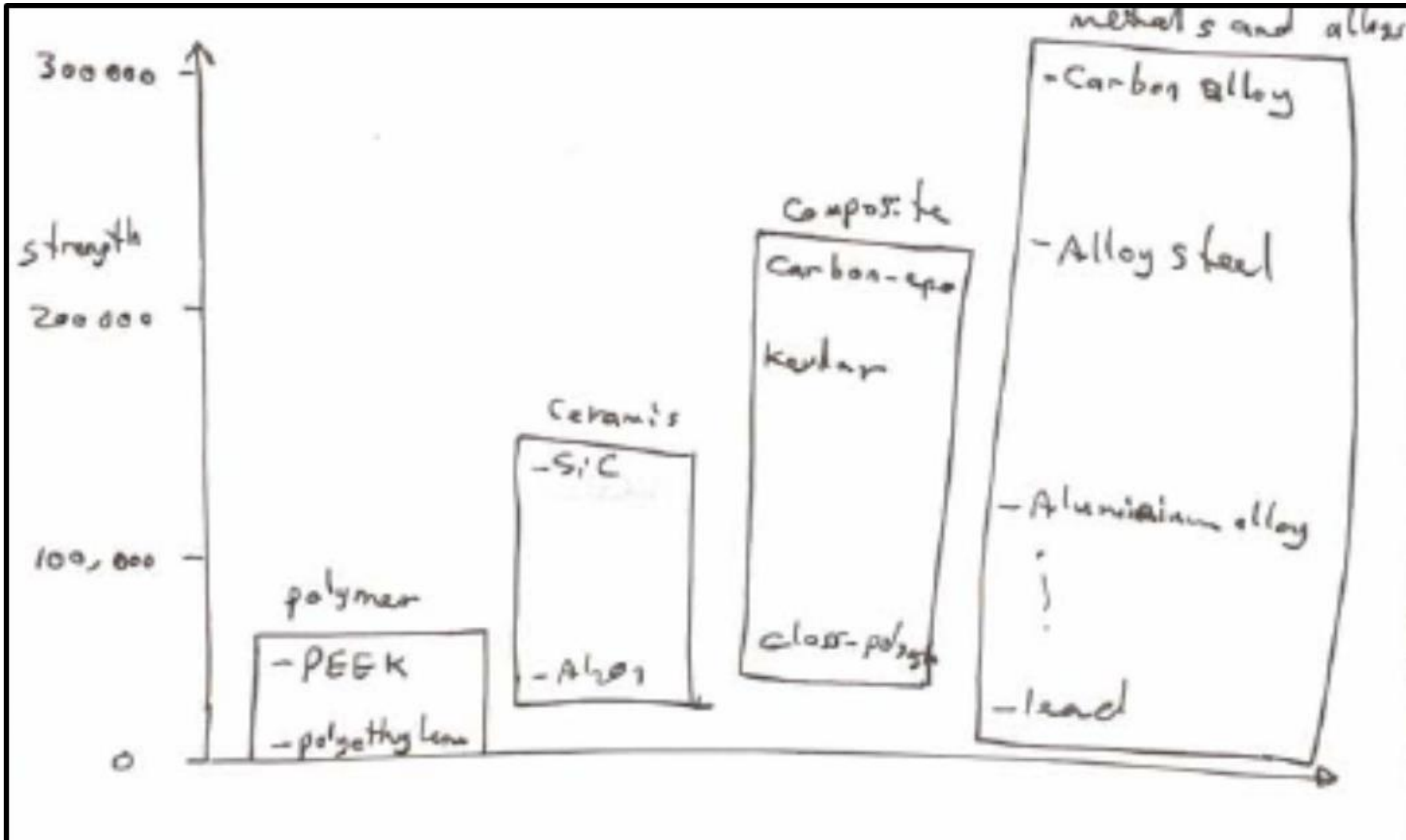
Comparison between Composite and Metals

1) Composites offer significant weight saving over existing metals. Composite can provide structures that are (25-45%) lighter than the conventional metal structure for the save functional requirement. This is due to lower density of the composites.

   i.e. densities of composites range from (1.26-1.82 gm/cm^3) as compared to (2.8 gm/cm^3) for aluminum.

2) Unidirectional fiber composite have specific tensile strength (ratio of material strength to density) about (4- 6) times greater than that of steel and aluminum.

3) Unidirectional composites have specific – modulus (ratio of the material stiffness to density) about (3 -5) times greater than of steel and aluminum.



300 000
strength
200 000
100, 000
0
polymer
-PEEK
-polyethylene
Ceramics
-SiC
-Al2O3
Composite
Carbon-epo
Kevlar
Glass-polyes
methals and alloys
-Carbon alloy
-Alloy steel
-Aluminium alloy
-lead

6.2 - Durability of Polymer Composites

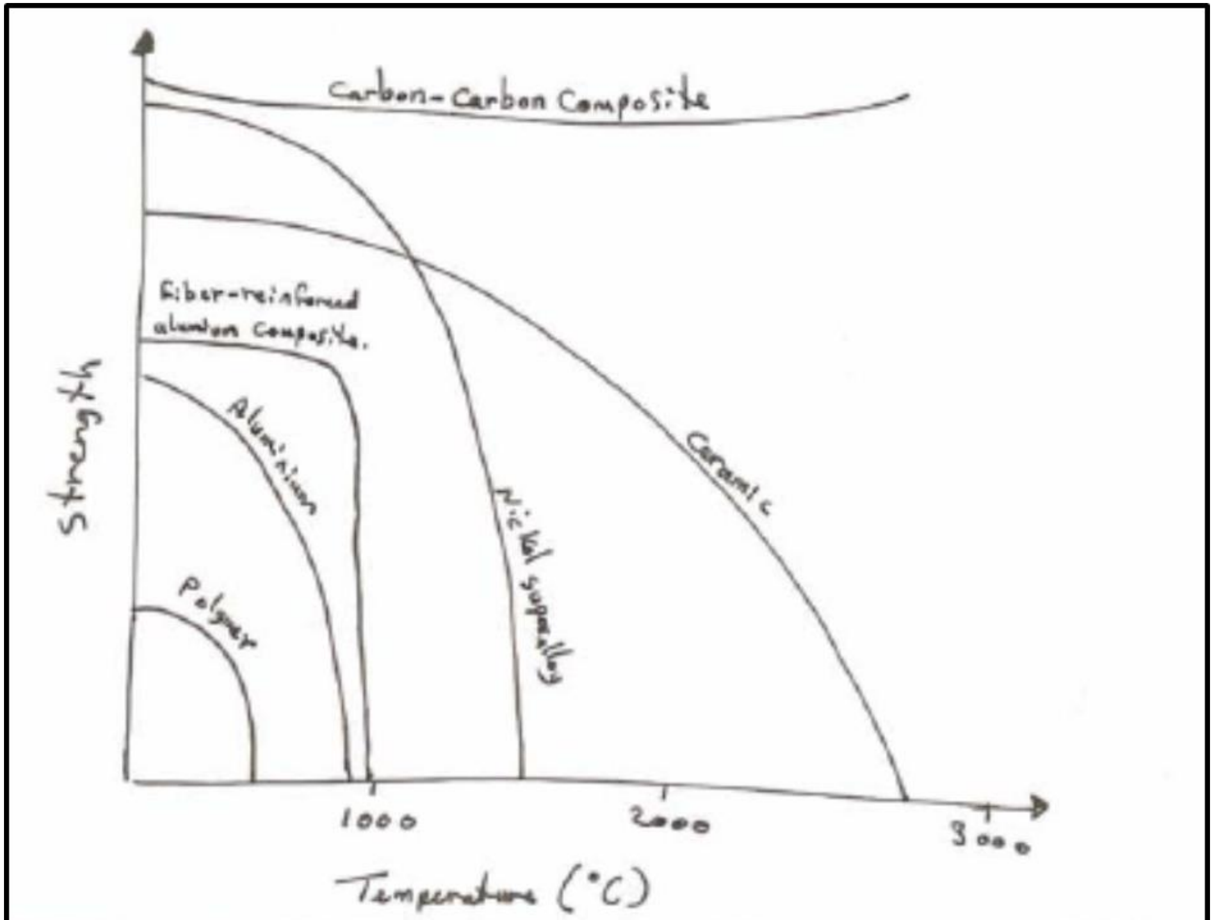
Polymer composites change with time and most significant factors are:-

1) Elevated temperature.
2) Fire.
3) Moisture.
4) Adversed chemical environments.
5) Natural weathering when exposed to sun's ultra- violet radiation.

6.2.1 - Temperature

- Fluctuating temperature have greater deterioration effect on the properties of composites. Different in coefficient of thermal expansion coefficient of reinforcement and matrix may cause deponding.
- Exposed to high temperatures lead to discoloration of the resin becoming yellow. As a result of exposure to high temperature, the composite becomes brittle.

The effect of temperature on strength of materials represented by the following figure


Carbon-Carbon Composite
fiber-reinforced
aluminum composite
Aluminum
Polymer
Nickel superalloy
Ceramic
Strength
1000
2000
3000
Temperature (°C)

6.2.2 - Firing

A composite material must meet appropriate standards of fire performance.

- Aluminum trihydrate
- Antimony trioxide

} Are used as fillers to enable flame – retardant properties

6.2.3 - Moisture

Polymer absorbs water which may cause a decrease in strength and modulus of elasticity. Absorption of water by polyesters and epoxies lead to swelling of laminate.

Water will also cause some surface flaws on fibers, long-term of water absorption may cause weakening of the bond between fiber and polymer

6.2.4 - Chemical Environments

6.2.5 - Weathering

Natural weathering can affect mechanical properties of composite through surface deboning.

Because of weathering is surface effect, thickness of laminate becomes important.

3mm thickness ⟹ (12-20%) reduction in flexural stress after 15 years

10 mm thickness ⟹ ~ 3% reduction in flexural stress after 50 years

Methods of Manufacture of FRP Components

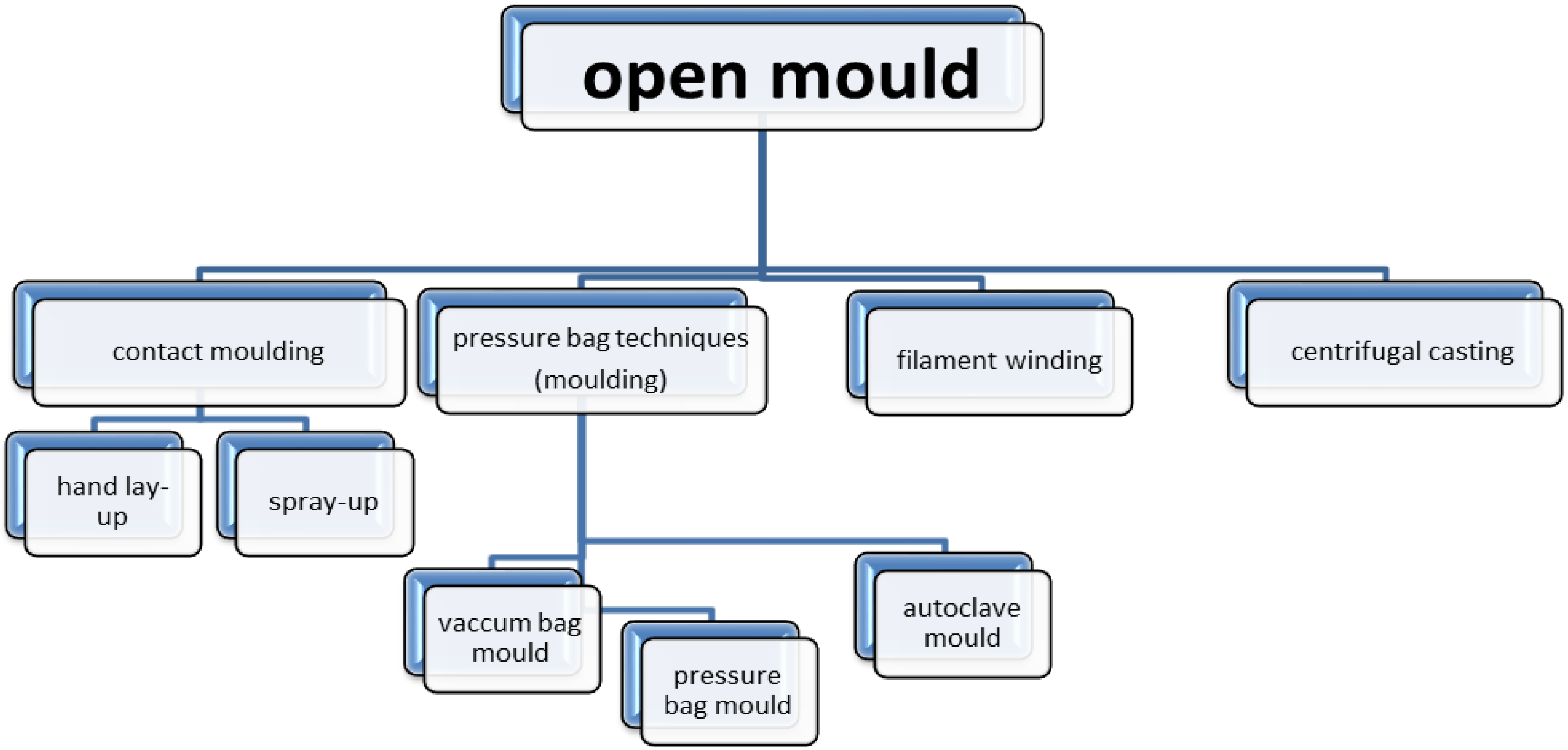
There are two groups of process used for the fabrication or (manufacturing) of FRP component

1) Open mould process.

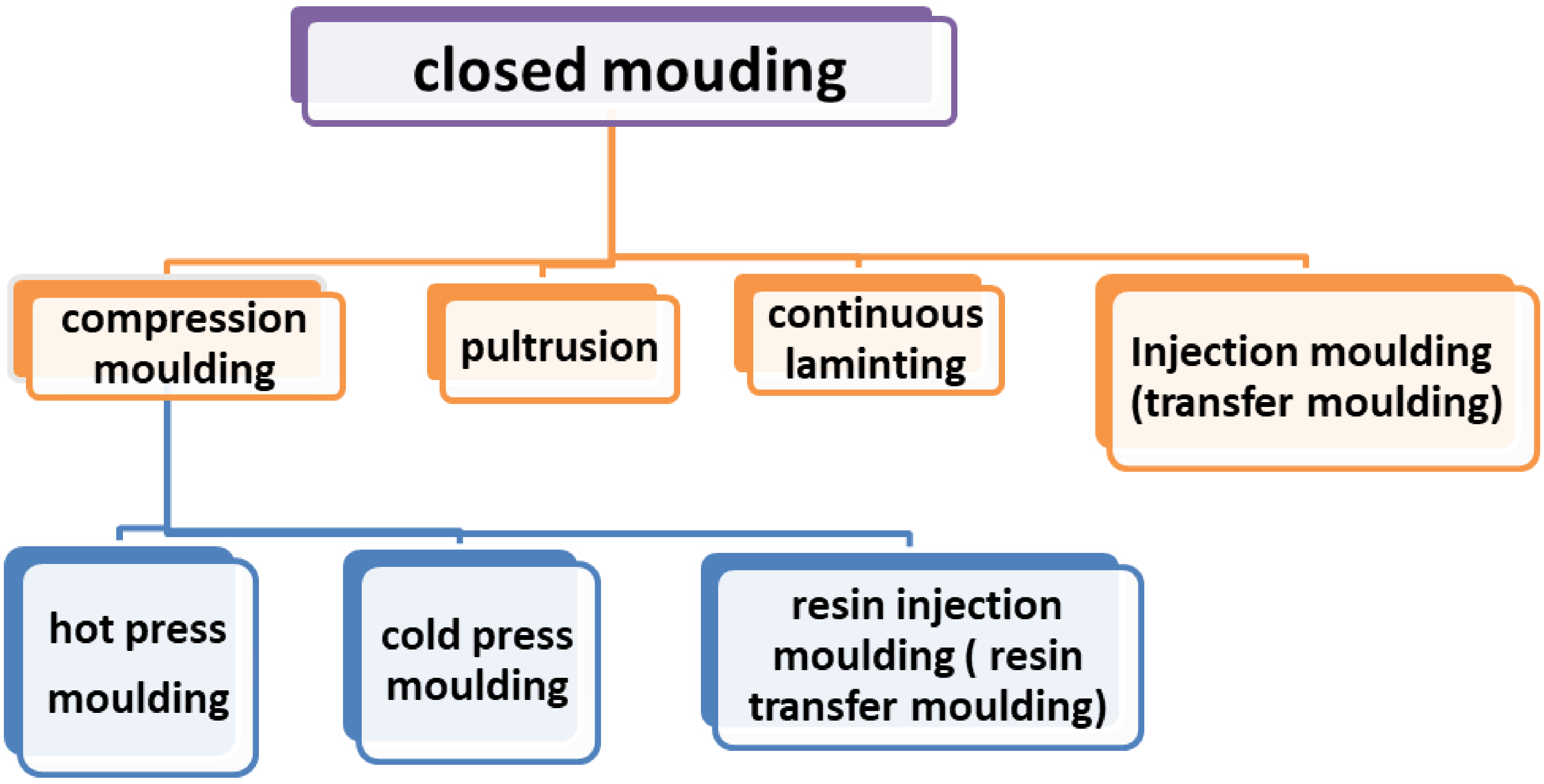
2) Closed mould process.

Open mould processes:- these processes use only one mould .

Heat, where required to cure the resin system can be effected by loading the assembly in to an oven.

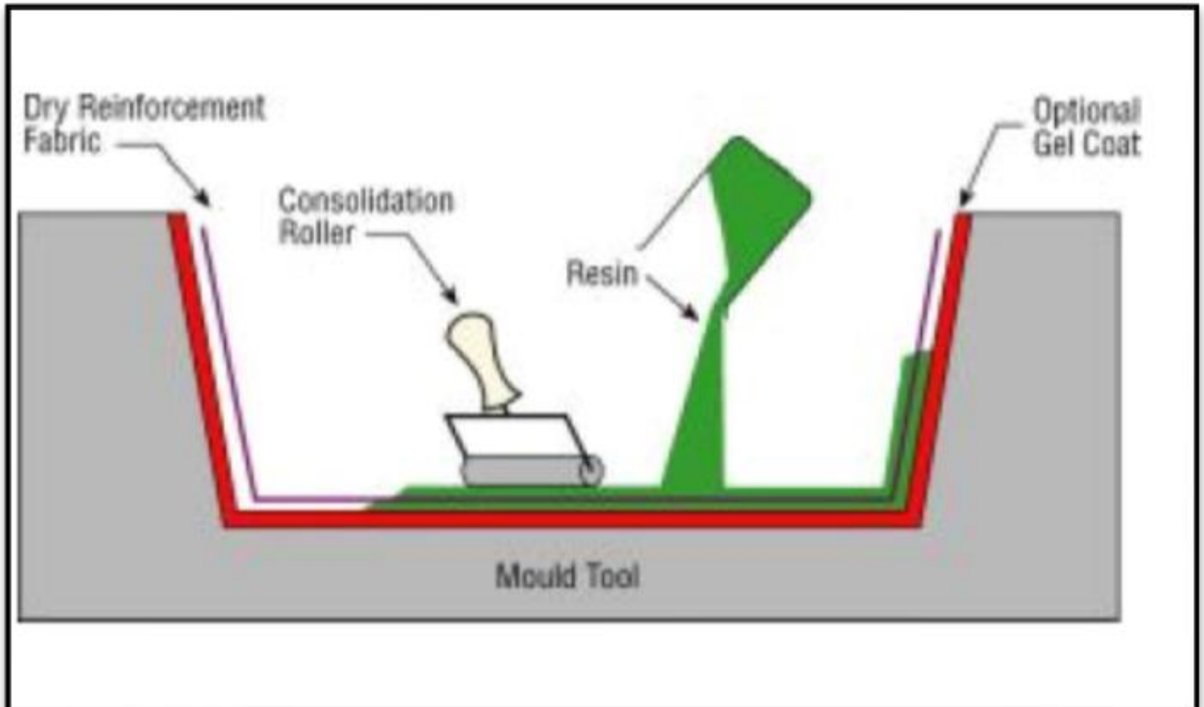


Closed mould processes :- In closed mould methods the product is formed with in a closed space by two mould or between mould and flexible membrane.



Contact moulding:-

Hand Lay- up Method :- It is the simplest , oldest and most common method



- The mold is firstly treated with a release agent, to ensure the final product can be easily removed.
- An even layer of resin, up to (0.5 mm) thickness is applied to the mould surface. This resin layer, known as the " gel coat " contains additives to give colour to the surface.

<u>The functions of the gel coat is to :-</u>

(i) Protect the fibers from external effects, mainly moisture penetration.

(ii) Provide a smooth finish surface.

- when the gel coat is sufficiently cured , the first layer of fibers is placed on resin and used brush and roller to ensure the impregnation between the fibers and the matrix .

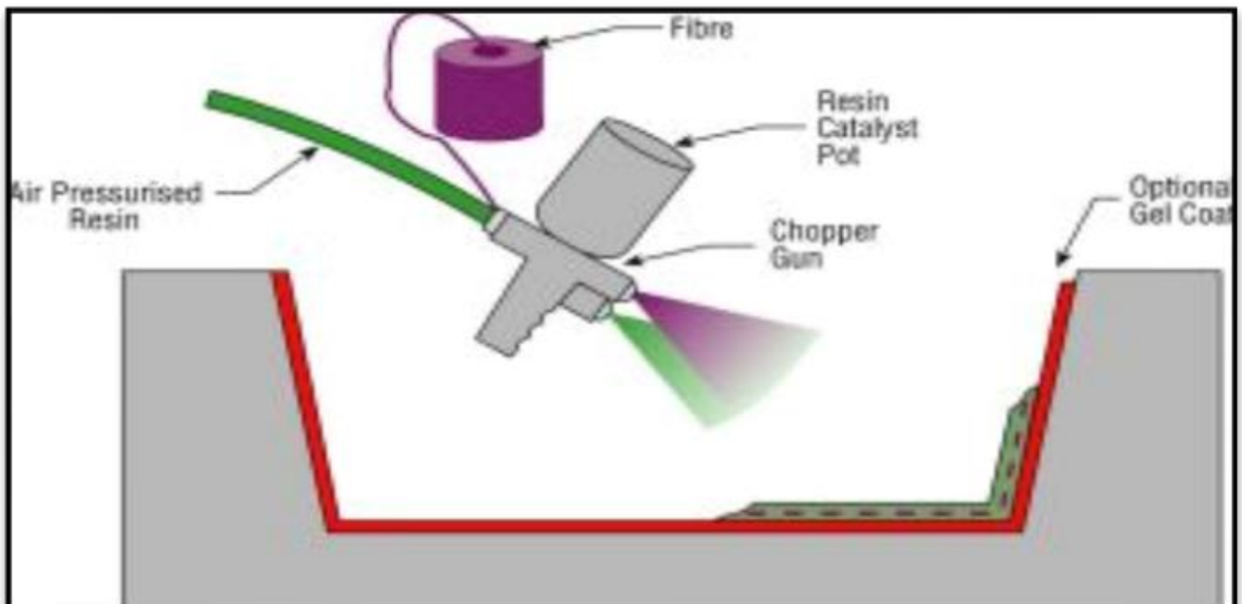
It is used for boats and medium to large building

2) **<u>spray -up Method :-</u>**

This method is essentially similar to the hand lay-up method, but the reinforcement is usually chopped strands.

- Fiber roving is fed continuously through a chopping unit. At the same time with resin by means of a spray gun.

The mixture is then rolled to consolidate and remove any air that may be present in the composite



It is used for:-

1. boat hulls
2. containers
3. automobile body parts
4. furniture
5. large structure panels

Advantages of the contact moulding:-

6. Large and complex items can be produce.
7. Production rate requirements are low.
8. Low cost equipment’s.

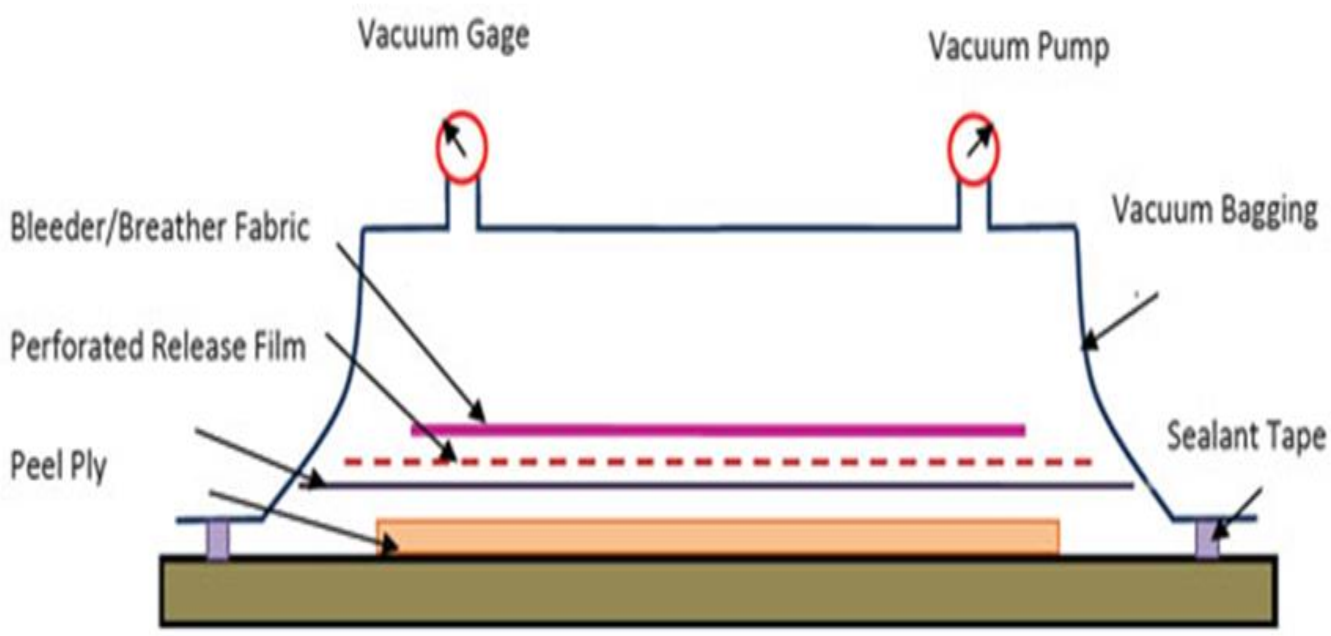
Disadvantages of the contacact moulding:-

9. Longer cure times required.
10. Considerable operator skill required.

Gives one smooth finish surface.

Pressure bag Mouldings:-

1- **Vacuum bagging moulding :-** Vacuum bagging is a partially closed moulding technology .After resin has been applied a flexible membrane (plastic sheet) is placed over the wet laminate and sealed along the edge of the mould to form a "bag" and vacuum is created



Advantages:

1. Lower void contents are achieved than with wet lay-up.
2. Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

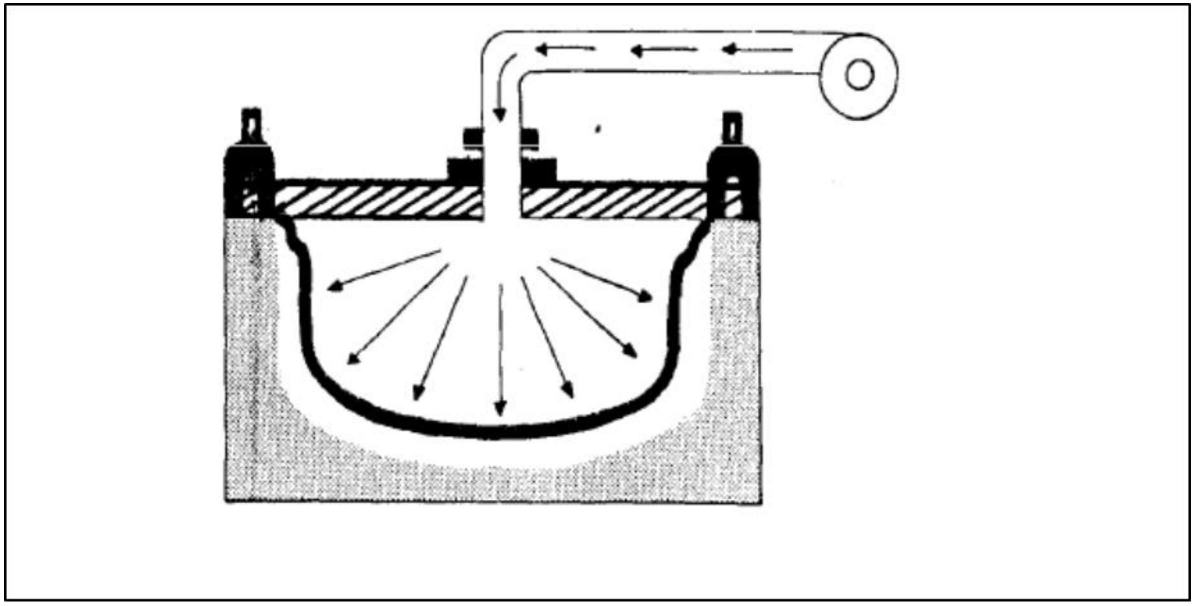
Disadvantages:

1. A higher level of skill is required by the operators.

Applications:

Large one-off cruising boats, race car components, core-bonding in production boats.

2- **Pressure bag moulding**:- this method is similar to the vacuum bag technique, except that in this case, the pressure is applied directly to open surface.



1- **Autoclave:-** An autoclave is a further development of the pressure bag method. An autoclave consists of cylindrical vessel constructed to withstand high pressure and temperature. It is used to produce a very superior quality composite.

Advantages:

1. Large components can be fabricated.
2. Better surface finish.

Disadvantages:

1. Initial cost of tooling is high.
2. Running and maintenance cost is high.
3. Not suitable for small products.

Applications:

The process is suitable for aerospace, automobile parts like wing box, chassis, bumpers, etc.

Filament winding:-

This method consists of winding continuous fiber reinforcement, under tension over mandrel to form a hollow shape (usually cylindrical). (i.e. It is used for tubular composite parts).

Where the fibers are first fed through a resin bath and the continuously wound onto mandrel and finally the composite part is removed from the mandrel as shown in the following figure.

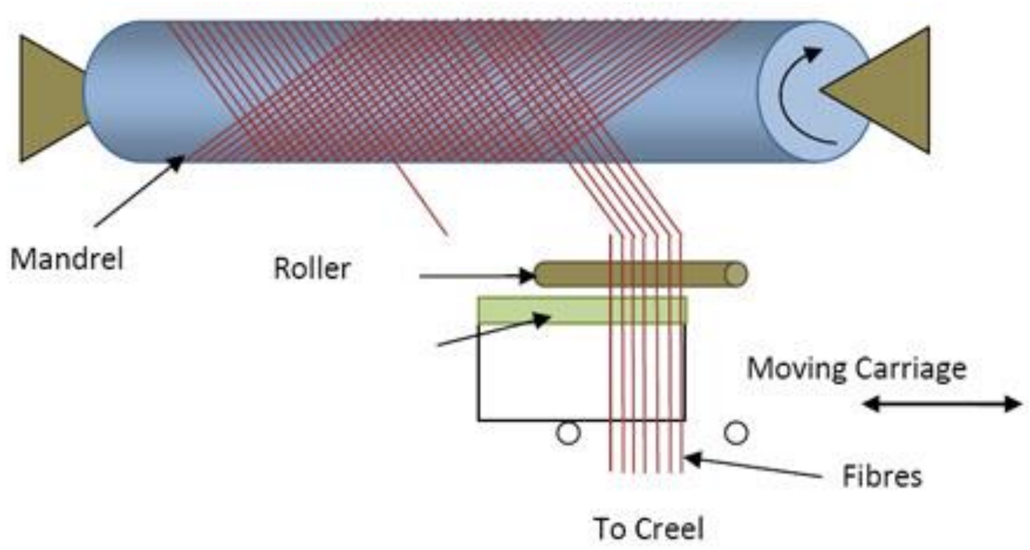
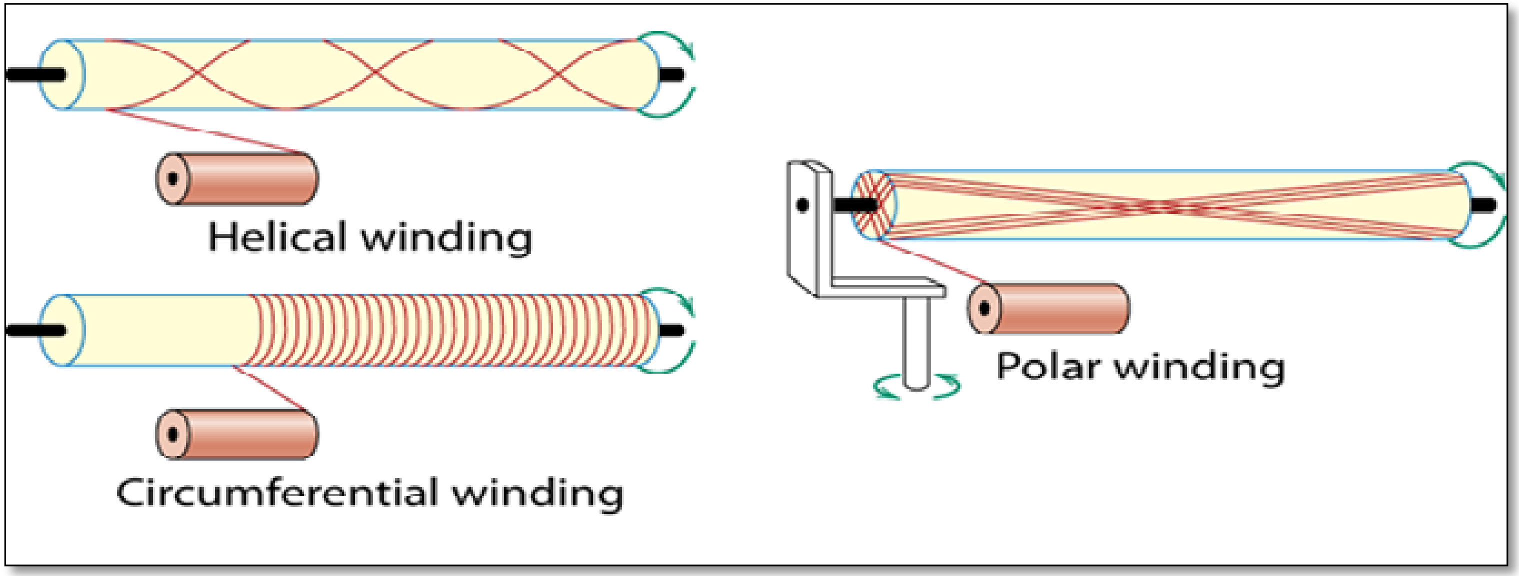


Figure: Filament winding

Various winding patterns are possible (i.e., circumferential, helical and polar) to give the design mechanical characteristics as shown.



Advantages of filament winding:-

1) It is used for large and small components, especially of hollow, cylindrical.
2) Produces a high quality composite.
3) The process can be very fast.
4) The process is economic.

Disadvantages of filament winding:-

1. Expensive method.

1. Resins with low viscosity are needed.

2. Mandrel costs for large components can be high.

3. The external surface of the component is not smoothly finished.

Applications:

Pressure bottles, rocket motor casing, chemical storage tanks, pipelines, gas cylinders, fire-fighters, breathing tanks etc

Centrifugal casting:- Mixtures of fibers and resin are introduced into a rotating mould .(casting depend on centrifugal force).

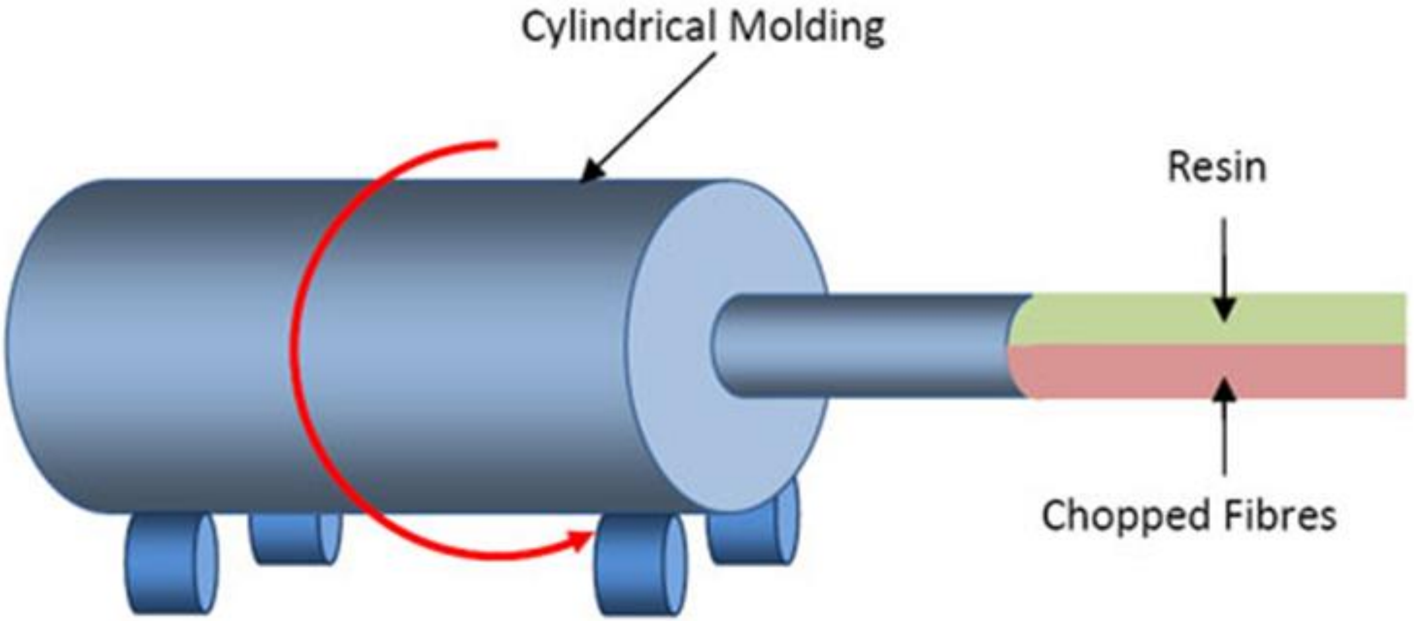
Advantages:

1. Suitable for small hollow cylindrical products.
2. Economic for small production.

Disadvantages:

1. Complex shape can not be made.
2. Resin with low viscosity is needed.
3. The finish of the inner side of the product is not good.

The structural properties may not be good as the chopped fibres are used.

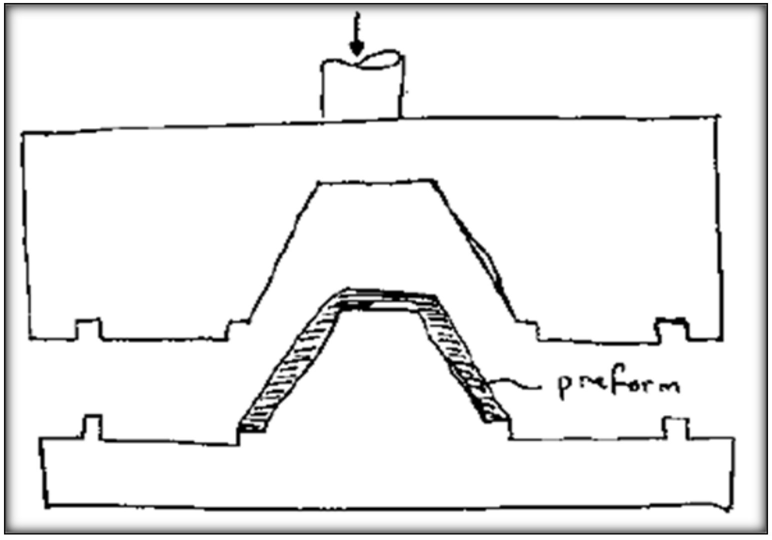


Applications:

The applications include the hollow cylindrical parts like motor casing, engine covers, etc.

Compression moulding

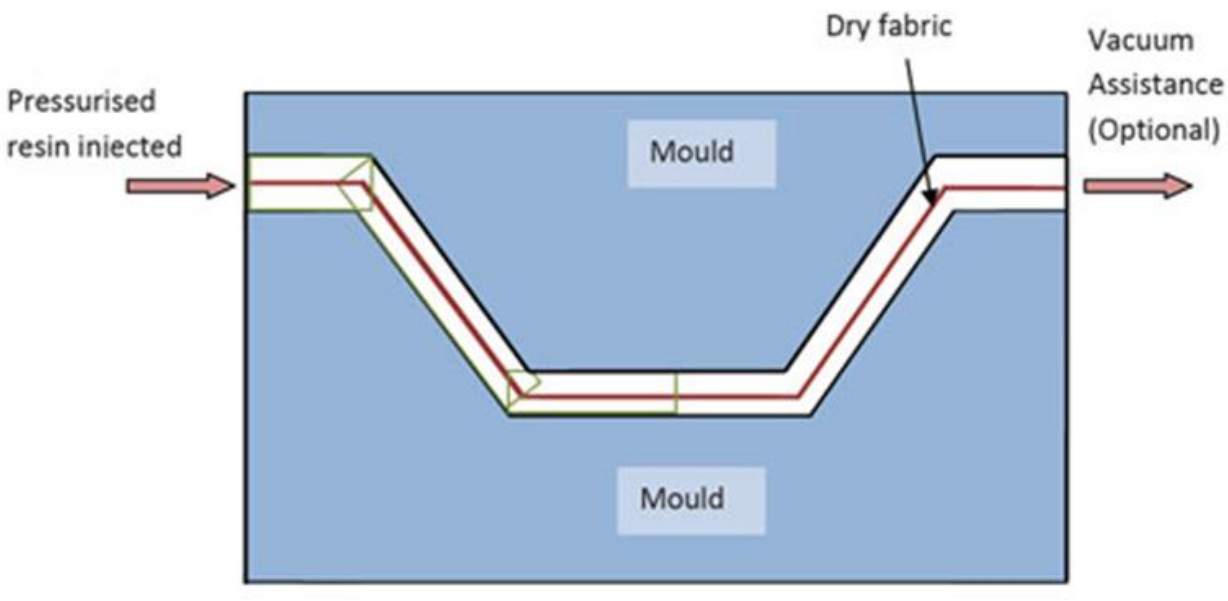
1- **Hot press moulding: -** in this method, individual plies are cut and laid on top of each other to form the perform material. And put on bottom half of the mould. The mould is closed under pressure and heat applied simultan eausly as shown in the following figure.



- **<u>cold press moulding:-</u>** This method is basically the same as the hot press moulding technique, except that no external heat is applied.

- **<u>Resin injection moulding:</u>**- In this method , the reinforcement is placed in

the bottom mould and the top mould is closed over it. Then the resin is inject in the mould . It is also known as " resin transfer molding "



Advantages of Compression moulding:-

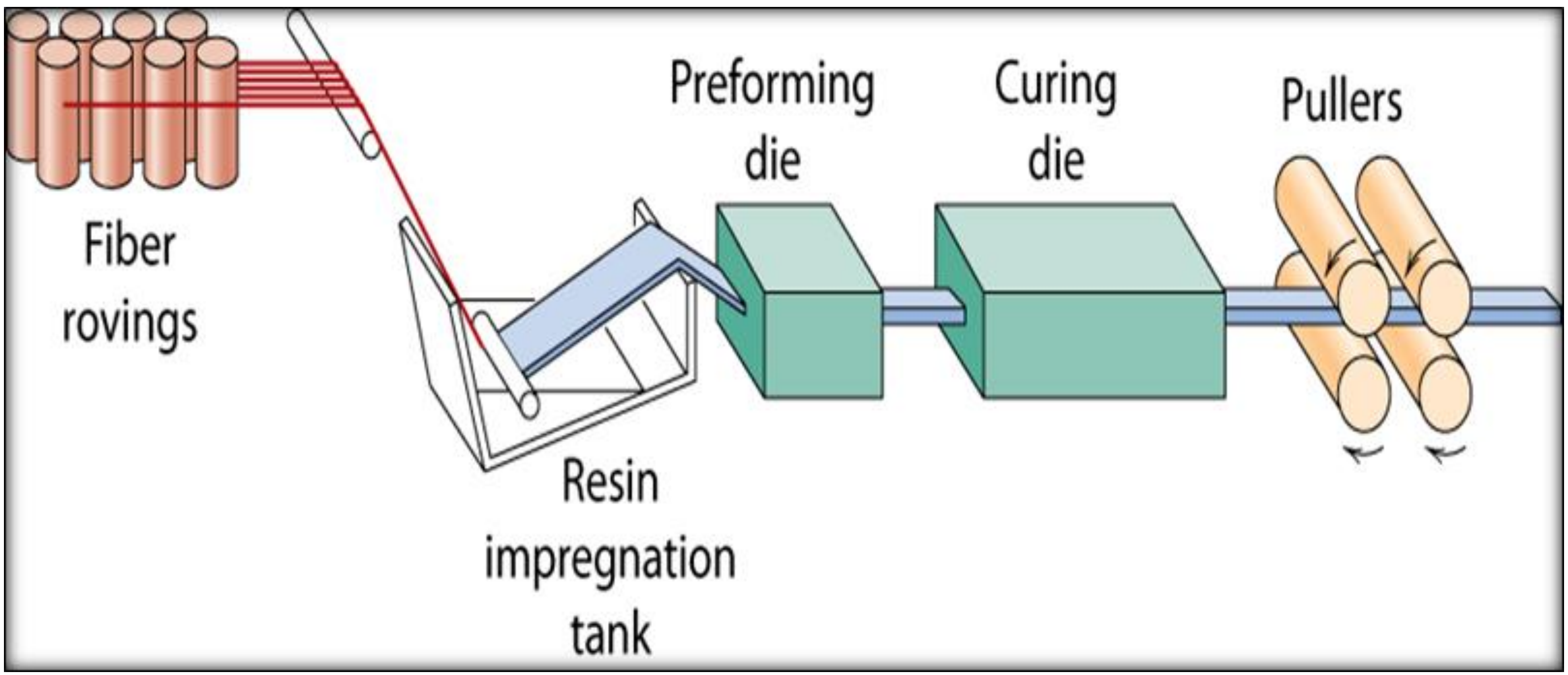
1) All surfaces have a smooth finish.
2) Application of pressure contributes to elimination of voids.
3) Heat application accelerates curing time.
4) Less labour skill required.
5) Complex shape components produced.

Disadvantages of Compression moulding:-

1) Uneconomical for production of a small quantity of components.
2) Difficult to produce large size components.

Pultrusion:-

Is used for the manufacture of components having continuous length and a constant cross-sectional shape (i.e. rods, tubes, beam , panels , I-section, etc.) As show in the following figure.



The process consists of impregnating continuous fiber roving in a resin bath and then drawing them through a die to obtain the desired shape of the section.

Advantages of pultrusion:-

1- Easily automated process.

2- High production rates.

3- High quality composite

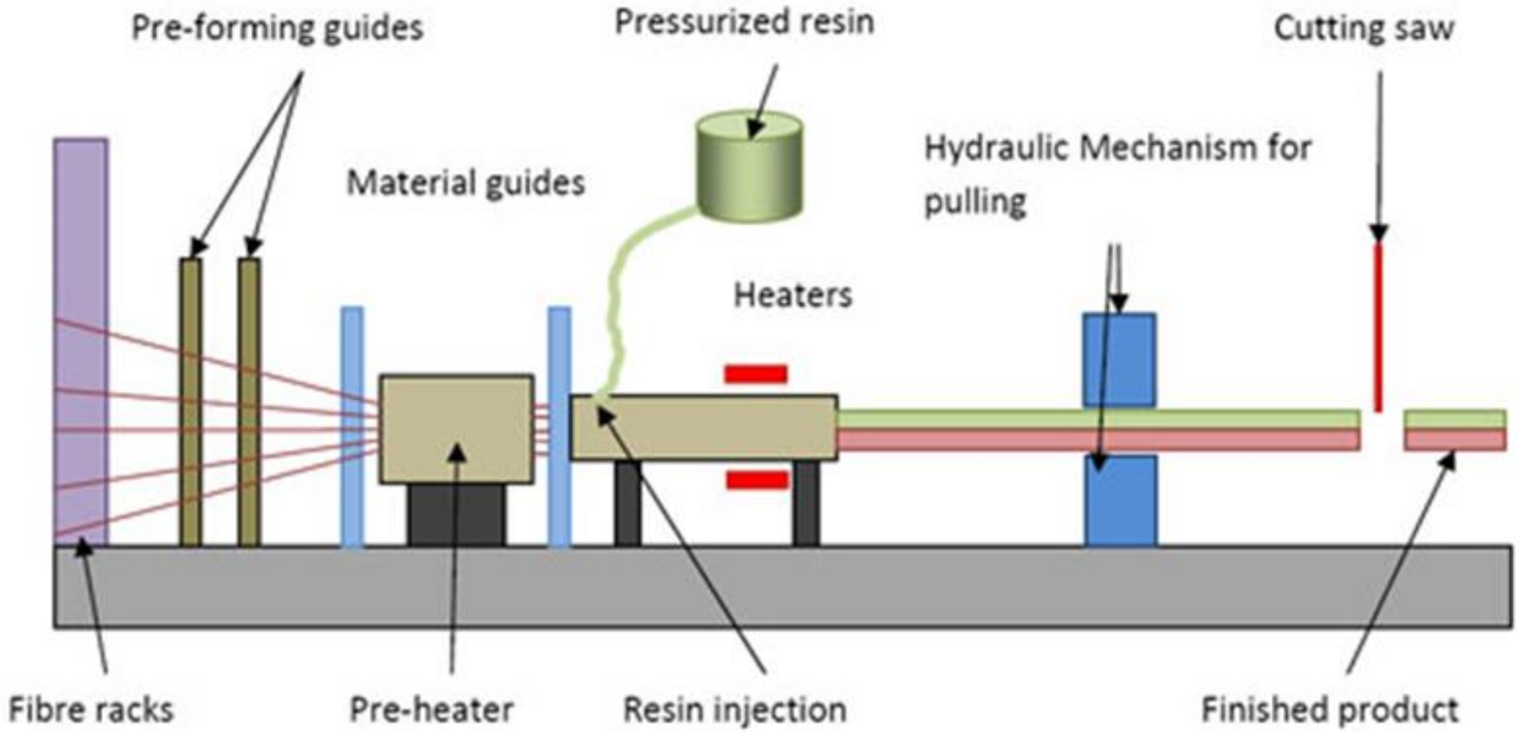
Disadvantages of pultrusion:-

1- Uneconomical for production of small quantity of components.

2- It is used for component have constant cross- sectional area.

Applications:

Beams and girders used in roof structures, bridges, ladders, frameworks


Pre-forming guides
Pressurized resin
Cutting saw
Hydraulic Mechanism for pulling
Material guides
Heaters
Fibre racks
Pre-heater
Resin injection
Finished product

Continuous laminating:- This process is similar to the pultrusion method, but the continuous lamination method is design to produce a composite in a flat or corrugated form. The reinforcement layers are impregnated in resin and sandwich between them

Injection moulding:- (transfer moulding) plastic polymer mixed with short fibers is injected, usually at high at high pressure, into the cavity of a split mould.