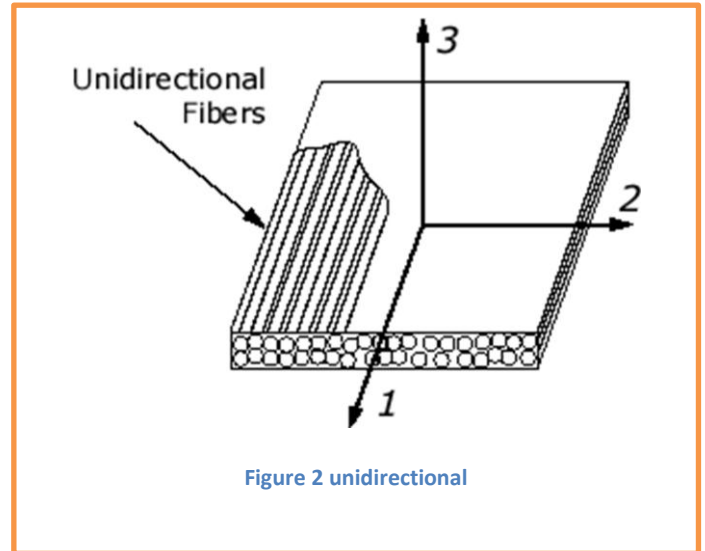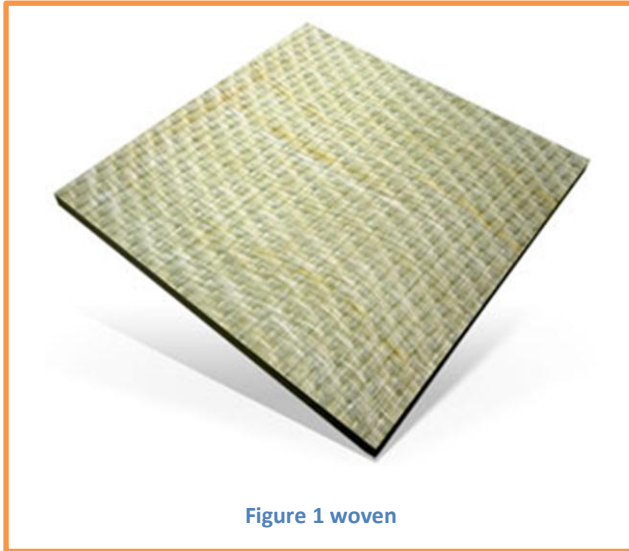## Laminate Composite Materials

   Those consist of layers (plies) of various materials

Lamina (ply): - A composite made by single layer of material. Usually a flat arrangement of unidirectional fibers or woven fibers in matrix.

Figure 1 woven

Figure 2 unidirectional

Laminate :- A material made by bonding together a series of lamiae. Plywood is an example where thin sheets of wood are bonded together to give a stronger laminated structure.

Application :-

   (i) Bimetal   e.g. simple thermostat (temperature indicator)

$\alpha_A > \alpha_B$

where α is the thermal expansion.

at $T = T_{ref.}$

at $T > T_{ref.}$
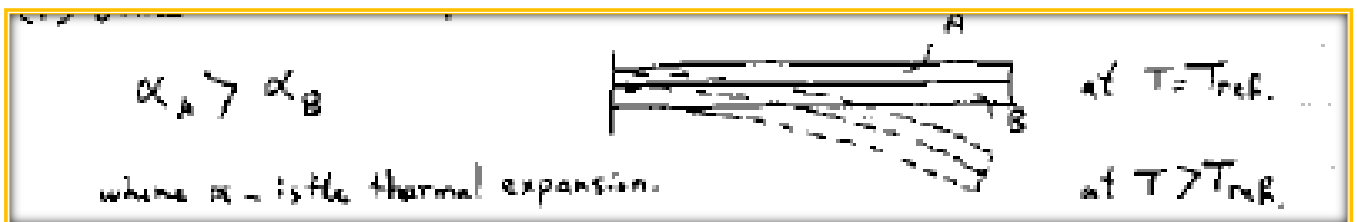
For single homogenous strip , if T ⬆ ⟹ extension only

- for bimetals if T ⬆ ⟹ coupling behavior bending and extension .

   By measuring the curvature or deflection the strip can turn on or turn off a furnace or air conditioner.

Bimetallic :- A laminate composite material produced by joining two strips of metal with different thermal expansion coefficient .

(ii) Clad Metals

Clad materials are:-

Metal- metal composites clad materials.

Provide combination of good corrosion

 resistance with high strength.
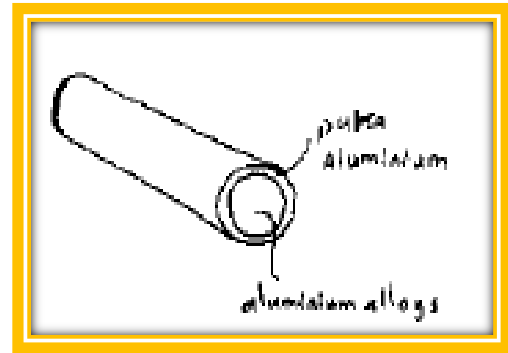
Aluminum alloy are not very corrosive resistance, where as pure aluminum is so , a cladding of pure aluminum over a high strength aluminum alloys is a composite material with better properties.

The thickness of the pure aluminum layer is about (1% to 15%) of the total thickness, is used in a storage tank, aircraft construction and heat exchangers.

(iii) Laminated Glass e.g. " safely glass "

Due to plastic the deforms occurs to high strain without fracture.
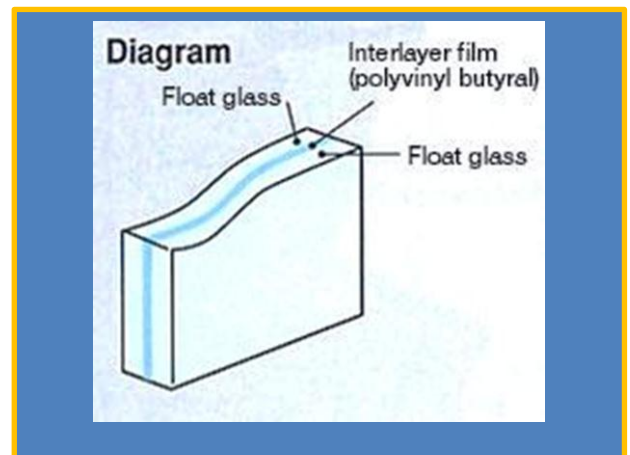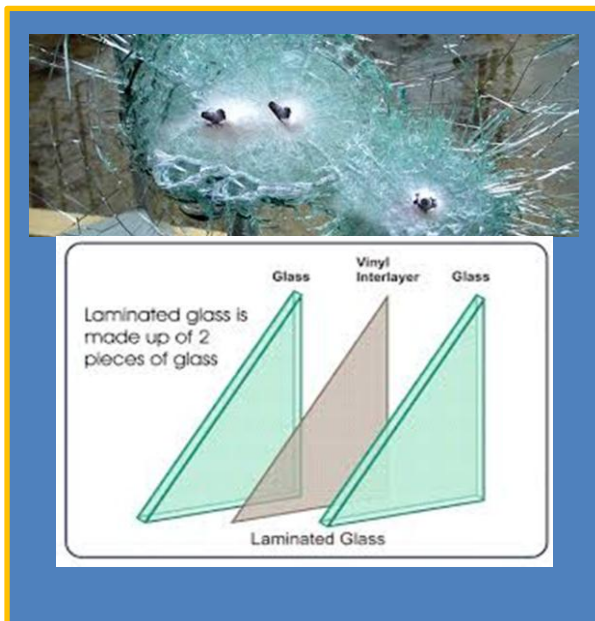
(iv) Laminated fibrous composite

These involve fibrous composites and lamination techniques.

They are commonly termed laminated fiber reinforced composites. e.g;

-   Fiber glass boat hulls.
-   Aircraft wing panels and body section…….. etc.

<u>Rule of mixtures</u>:- some properties of the laminar composite materials in the longitudinal direction are estimated from the rule of mixtures . The density, electrical and thermal conductivity, and modulus of elasticity **<u>parallel to the laminae</u>**.

Density $= \rho_{c,II} = \sum \rho_i * V_i$

Electrical conductivity $= \sigma_{c,II} = \sum \sigma_i * V_i$

Thermal conductivity $= K_{C,II} = \sum K_i * V_i$

Modulus of elasticity $= E_{C,II} = \sum E_i * V_i$

While the **<u>properties perpendicular to the laminae</u>**

Electrical conductivity $= \dfrac{1}{\sigma_{c,\perp}} = \sum \dfrac{V_i}{\sigma_i}$

Thermal conductivity $= \dfrac{1}{K_{c,\perp}} = \sum \dfrac{V_i}{K_i}$

Modulus of elasticity $= \dfrac{1}{E_{c,\perp}} = \sum \dfrac{V_i}{E_i}$

Example:

A sheet of plywood consist of three equally thickness sheets, the left and right sheets having their fiber in the same direction and the middle sheet with its fiber at right angle . The wood has a tensile modulus for forces in the direction parallel to the fiber of (10 GPa) ,and in the transverse direction (0.4 GPa).Determine the tensile modulus of the laminate when loaded in a direction parallel to the fiber direction of the outer sheet and the tensile modulus of the laminate when loaded in a directional perpendicular to the fiber direction of the outer sheet .
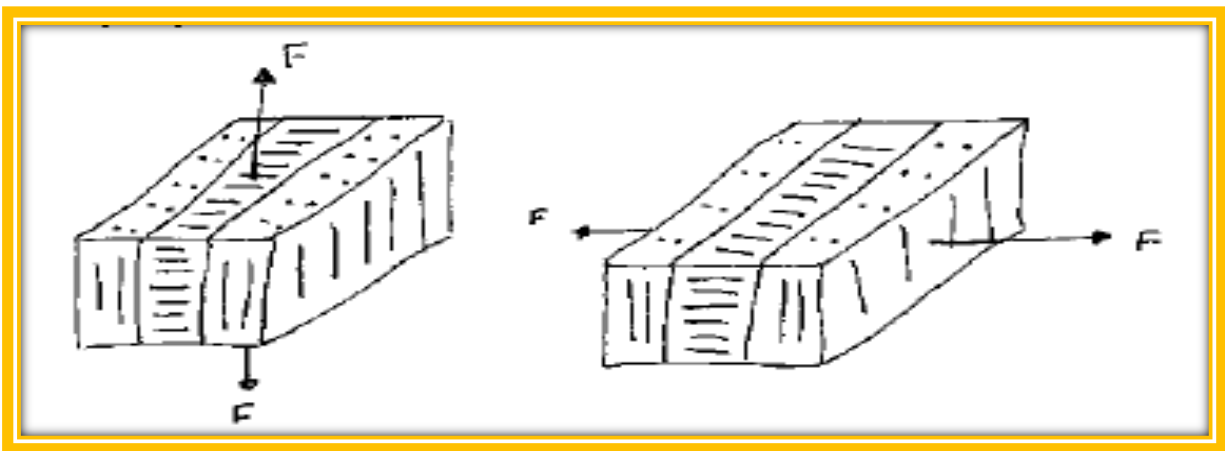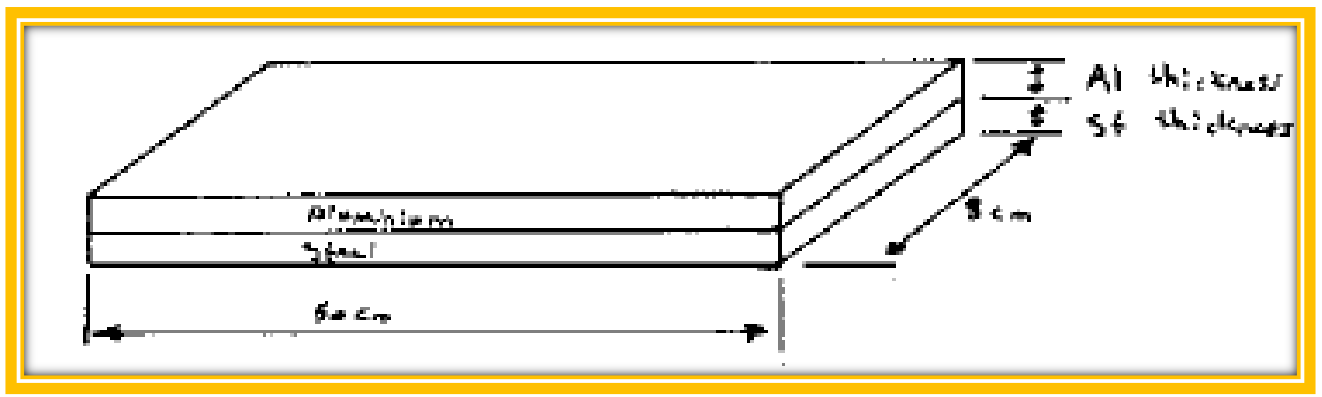

Solution:-

$$E_{c,II} = E_1 * V_1 + E_2 * V_2 + E_3 * V_3$$

$$= 10*\frac{1}{3} + 0.4 * \frac{1}{3} + 10 * \frac{1}{3} = 6.8 \ GPa$$

$$\frac{1}{E_{C,\perp}} = \frac{V_1}{E_1} + \frac{V_2}{E_2} + \frac{V_3}{E_3} = \frac{\frac{1}{3}}{10} + \frac{\frac{1}{3}}{0.4} + \frac{\frac{1}{3}}{10} = 1.11 \ GPa$$

Example: for the following composite beam (multi layer beam)

Determine the modulus of elasticity of the composite beam in both directions at the following conditions

AL thickness (cm)	St thickness (cm)
1	1
0.5	1.5
1.5	0.5

Note :-

E_{st} = 207 GPa

E_{al}= 68.6 GPa

And compare the results of the composite beam .

Solution:-

at V_{Al} = 0.5 and V_{St}= 0.5

$$E_{c,II} = E_{Al} * V_{Al} + E_{St} * V_{St} = 68.6 * 0.5 + 207 * 0.5 = 137.8 \text{ GPa}$$

$$E_{C,\perp} = \frac{68.6 * 207}{207 * 0.5 + 68.8 * 0.5} = 103.1 \ GPa$$

at V_{Al} = 0.25 and V_{St}= 0.75

$$E_{c,II} = E_{Al} * V_{Al} + E_{St} * V_{St} = 68.6 * 0.25 + 207 * 0.75 = 172.24 \text{ GPa}$$

$$E_{C,\perp} = \frac{E_{St} * E_{Al}}{E_{Al} * V_{Al} + E_{St} * V_{St}} = \frac{207 * 68.6}{207 * 0.25 + 68.8 * 0.75} = 137.57 \ GPa$$

at $V_{Al} = 0.75$ and $V_{St} = 0.25$

$$E_{c,II} = E_{Al} * V_{Al} + E_{St} * V_{St} = 68.6 * 0.75 + 207 * 0.25 = 103.2 \text{ GPa}$$

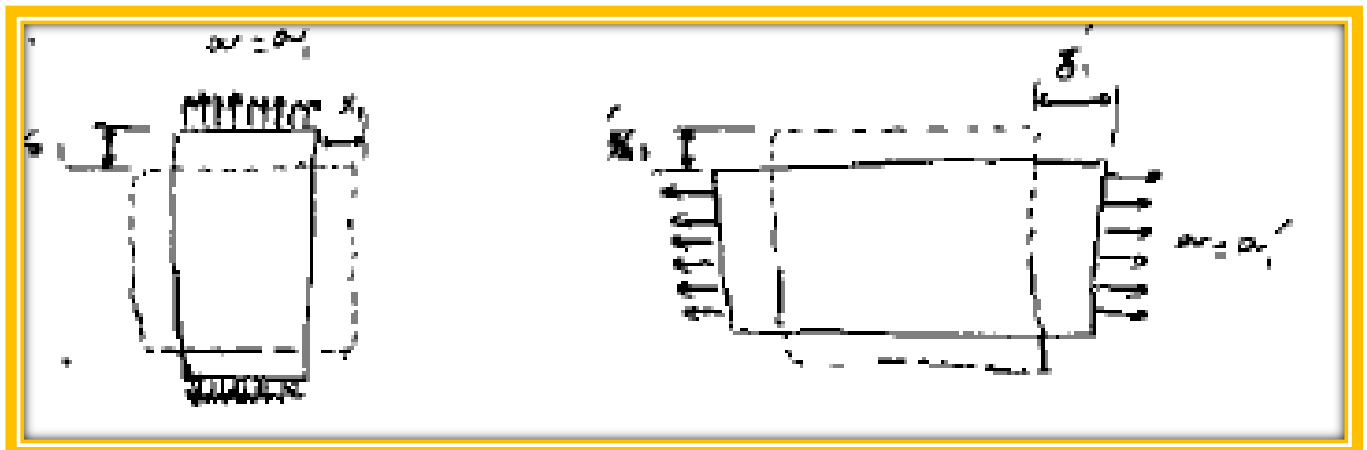$$E_{C,\perp} = \frac{E_{St} * E_{Al}}{E_{Al} * V_{Al} + E_{St} * V_{St}} = \frac{207 * 68.6}{207 * 0.75 + 68.8 * 0.25} = 82.37 \, GPa$$

Steel thickness (cm)	Aluminum thickness (cm)	$E_{c,II}$ (GPa)	$E_{C,\perp}$ (GPa)
2	0	207	207
1.5	0.5	172.24	137.57
1	1	137.8	103.1
0.5	1.5	103.2	82.37
0	2	68.6	68.6

Composite materials are different form engineering material most common engineering materials are homogeneous and isotropic.

A Homogeneous body:- material properties (stiffness, strength ,…….etc.) remain constant form point to point in a direction in the body, i.e.(The properties are not a function at a point in the body).

An Isotropic Material :- has material properties that are the same in every direction at a point in the body .
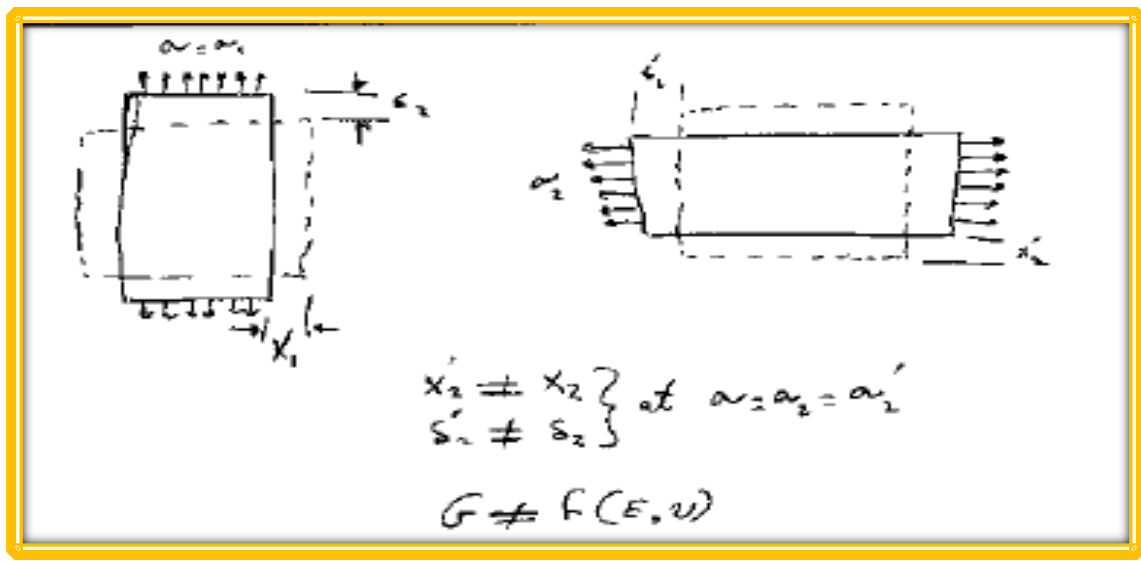
$$\begin{rcases} \acute{x_1} = x_1 \\ \acute{s_1} = s_1 \end{rcases} \text{ at } \alpha = \alpha_1 = \acute{\alpha_1} \qquad G = f(E,\upsilon) = \frac{E}{2(1+\upsilon)}$$
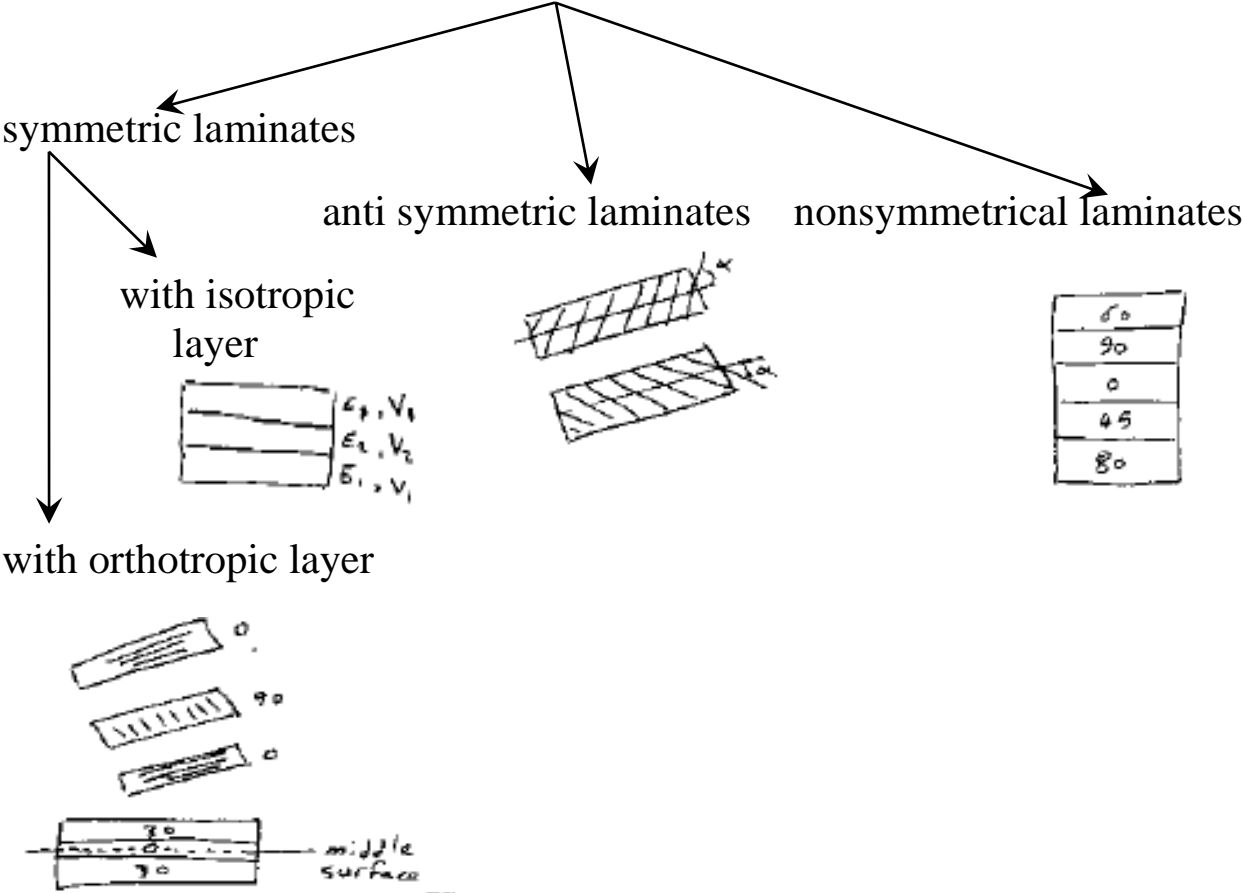
While composite materials are inhomogeneous (heterogeneous) and non isotropic (orthotropic and anisotropic).

<u>An Inhomogeneous body :-</u> has non uniform properties over the body . i.e. the properties are a function of position in the body.

<u>An Orthotropic Material :-</u> has material properties that are different in three mutually perpendicular directions at a point of the body .

$$\begin{rcases} \acute{x_2} \neq x_2 \\ \acute{s_2} \neq s_2 \end{rcases} \text{ at } \alpha = \alpha_2 = \acute{\alpha_2}$$

$$G \neq f(E,\upsilon)$$

Generally laminate layers are bonded by the same matrix used in the plies

symmetric laminates

anti symmetric laminates   nonsymmetrical laminates

with isotropic
layer

with orthotropic layer

Also the properties of a unidirectional lamina are found by using the following equations:-

$$E_1 = E_f * V_f + E_m * V_m$$

$$E_2 = \frac{E_f * E_m}{E_f * V_m + E_m * V_f}$$

$$G_{12} = \frac{G_f * G_m}{G_f * V_m + G_m * V_f} \qquad\qquad G_f = \frac{E_f}{2(1+v_f)}$$

$$G_m = \frac{E_m}{2(1+v_m)}$$

$$v_{12} = v_f * V_f + v_m * V_m$$

$$\frac{E_1}{v_{12}} = \frac{E_2}{v_{21}} \quad (\text{law of Maxwell's theorem})$$

Axes:-

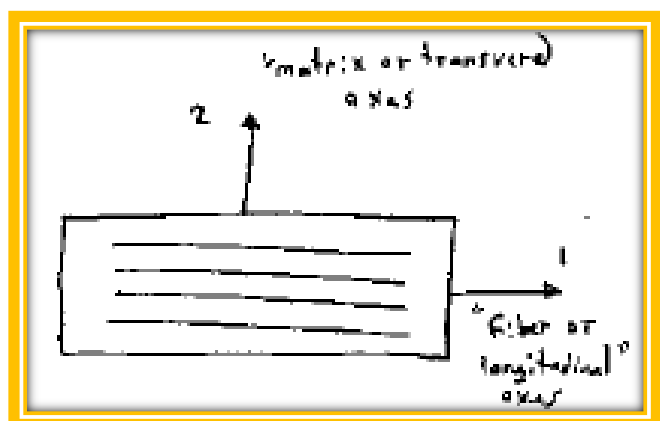Materials axes

Principal axes

Symmetry axes

A set of mutually perpendicular directions parallel and perpendicular to the fiber direction

$$E_x = E_1 = E_m * V_m + E_f * V_f$$

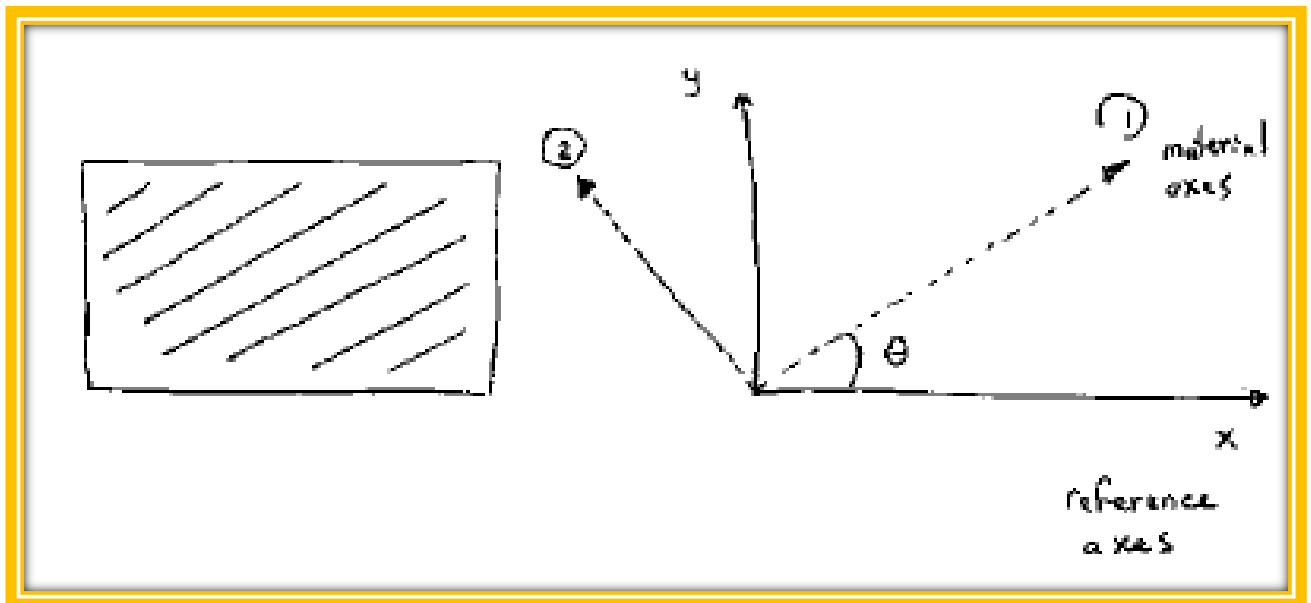$$\frac{1}{E_y} = \frac{1}{E_2} = \frac{V_m}{E_m} + \frac{V_f}{E_f}$$

Reference axes ⎤

Structure axes   ⎬   A set of mutually perpendicular directions parallel and perpendicular to the reference direction generally coincident with the external loading system axes

Loading axes ⎦

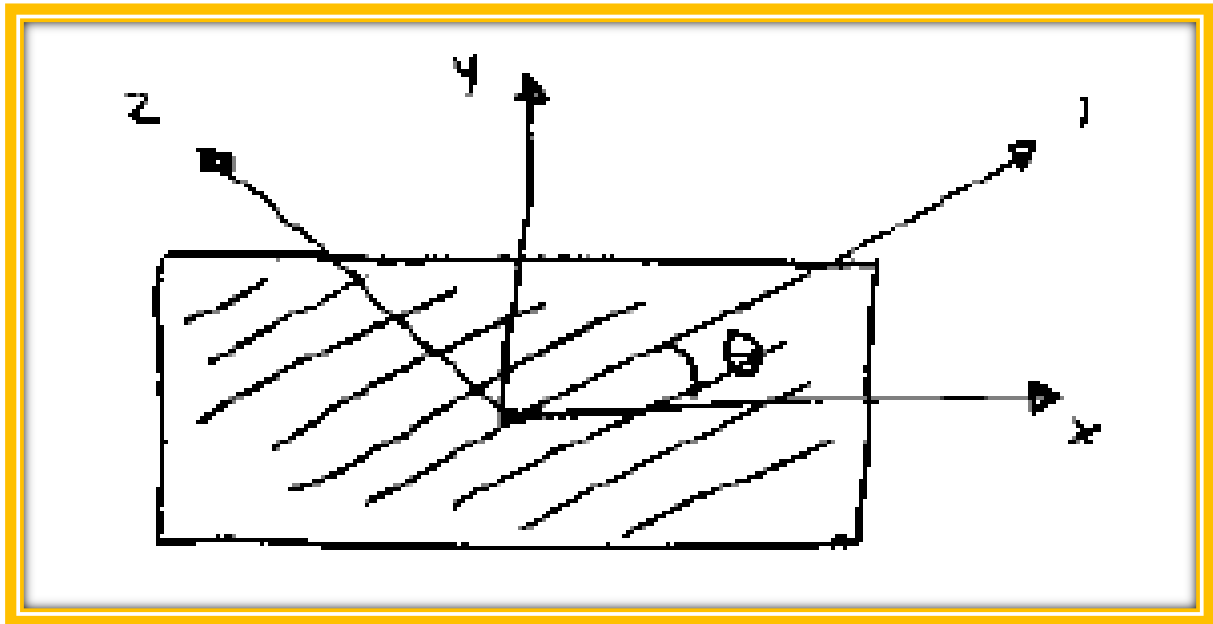$$E_x = f(E_1, E_2, G_{12}, \nu_{12}, \theta)$$

$$E_y = f(E_1, E_2, G_{12}, \nu_{12}, \theta)$$

Transformation of Engineering Elastic Constants :-

From the definition of an orthotropic material, the composite ply will have different properties in different directions at a point .

Now need to know how $(E_1, E_2, G_{12}, \nu_{12}, \theta)$ change with the axes directions .

The elastic moduli for an angle lamina are given as:-

$$\frac{1}{E_x} = \frac{\cos^4\theta}{E_1} + \frac{\sin^4\theta}{E_2} + \left(\frac{1}{G_{12}} - \frac{2v_{12}}{E_1}\right) * \sin^2\theta * \cos^2\theta$$

And

$$v_{xy} = E_x\left[\frac{v_{12}}{E_1}(\sin^4\theta + \cos^4\theta) - \left(\frac{1}{E_1} + \frac{1}{E_2} - \frac{1}{G_{12}}\right)\sin^2\theta * \cos^2\theta\right]$$

$$\frac{1}{E_y} = \frac{\sin^4\theta}{E_1} + \frac{\cos^4\theta}{E_2} + \left(\frac{1}{G_{12}} - \frac{2v_{12}}{E_1}\right) * \sin^2\theta * \cos^2\theta$$

$$v_{yx} = E_y\left[\frac{v_{12}}{E_1}(\sin^4\theta + \cos^4\theta) - \left(\frac{1}{E_1} + \frac{1}{E_2} - \frac{1}{G_{12}}\right)\sin^2\theta * \cos^2\theta\right]$$

$$\frac{1}{G_{xy}} = \left(\frac{4}{E_1} + \frac{4}{E_2} + \frac{8v_{12}}{E_1}\right) * \cos^2\theta * \sin^2\theta + \frac{(\cos^2\theta - \sin^2\theta)^2}{G_{12}}$$

Example :- for the data given

E_1=200MPa E_2=10MPa G_{12}=5MPa v_{12}=0.3

Calculate and draw the variation of equivalent elastic properties with the angle of fiber i.e. $(E_x, E_y, G_{xy}, v_{xy}, v_{yx})$

θ^0	E_x	E_y	G_{xy}	v_{xy}	v_{yx}
0	200	10	5	0.3	0.02
10	95	10	5.3	0.4	0.04
20	39	10	6.2	0.43	0.11
30	22	11	7.7	0.41	0.21
40	15	12	9.1	0.36	0.29
45	13	13	9.3	0.32	0.32
50	12	15	9.1	0.29	0.36
60	11	22	7.7	0.21	0.41
70	10	39	6.2	0.11	0.43
80	10	95	5.3	0.04	0.4
90	10	200	5	0.02	0.3
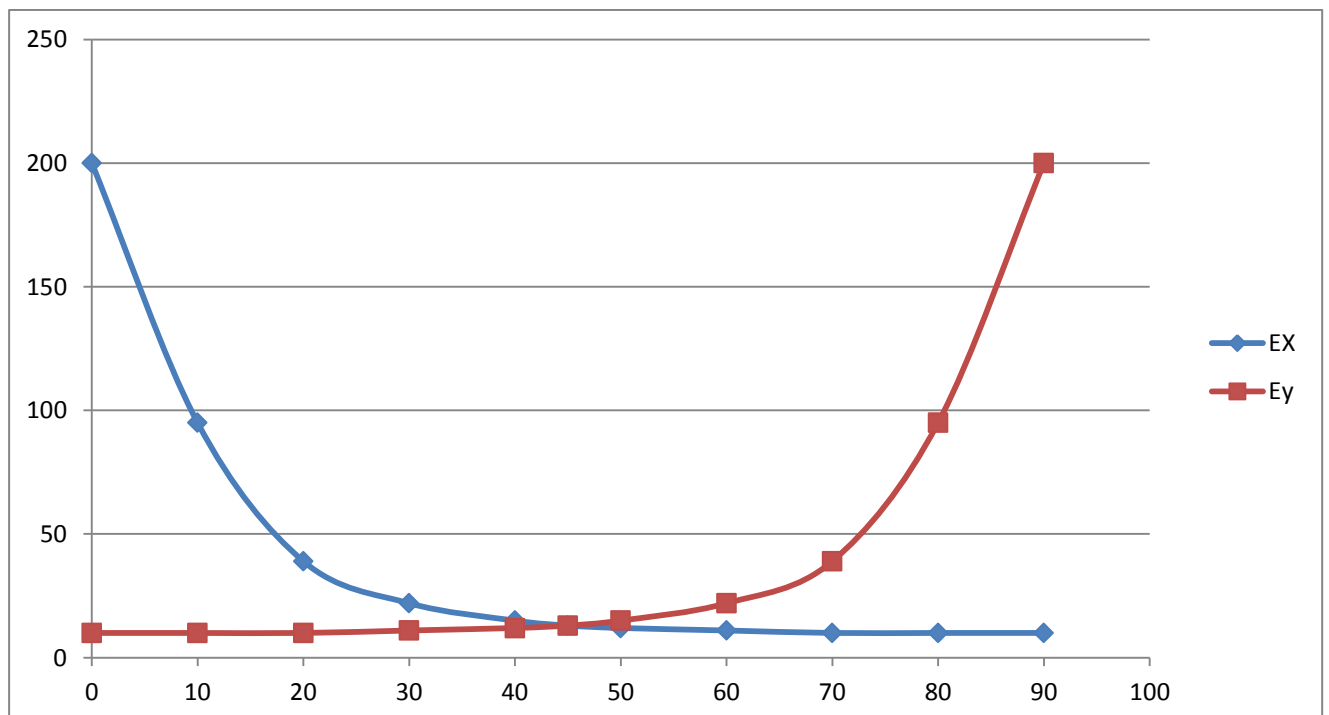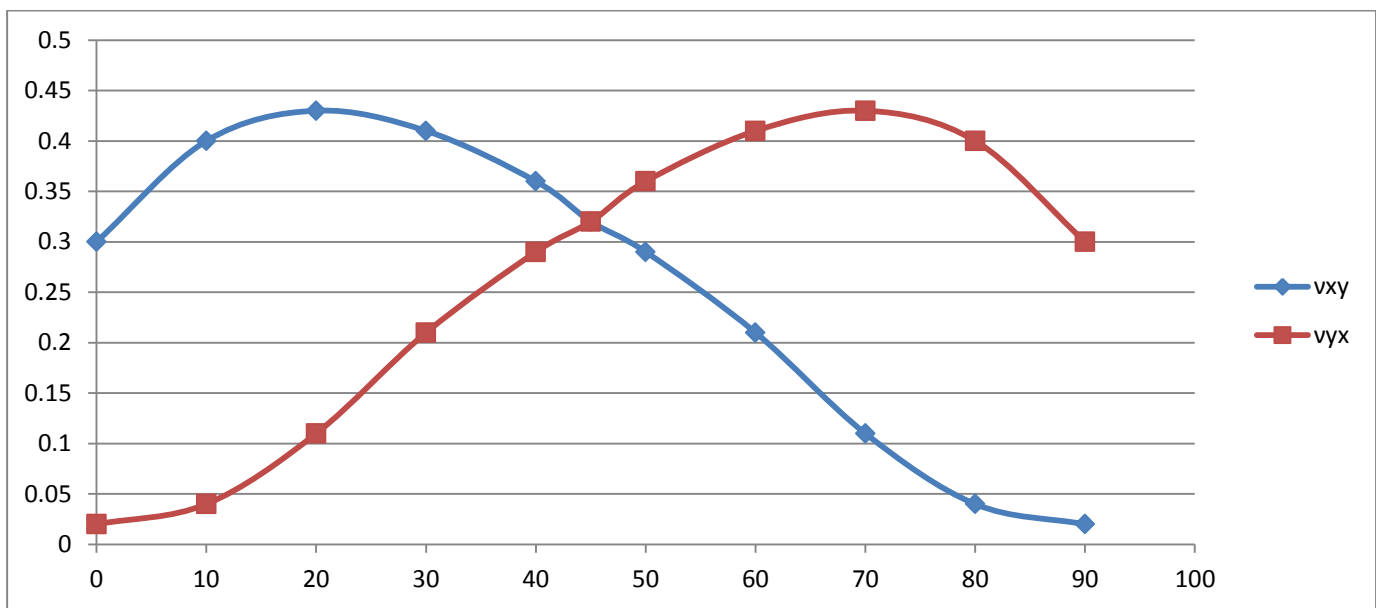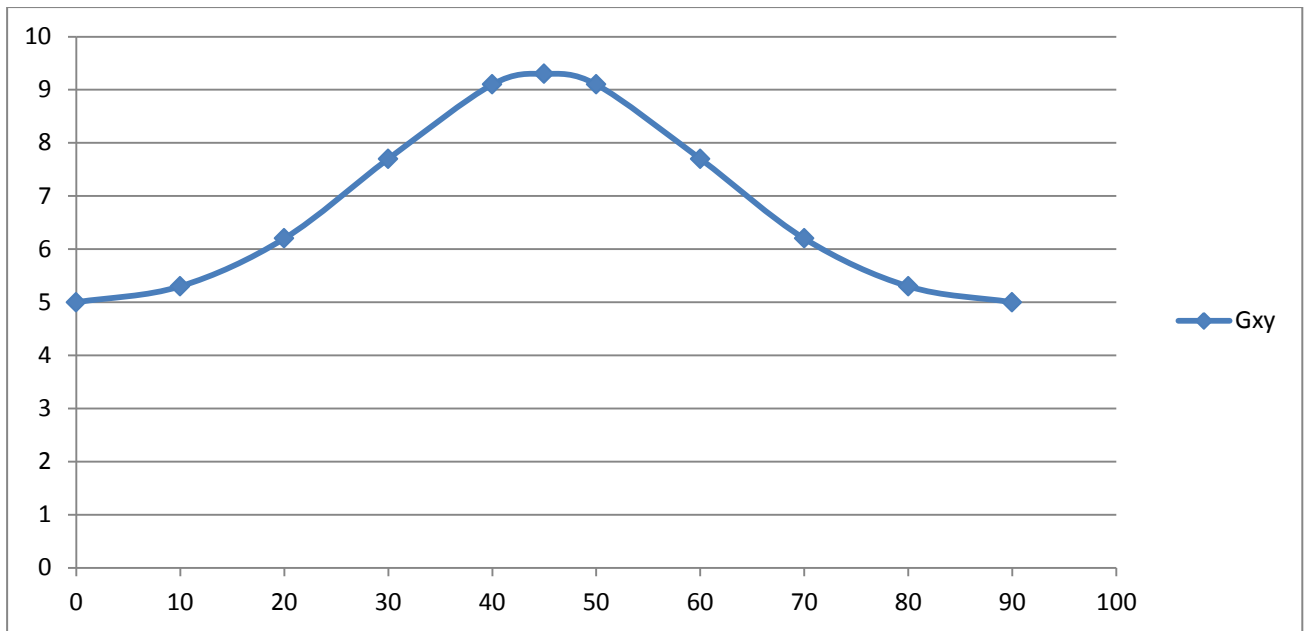
The general observation:-

1- When $\theta = 0^0$, i.e. specially orthotropic ply

$$E_x = E_1 \qquad\qquad E_y = E_2$$

$$\nu_{xy} = \nu_{12} \qquad\qquad \nu_{yx} = \nu_{21} \qquad\qquad G_{xy} = G_{12}$$

2- When $\theta = 90^0$, i.e. specially orthotropic ply

$$E_x = E_2 \qquad\qquad E_y = E_1$$

$$\nu_{xy} = \nu_{21} \qquad\qquad \nu_{yx} = \nu_{12}$$

3- When $\theta = 45^0$

G_{xy} is largest

$$E_x = E_y$$

$$\nu_{xy} = \nu_{yx}$$
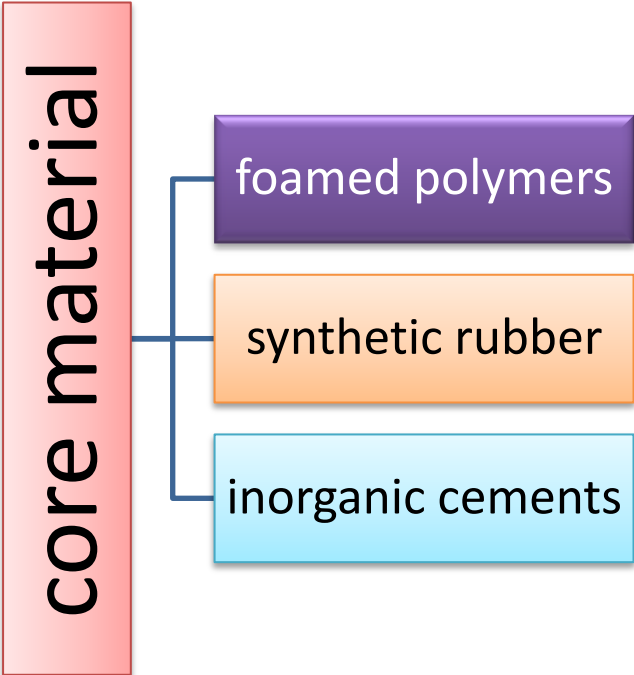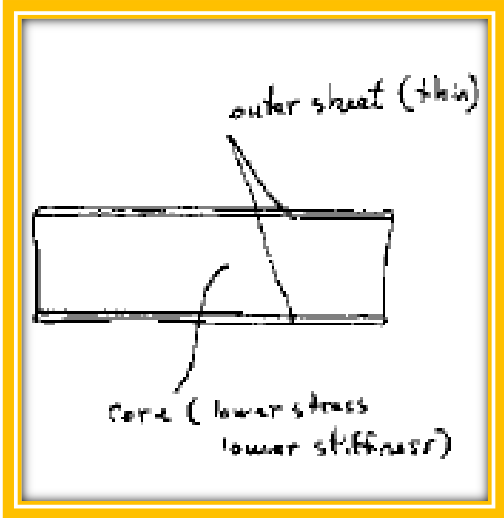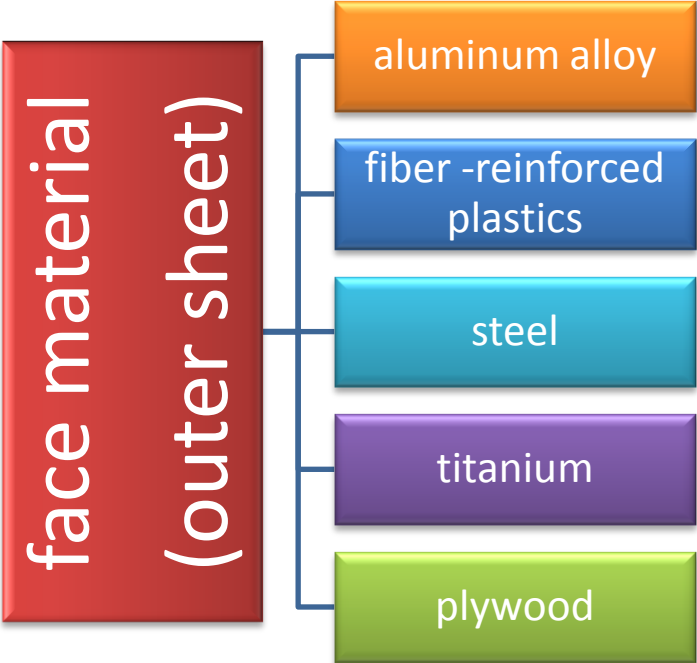
Example :- for the following data

E_1= 100GPa E_2=10GPa G_{12}= 5GPa

$\nu_{12} = 0.29$ *and* $\theta = 45^0$

Calculate the equivalent elastic constants $(E_x, \nu_{xy}, E_y, \nu_{yx}, G_{xy})$

Sandwich:- a composite material construct of a light weight, low density material called (core) surrounded by solid layers. The sandwich combines overall light weight with excellent stiffness.

face material (outer sheet)
- aluminum alloy
- fiber -reinforced plastics
- steel
- titanium
- plywood

outer sheet (thin)

core (lower stress lower stiffness)

core material
- foamed polymers
- synthetic rubber
- inorganic cements

Function of core:-

1- Separates the faces
2- Resists deformations perpendicular to the face plane .
3- It provides a certain degree of shear rigidity.

Another popular core consists of a " honey combs" – thin sheet that have been formed from interlocking hexagonal cell
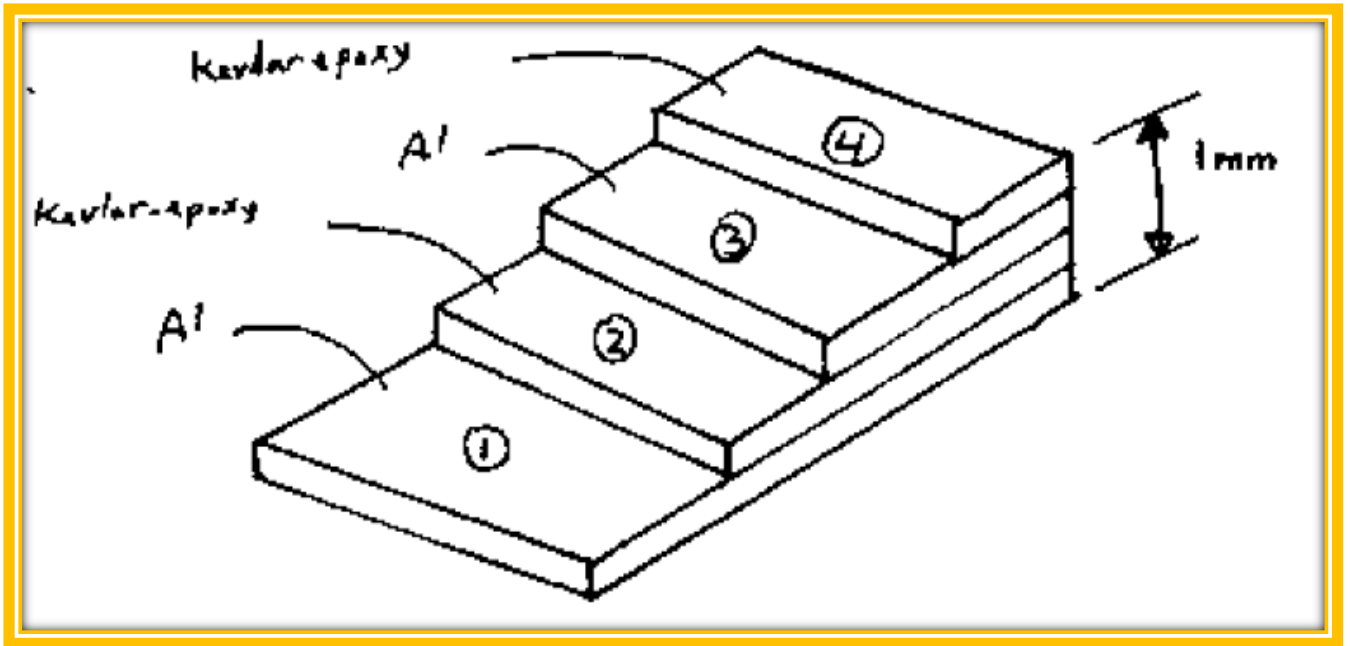

Where sandwich materials, including honey combs , with solid facing .
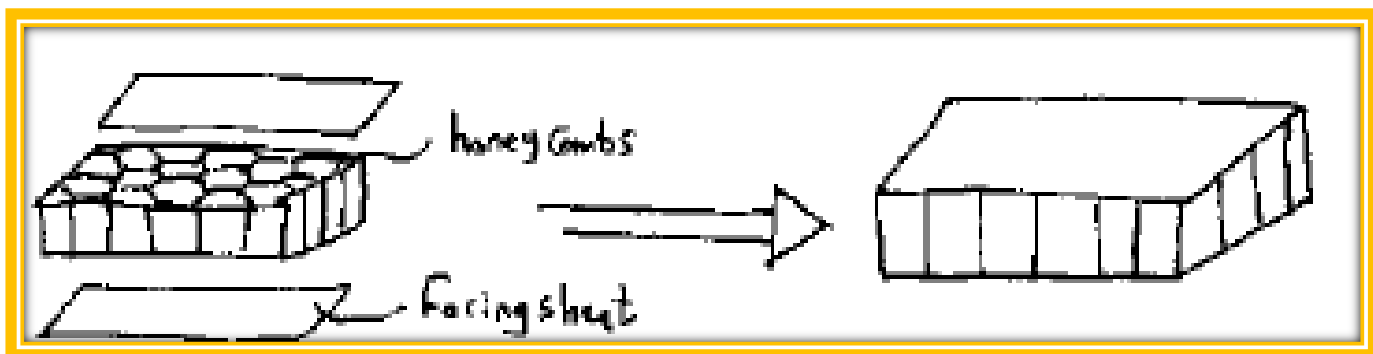
It is benefit for structure of small weight and large bending stiffness.

Sandwich panels are found in a wide varity of application they include roofs, floors and walls of building and in aircraft for wings.

While for multi- layer composite the thickness may be equal or not equal.

Like for aircraft applications

Determination of neutral axis , equivalent stiffness and stresses of multi-layer composite:-

General Information :-

The simple beam theory for isotropic beam that :-

$$\frac{\sigma}{Y} = \frac{M}{I} = \frac{E}{R}$$

And $S = MR = EI$ "equivalent stiffness"

$$I = \frac{bh^3}{12} = \text{moment of inertia}$$
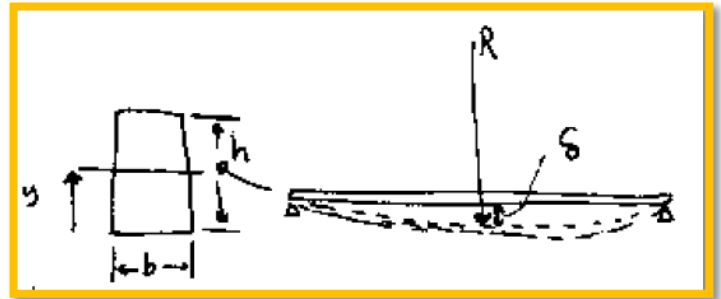
R- radius of curvature

E-modulus of elasticity   M-bending moment

Y- position of neutral axes σ-stress at outer surfaces (bottom and top)

A beam of layers (n) of each modulus of elasticity E_i (i = 1, 2……..,n) , And

b- is the width of the beam

R- is the radius of curvature

σ_i- stress in each layer

Therefore the position of neutral axes can be derived from the equilibrium equation:

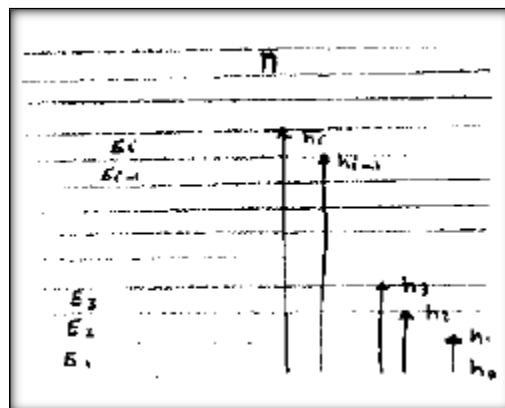$$\int_{h_0}^{h_1} \sigma_1 * b * dy + \int_{h_1}^{h_2} \sigma_2 * b * dy + \cdots\cdots\cdots + \int_{h_{i-1}}^{h_i} \sigma_i * b * dy = 0$$

$$\sigma_i = E_i * \epsilon_i = E_i \frac{y - y_0}{R}$$

By derivation

$$y_0 = \frac{1}{2} * \frac{\sum_{i=1}^{n} E_i * (h_i^2 - h_{i-1}^2)}{\sum_{i=1}^{n} E_i * (h_i - h_{i-1})}$$

Also from the equilibrium equation of bending moment about the neutal axis the equivalent stiffness can be derived:

$$M = \int_{h_0}^{h_1} \sigma_1 * b * dy.y + \int_{h_1}^{h_2} \sigma_2 * b * dy.y + \cdots\cdots\cdots + \int_{h_{i-1}}^{h_i} \sigma_i * b * dy.y$$

By derivation

$$MR = \frac{b}{6} \sum_{i=1}^{n} E_i [2(h_i^3 - h_{i-1}^3) - 3y_0(h_i^2 - h_{i-1}^2)]$$

$MR = EI = S$

If the beam is cantilever beam

$$\delta = \frac{P * L^3}{3EI}$$

While if the beam is simply supported

$$\delta = \frac{P * L^3}{48EI}$$

And the stresses

$$\sigma_{max} = \frac{M * Y_{max}}{I}$$ where :-   M- bending moment

$$\sigma_{min} = \frac{M * Y_{min}}{I}$$ Y_{max}, Y_{min} − distance to neutral axes

I- Moment of inertia

Example :- Find the maximum deflection and position of neutral axis of the following sandwich beam . Also determine the maximum stresses.

b = width = 8cm

Est= 207 GPa =207*10^5 N/cm²

E_{Al}= 68.9 GPa =68.9*10^5 N/cm²

Solution

$$y_0 = \frac{1}{2} * \frac{\sum_{i=1}^{n} E_i*(h_i^2 - h_{i-1}^2)}{\sum_{i=1}^{n} E_i*(h_i - h_{i-1})} = \frac{1}{2} * \frac{\sum_{i=1}^{2} E_i*(h_i^2 - h_{i-1}^2)}{\sum_{i=1}^{2} E_i*(h_i - h_{i-1})}$$

$$y_0 = \frac{1}{2} * \frac{207(1^2 - 0^2) + 68.9(2^2 - 1^2)}{207(1-0) + 68.9(2-1)}$$
$$= 0.75\ Cm\ \ from\ the\ bottom$$

Determination of S (equivalent stiffness)

$$S= MR = \frac{b}{6}\sum_{i=1}^{2} E_i[2(h_i^3 - h_{i-1}^3) - 3y_0(h_i^2 - h_{i-1}^2)]$$

$$MR= \frac{10^5*8}{6}[207\{2(1^3 - 0^3) - 3 * 0.75(1^2 - 0^2\} + 68.9\{2(2^3 - 1^3) - 3 * 0.75(2^2 - 1^2)\}]$$

$\therefore S$ =MR=EI=597*10^5 N.cm^2

$\therefore$ max. Deflection $\delta = \dfrac{P*L^3}{3EI} = \dfrac{10^3*50^3}{3*597*10^5} = 0.698\ Cm$

M=P*l=10^3*50=50000 N.cm

$I = \dfrac{b*h^3}{12} = \dfrac{8*2^3}{12} = 5.3333\ cm^4$

$Y_{max.}$= 1.25 cm   , $Y_{min.}$= - 0.75 cm

$\sigma_{max} = \sigma_t = \dfrac{M*Y_{max}}{I} = \dfrac{50000*1.25}{5.3333} = 11718.8\ \dfrac{N}{Cm^2}$

$\sigma_{min} = \sigma_c = \dfrac{M*Y_{min}}{I} = \dfrac{50000*(-0.75)}{5.3333} = -7031.3\ \dfrac{N}{Cm^2}$
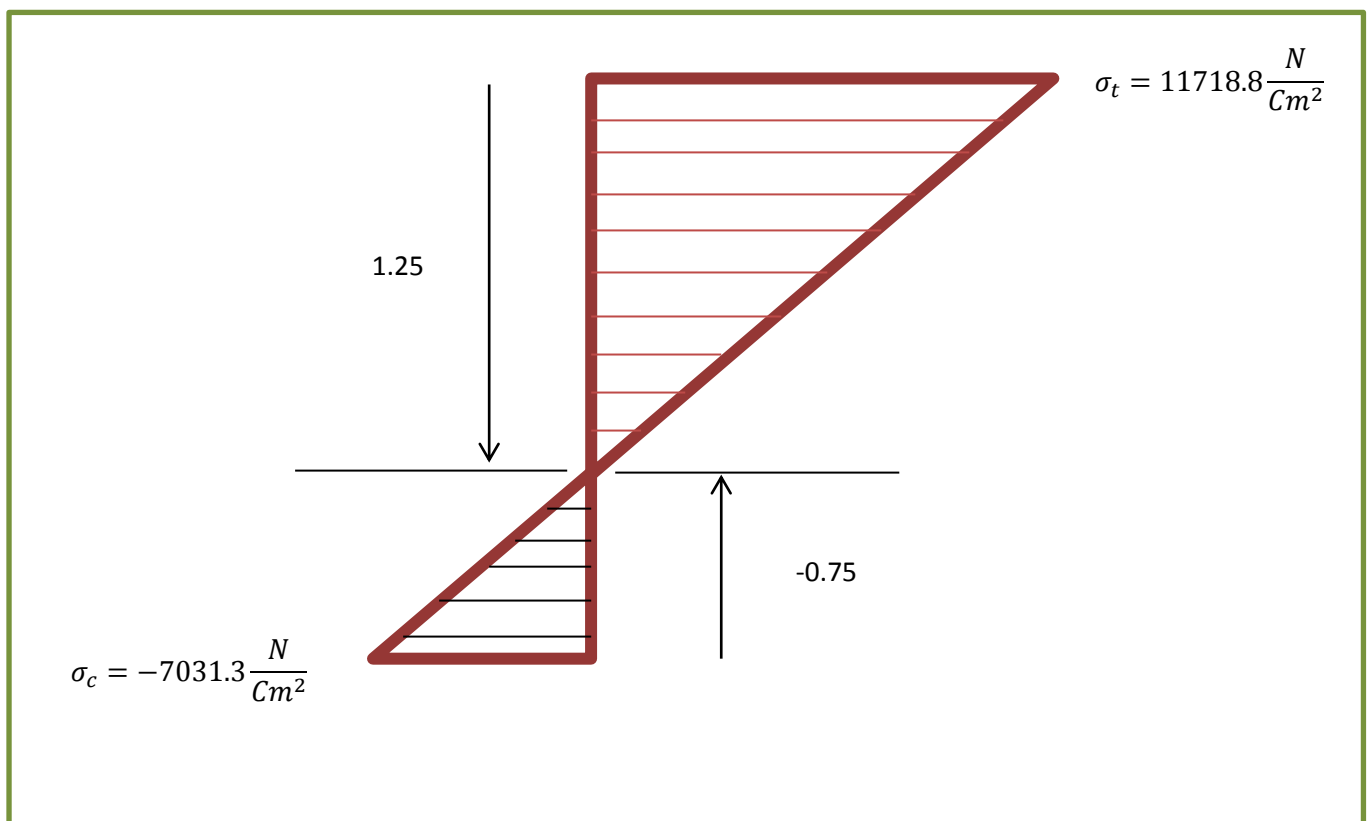
Example :- A laminate consists of a sheet of polyurethane foam of thickness (l0 mm) between two sheets of random discontinuous fiber-reinforced polyester, each of thickness (2 mm) . Determine the elastic modulus of the laminate when the faces are applied in a directional parallel to the forces of the laminate.

Note:-

$E_{foam} = 0.3$ GPa

$E_{polyester} = 7$ GPa

Solution:-

$V_c = 14$

$$\therefore V_{foam} = \frac{10}{14} = 0.714$$

$$V_{polyester} = \frac{4}{14} = 0.286$$

$$E_{sandwich} = 0.3 * 0.714 + 7 * 0.286 = 2.2 \, GPa$$

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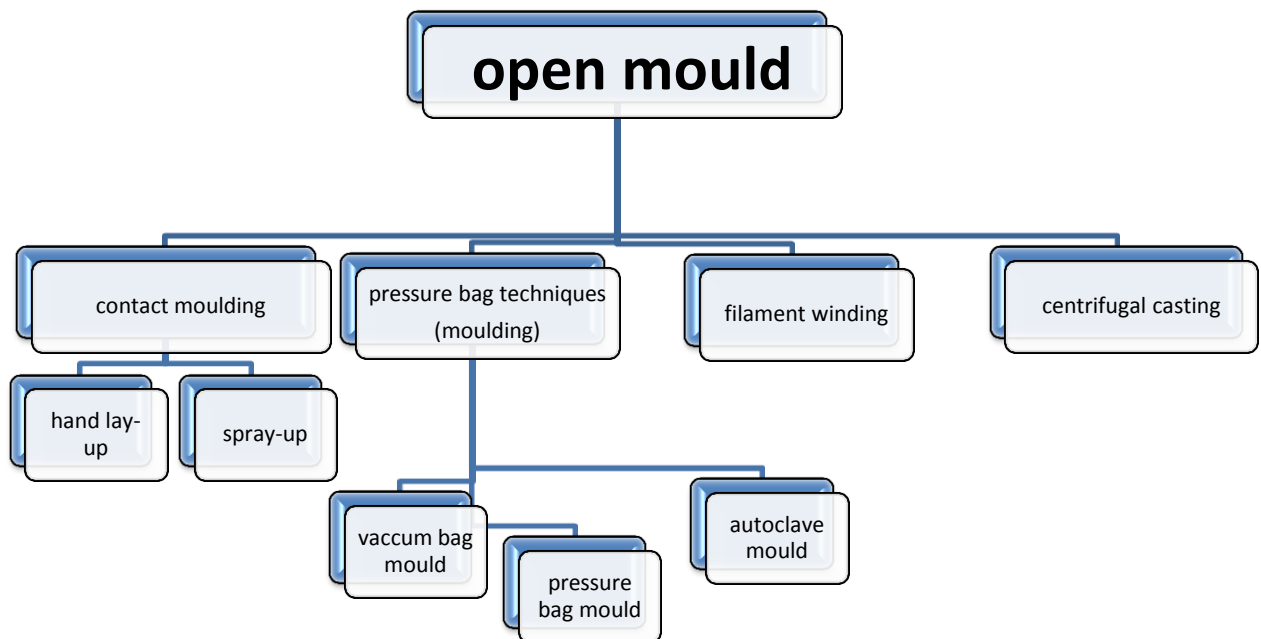
Closed mould processes :- In closed mould methods the product is formed with in a closed space by two mould or between mould and flexible membrane.
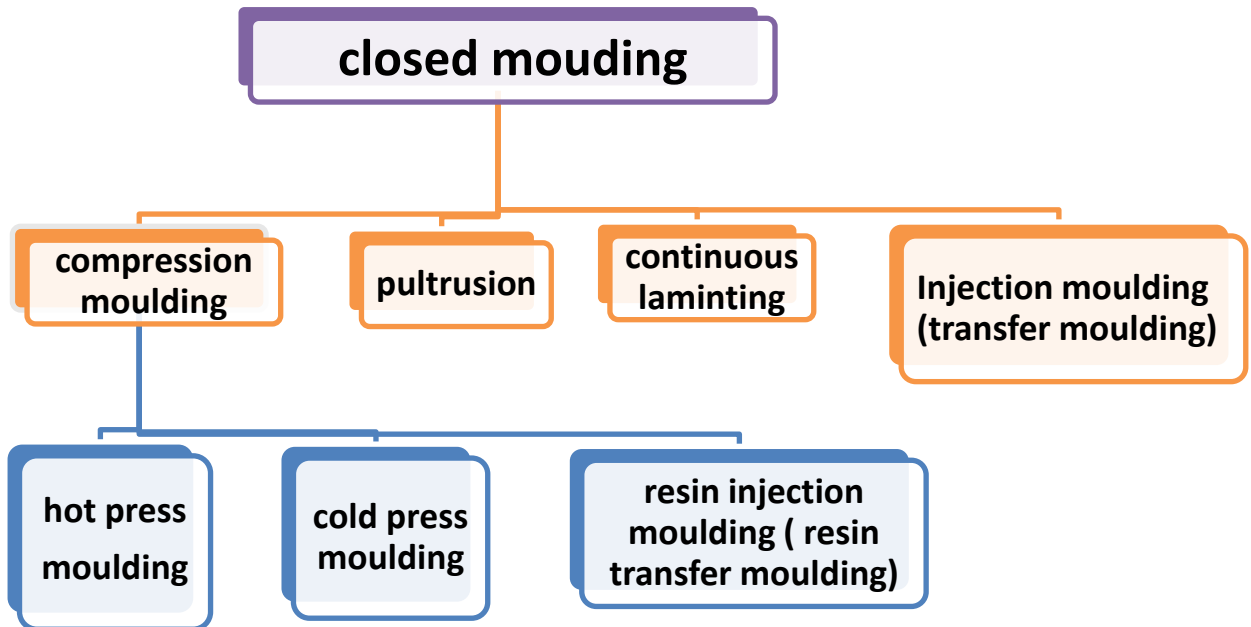
Contact moulding:-

(1)   **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 <u>colour</u> to the surface.

The functions of the gel coat is to :-

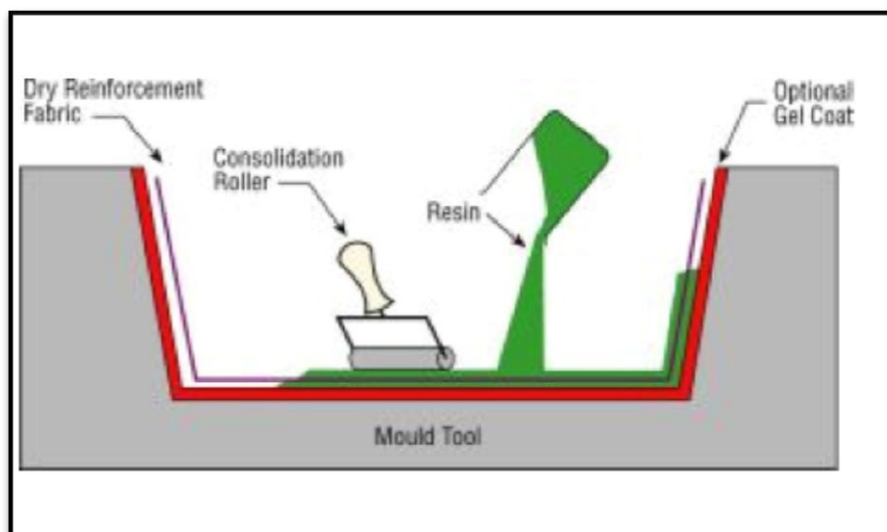**(i)** Protect the fibers from external effects, mainly moisture penetration.

(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.
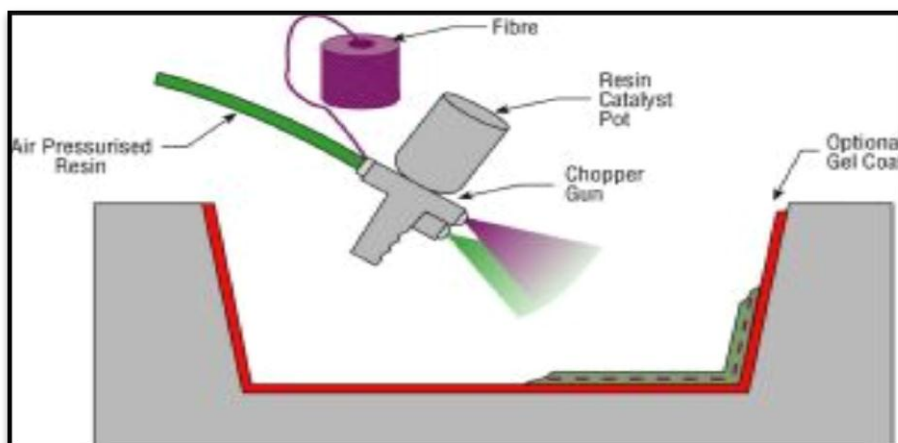
It is used for:-

- ❖ boat hulls
- ❖ containers
- ❖ automobile body parts
- ❖ furniture
- ❖ large structure panels

Advantages of the contact moulding:-

1. Large and complex items can be produce.

2. Production rate requirements are low.

3. Low cost equipment's.

Disadvantages of the contacact moulding:-

1. Longer cure times required.

2. Considerable operator skill required.

3. 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

ME 338: Manufacturing Processes II
Instructor: Ramesh Singh; Notes: Prof. Singh/ Ganesh Soni
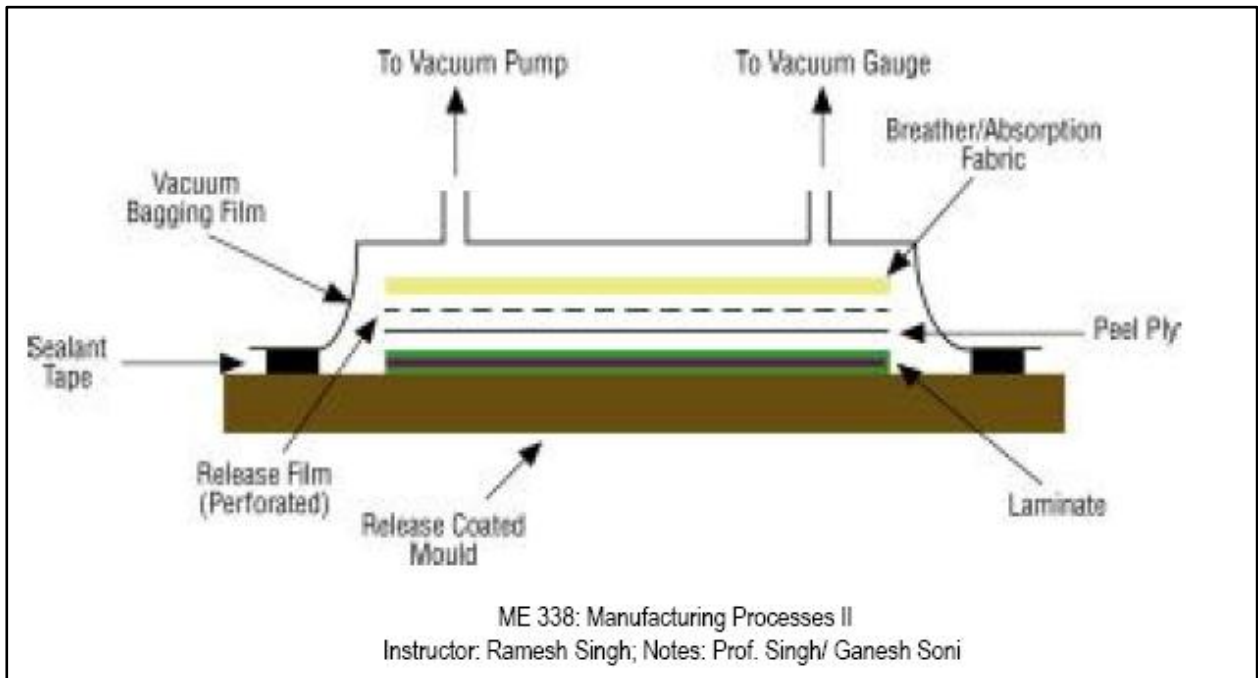
2- **Pressure bag moulding**:- this method is similar to the vaccum bag technique, except that in this case, the pressure is applied directly to open surface.
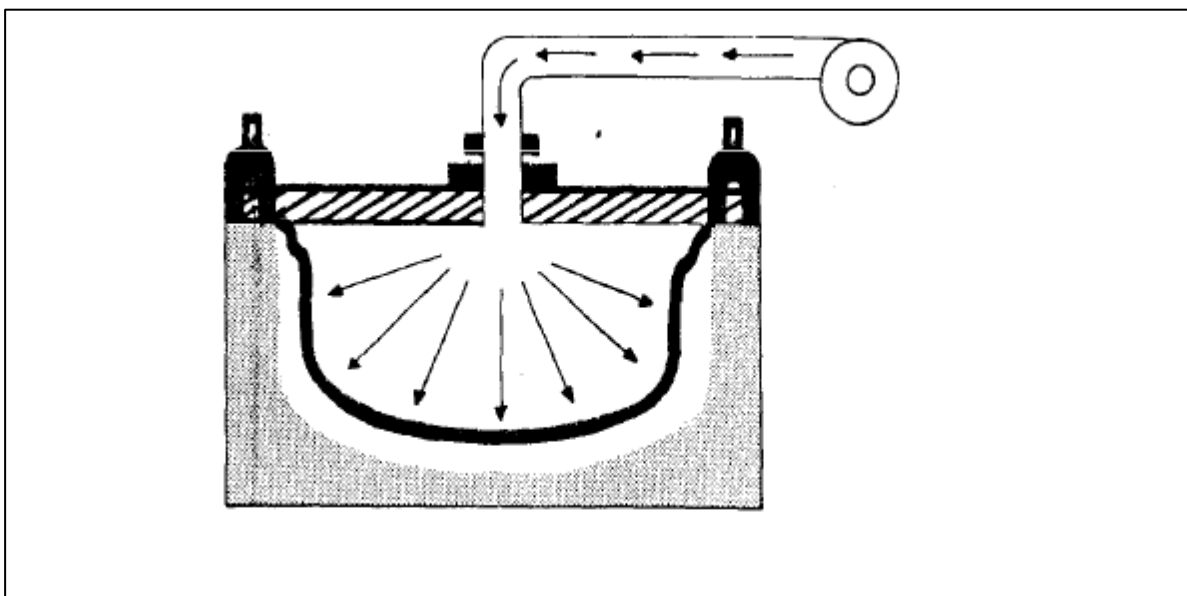
3- **Autoclave:-** An autoclave is a further development of the pressure bag method. An autoclave consists of cylindrical vessel constructed to withstand high pressure and temperature. It is used to produce a very superior quality composite.

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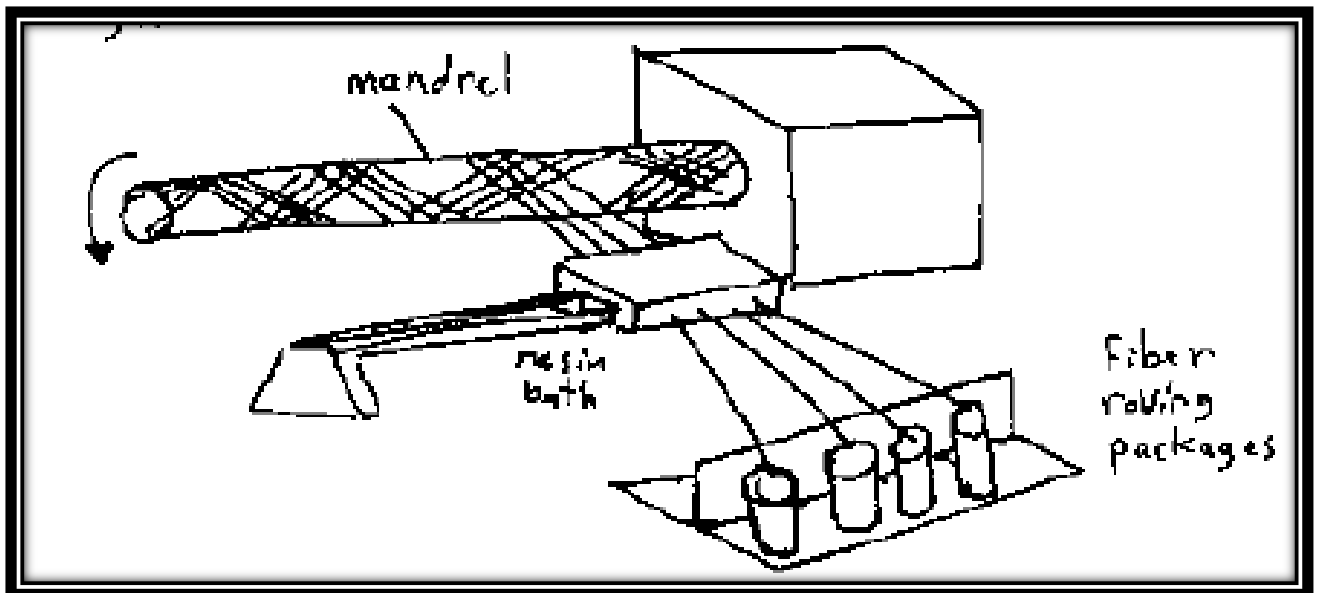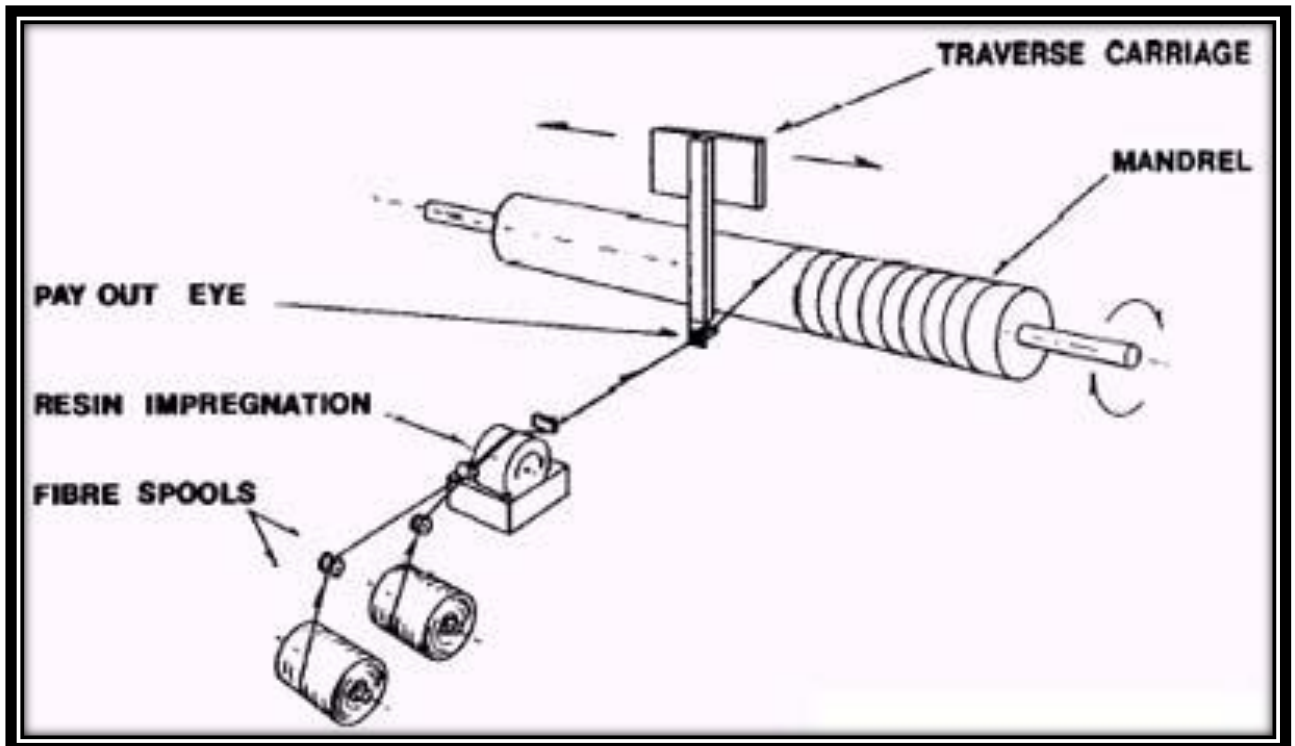
Various winding patterns are possible (i.e., circumferential, helical and polar) to give the design mechanical characteristics as shown.

Helical winding

Circumferential winding

Polar winding
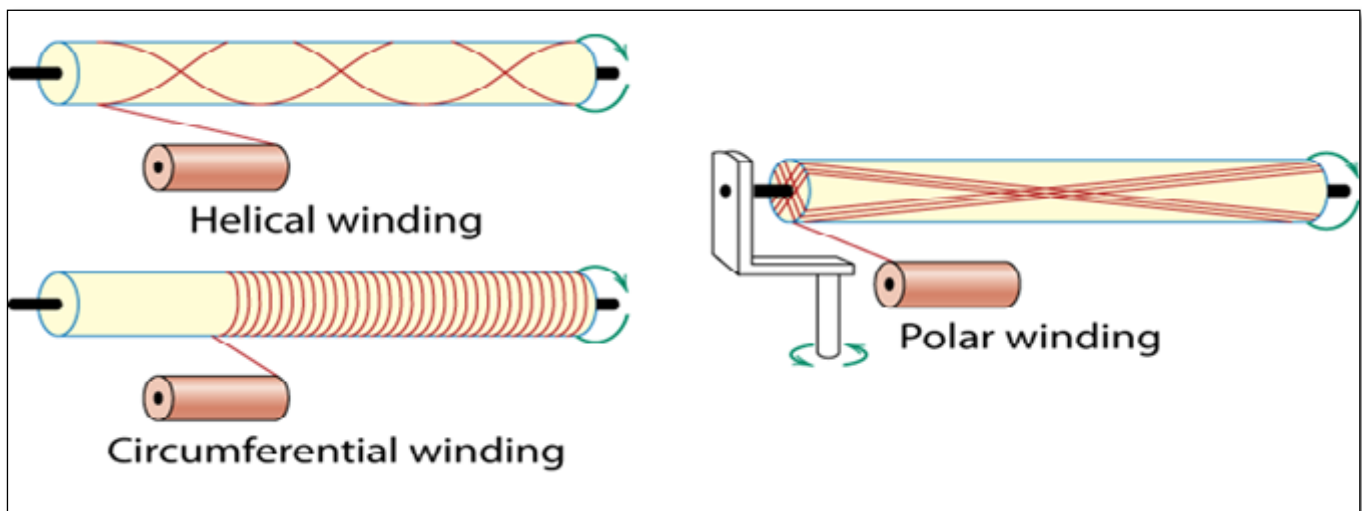
Advantages of filament winding:-

1) It is used for large and small components, especially of hollow, cylindrical.

2) Produces a high quality composite.

Disadvantages of filament winding:-

- expensive method.

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

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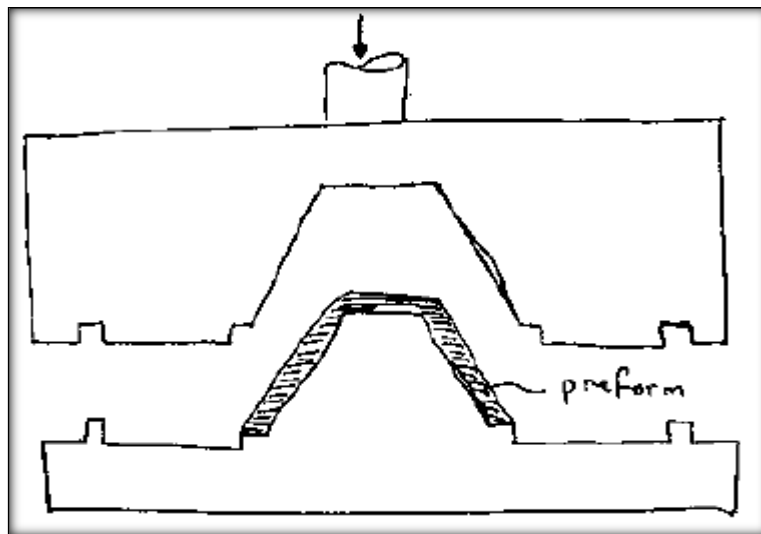
2- **cold press moulding:-** This method is basically the same as the hot press moulding technique, except that no external heat is applied.

4-**Resin injection moulding:-** 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:-

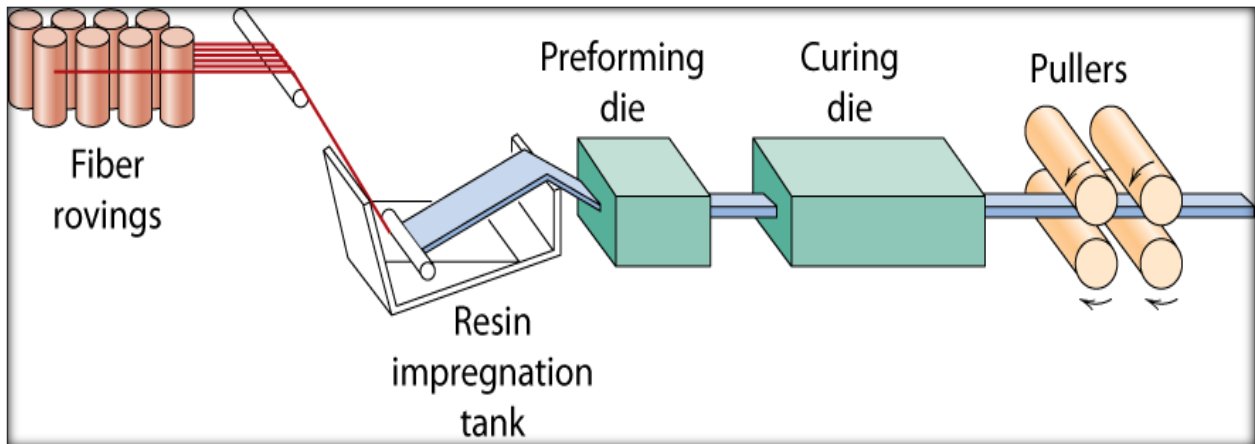Is used for the manufacture of components having continuous length and a constant cross-sectional shape (i.e. rods, tubes, beam , panels , I-section, etc.) As show in the following figure.

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.

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.

Polymer- matrix composite (PMC$_S$) : consist of a polymer resin as matrix, with fiber as the reinforcement medium.

It is may be:

- **Carbon fiber - reinforced polymer** – It is used for

  Fishing rods   Rocket motor cases

  Pressure vessels
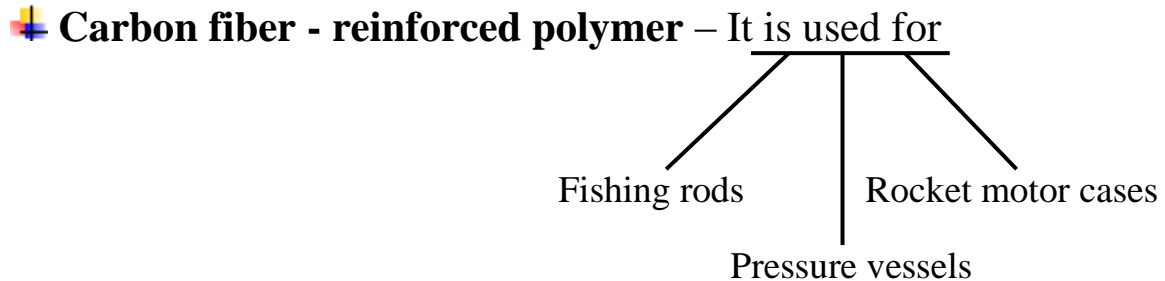
- **Glass fiber- reinforced polymer**- It is used for car body
- **Aramid fiber-reinforced polymer**-It may be used for tires ropes, It may be as a replacement for asbestos in automotive brake and clutch linings, gaskets. (which retain their mechanical properties is between-200 to 200^{0}C)

- **Boron fiber-reinforced polymer** - (helicopter rotor blades)

Fiberglass is simply a composite consisting of glass fibers, either continuous or discontinuous, contained within a polymer matrix.

The applications of fiberglass:-

- ❖ Automotive and marine bodies.
- ❖ Plastic pipes.
- ❖ Storage containers.
- ❖ Industrial floorings.

The following method commonly used for the manufacture of fiber- reinforced polymer matrix composites

1) hand lay-up
2) spray-up
3) resin transfer moulding
4) pultrusion
5) filament winding
6) continuous laminating

Metal-Matrix composite (MMC_S)

are made by dispersing a reinforcing material into a metal matrix. As the name implies, for metal-matrix composites (MMCs), the matrix is a ductile metal. These materials may be utilized at higher service temperatures than their base metal counterparts; furthermore, the reinforcement may improve specific stiffness, specific strength, abrasion resistance, creep resistance, thermal conductivity, and dimensional stability. **Some of the advantages of these materials over the polymer matrix composites include**:

➢ higher operating temperatures,

➢ no flammability,

➢ do not absorb moisture,

➢ have better electrical and thermal conductivity,

➢ are resistant to radiation damage,

➢ greater resistance to degradation by organic fluids.

The super alloys, as well as alloys of aluminum, magnesium, titanium, and copper, are employed as matrix materials. The reinforcement may be in the form of particulates, both continuous and discontinuous fibers, and whiskers; concentrations normally range between 10 and 60 vol%. Continuous fiber materials include carbon, silicon carbide, boron, alumina, and the refractory metals. On the other hand, discontinuous reinforcements consist primarily of silicon carbide whiskers, chopped fibers of alumina and carbon, and particulates of silicon carbide and alumina

The following demands are generally applicable

1. low density,

2. Mechanical compatibility (a thermal expansion coefficient which is low but adapted to the matrix),

3. Chemical compatibility,

4. Thermal stability,

5. High Young's modulus,

6. High compression and tensile strength,

7. Good process ability,

8. Economic efficiency.

The methods used for manufacturing metal - matrix composites can be grouped as:

1) **Solid state method:**

Is a forming and fabrication technique consisting of three major processing stages. First powdered metal and dispersed metal or ceramic powder or discontinuous fibers are mixed. Next, the powder is injected into a mold or passed through a die to produce a compact of weakly cohesive structure. Finally, the end part which formed by applying pressure may be sintered in a proper temperature and atmosphere to produce a final composite compact. This compact may need to undergo a secondary manufacturing process like rolling or extrusion to produce the desired shape to suite the application

2) **liquid state mathods**: mix the fibers or particles with the liquid metal and then cast the metal.

3) **deposition methods:** in this method the matrix material is vapour deposited or electroplated onto the fibers. Then fabricate the coated fiber on hot pressed.

Cermic – Matrix Compsites (CMC$_S$) : The design goal is to increase the Fracture toughness for the material.

Application

❖ Cutting tools.
❖ Wear parts.
❖ Aircraft gas turbine engines
❖ Component in automobile.

The methods that used producing ceramic matrix composites include:

- Hot pressing.
- Liquid phase sintering techniques.
- Vapour deposing.

Carbon - carbon composites:-

Both the reinforcement and matrix are carbon. These materials are relatively new and expensive.

The desirable properties include

1. High tensile modulus
   High tensile strength — which are retained to temperature excess of 2000^0C
2. Resistance to creep.
3. Have low coefficient of thermal expansion.
4. High thermal conductivity.

   It is used in rocket motors

Hybrid composites:-

This is obtained by using two or more different kinds of fibers in a single matrix, hybrids have better properties than composites containing only a single fiber type .

Application

- Sporting goods

Elastomer

Is a polymer with the property of elasticity, the term, which is derived from elastic polymer, is often used interchangeably with the term of rubber.

Elastomer (natural and synthetic rubber) is an amorphous polymer which shows very large strains when subjected to stress and which returns to its original dimensions when stress is removed.

In order to improve the properties of rubber, various chemical additives such as sulfur, accelerator, and activators are added to the rubber to be as a compound.

These materials are added during the mixing process and then react with rubber during "vulcanization" process by using heat and pressure.
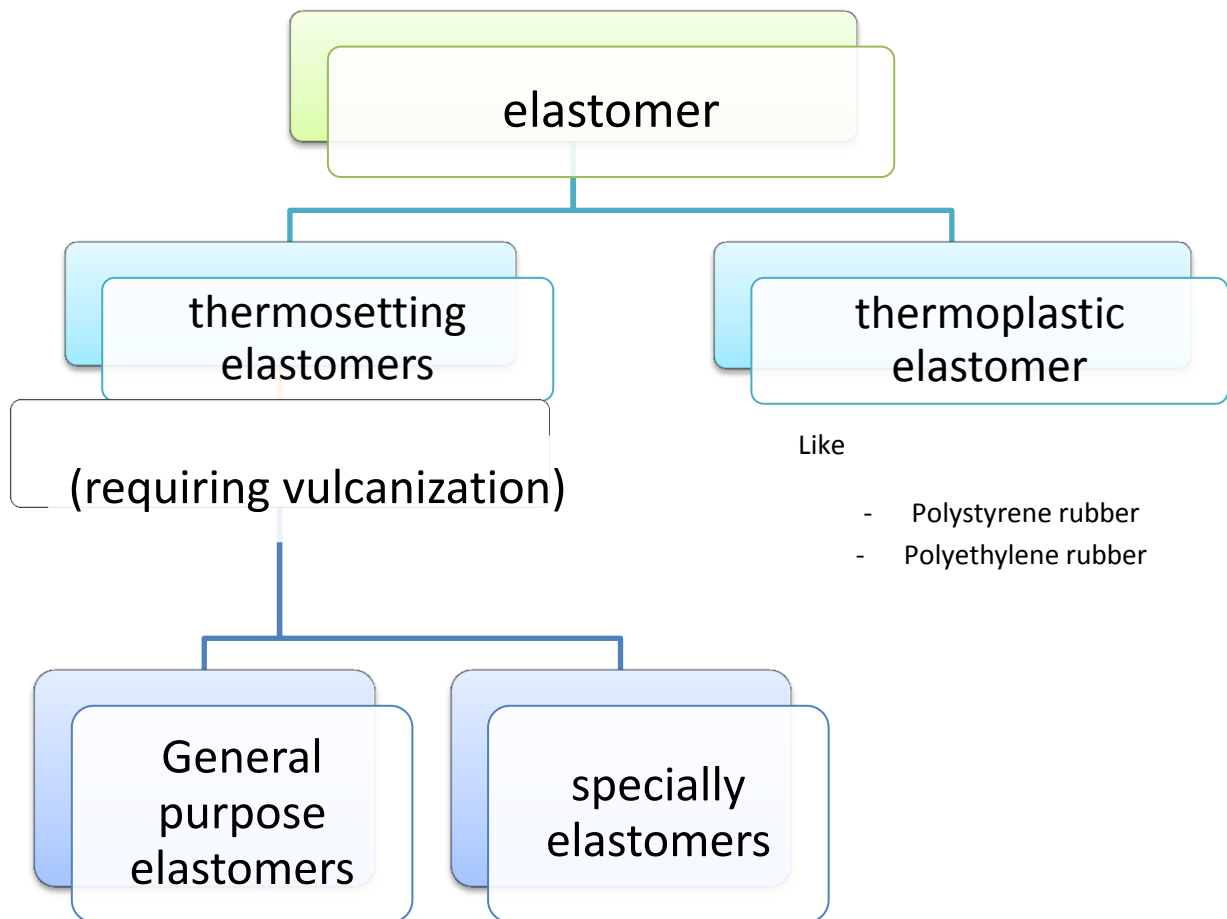
Vulcanization:- refer to a specific curing process of rubber involving high heat and pressure , after the addition of sulfur or other equivalent curatives , to convert it to accepted "rubbery" or " elastic " state .

Figure of vulcanized and unvulcanized rubber molecules

The properties that recognized the rubbers from other polymers are :-

1) High elasticity - rubber produced large deformations under the action of small stress ore recovering their origin dimensions after stress removal.
2) Strength is high – especially under conditions of shear and compression.
3) High tear resistance.
4) High resilience.
5) Rubbers have very long molecular chains.
6) Long life
7) Rubber absorb fillers, may be more than it weight.

```
                        elastomer


        thermosetting                    thermoplastic
         elastomers                        elastomer

                                     Like
        (requiring vulcanization)
                                        -   Polystyrene rubber
                                        -   Polyethylene rubber


        General              specially
        purpose              elastomers
        elastomers
```

Like:-   Like :-

- Styrene butadiene rubber (SBR)   -   Neoprene rubber (CR)
- Butadiene rubber (BR)   -   Silicon rubber (MQ)
- Natural rubber (NR)

Applications:-

- Rubber is in tires which represent nearly (70%) or the rubber production.
- Power transmission belts.
- The hose and sealing industry.
- The load bearing pad for bridges.
- Rain wear, foot wear, pipes and tubing, tank lining for oil storage, gaskets and diaphragms, sport goods…….etc.

Rubber processing Technology consists of:

a- Mastication and Mixing:

Mixing and mastication are conveniently done using two roll mills (calendar)
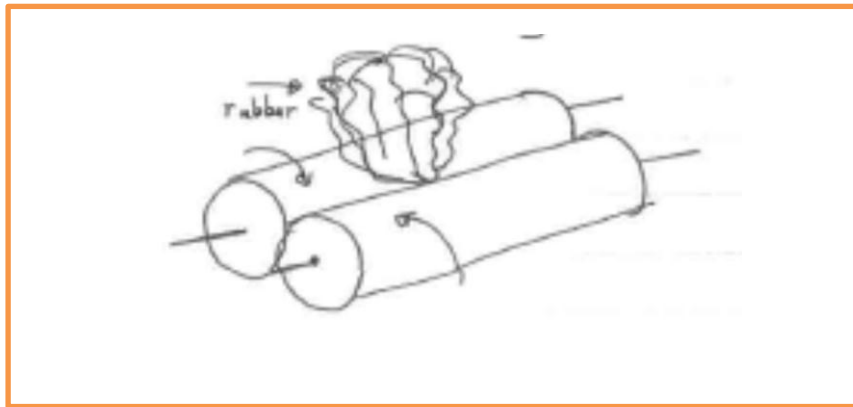
b-compression molding and vulcanization