INTRODUCTION TO BASICS OF COMPOSITE STRUCTURE

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Abstract: The popularity of composite material widen day by day, use of composite is not new, where it can be traced back in 1500 B.C. too and that is enough to justify its popularity even in old time. Now days composites are used in various applications, many domains such as space, plastic processing industries, tools and equipment's manufacturer, biomedical engineering, sports equipment manufacturer are referring composites as an alternative material over traditional material so the advance technologies have also develop to process this material in to final shape and size. This approach satisfying the need of customer in best possible regards and thus researcher are going on to upgrade the use of this material to next level of benchmark. Industrial designer first needs to familiar with basis structure of composite, its behaviour and processing techniques, in the view of same, the paper is written let to percolate the knowledge among readers about basic structure of composites and many relevant things about it.

Keywords: Composite, fibre, matrix, resin, alloys, metals etc.

1. Introduction to composites structure: The history of composites can be traced long back, approximately in the time 1500 B.C. the use of composite was popular this time in making of mud bricks which were reinforced with straws and Bamboos to impart the required amount of strength. Use of arrows and bows by Mongolian also justifies the fact the use of composite was popular in the old pages of history too. The use of composites started gaining popularity in 1930, in the year 1947 the US Navy was manufactured Boats which were made of composites. The boat structure was light weight, corrosion resistance, less susceptible to sea water attacks and thus showing high reliability.

In today's date, use of composite earning its popularity in the domains such as space applications, defence, biomedical, sports, shipping and packing industry etc.

Composite material can be extracted from natural resources which off course needed to proceed at laboratory to impart said perfection and later on it can be used in various applications. Synthetic fibres have also occupied the market to large extent now days. The natural composites found in bones, tree tissues, woods etc. synthetic fibres can be manufactured by laboratory method and enlisted as, carbon fibre, aramid fibre, born fibres, glass fibres etc.

Figure shows composition of composite structure, fibre are stiff elements, approximately 80% of total load is only sustained by fibres where remaining by matrix, fibre-matrix interface and coupling agents. Matrix receives the load and transfer to fibres by means of shear force. Matrix has good damping capacity and exhibits capacity of undergoing high strain before failure, contrast to this; fibres are stiff elements and show little strain by the time of failure. Ultimate load sustained by fibres by the time of failure is several times more than that could be by matrix. Coupling agents are connection or links between fibre and matrix, they retain the position of fibre and matrix during deformation and after deformation when external load is removed naturally. The another important contribution made in load sustaining by fibre-matrix interface, surface area of fibre defines the efficiency of load receiving and sustaining without undergoing for failure, adhesive elements ensure this interfacial bonding so the purpose will be served throughout the operation.

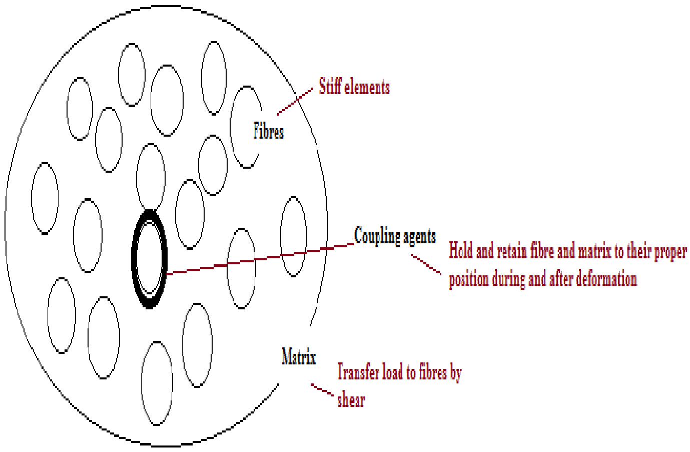


Fig (1.1): Basic composite structure comprise of fibre-matrix constituents

Mechanical performance of composites depends on fibre and matrix which are considered its major and important constituents. As per the fibres are concern, length, orientation, geometry and material of fibres affects the properties of composites, whereas material of matrix is only the associate property of matrix which makes impact on composite properties. Apart to these two, fibre-matrix interface, fibre distribution in matrix and percentage of fibre and matrix volume fraction maintained in composite structure defines the overall structural properties of composites and its ability to perform under critical loading conditions.

There are few key aspects one has to remember while addressing the manufacturing of composites and those are as follows,

- Smaller the diameter of fibres leads to reduce flaws and other defects in structure.
- Larger surface area of fibre leads to impart high ductility to the structure, enhance structural toughness and effectively address the load transfer from matrix to fibre.
- Bi-directional fibres enhances ability of structure to bend without let failure occurred.
- Fibre oriented in 0 degrees enhances longitudinal strength of structure.
- Fibres oriented in 90 degrees enhance transverse/Lateral strength.
- Fibres oriented in 45 degrees enhance shear/Oblique strength of structure.

Fibre material used in three forms viz. organic, inorganic and metal. Organic fibres are Kevlar, inorganic fibres are carbon, graphite, boron, glass, quartz, silicon carbide and alumina, metal fibres are steel, titanium, boron, tungsten and molybdenum etc.

Similarly matrix material used in composite structure making can be listed as, polymers, metals, ceramics, carbon, aluminium, titanium, magnesium, Ni-Cr alloys etc.

An Image below depicts microscopic structure of aluminium matrix and silicon reinforcing particles, which after mixed, how the resultant composite structure formed looks like.

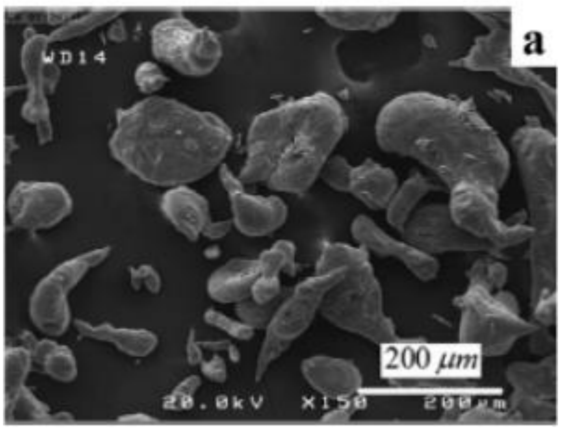


Image (1.1): Micro structure of Al7075 Matrix

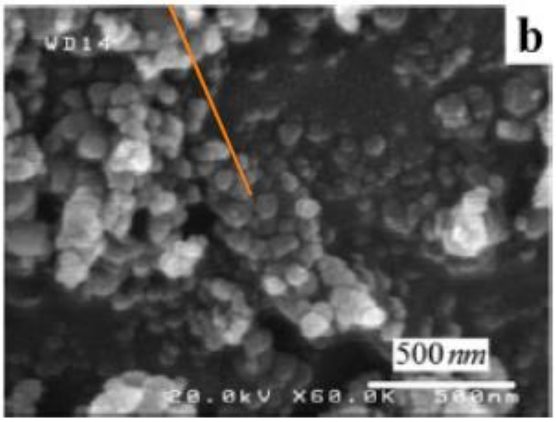


Image (1.2): Microstructure of Sic fibre reinforcement

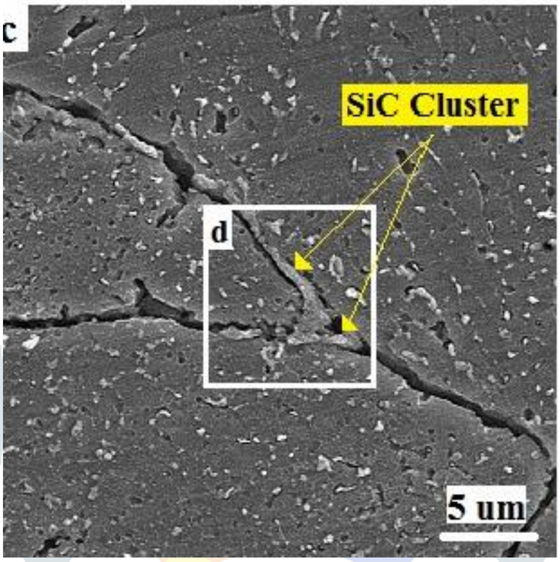


Image (1.3): Resultant composite structure

Structure purely distinguishes between **Sic** reinforcement and Al7075 matrix. The clustering of Sic reinforcement within dispersion medium of Al7075 matrix can be clearly seen in the image above. In the case of metal this distinguishing goes very difficult and after mixing alloying elements represents in bulk unlike separate clustering which for frequently comes to see in the case of composites.

Based on microstructure; the behaviour of composites can be analysed on the basis of two different scales namely, Micromechanical and Micromechanical. In micromechanical analysis interaction between constituents and their overall impact on properties and behaviour of composites is taken in to account, where, in macro-mechanical analysis the impact of constituents are considered to obtain average properties of composite structure, the structure is considered as homogeneous in macroscopic scale of evaluation and judging of structure performance.

Manufacturing of composites can be proceed by different methods, the selection of process of manufacturing is the function of type of geometry, its complexity, material chosen for manufacturing, process requirement etc. the few methods can be enlisted as, Filament Winding, Pultrusion, Hand Lay-Up, Spraying up, Resin Transfer Molding, Autoclave Moulding etc. Pultrusion is recommended for continuous and long structural manufacturing.

Hand lay-up is manual technique of forming the lamina and thus laminated structure. In spraying techniques, the mixture of fibre, matrix and resin is sprayed in mould which defines shape and geometry of product to be manufactured. The flow chart below depicts the process of moulding the final composite product from basic raw materials.

Composite material is the combination of two or more physically distinct and mechanically separable materials, sometime it included more than two materials and requirement varies from application to application. Few examples of composites can be given as, concrete and mortars used in construction applications, rubbers, plastics and many metallic alloy combinations.

Composite structure can be classified and studied well based on types of matrix and fibres used in its making.

2. Classification of composite material: Based on types of fibre, they can be studied as, Particulate and Fibre Reinforced Composites.

- **Particulate composite:** Particles of different shapes and size dispersed in matrix at random leads to form Quasi-Homogenous structure. Ex. Aluminium particles dispersed in rubber matrix.
- **FRP (Fibre Reinforced Polymer):** Fibres, may be short or continuous dispersed in to matrix with distinct boundaries maintained, the packing of fibres is scientific and not random like particulate composites. Arrangement of fibres follows triangular or rectangular pattern. The maximum percentage of fibres can be packed in to matrix is 80%, in the case off cylindrical fibres this percentage reach up to 90% sometimes. Continuous fibres are more efficient compared to short fibres such as whiskers.

"Based on matrix"

According to dispersed phase and dispersion medium composites can categorized in to as following types,

- **Metal matrix:** Metal fibres such as Boron reinforced in metal matrix.
- **Polymer matrix:** Combination of thermoplastic or thermosets resin with glass fibres.
- **Carbon-Carbon composites:** Graphite carbon matrix added with graphite fibres.
- **Ceramics matrix:** Ceramics rubber such as Alumina, Silicon added with ceramics matrix.

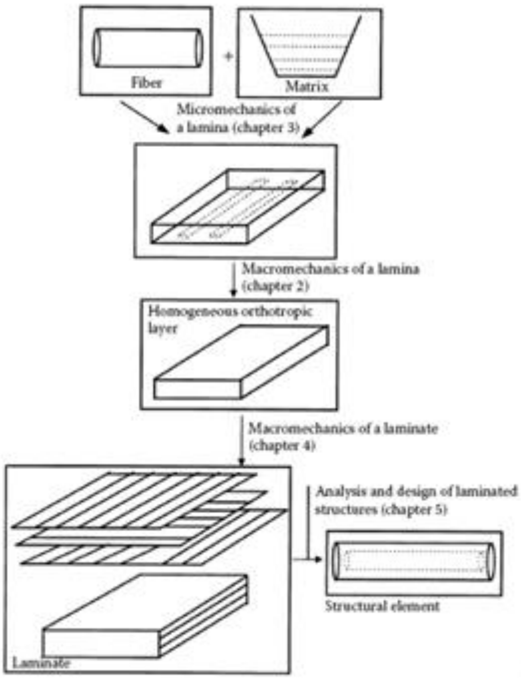


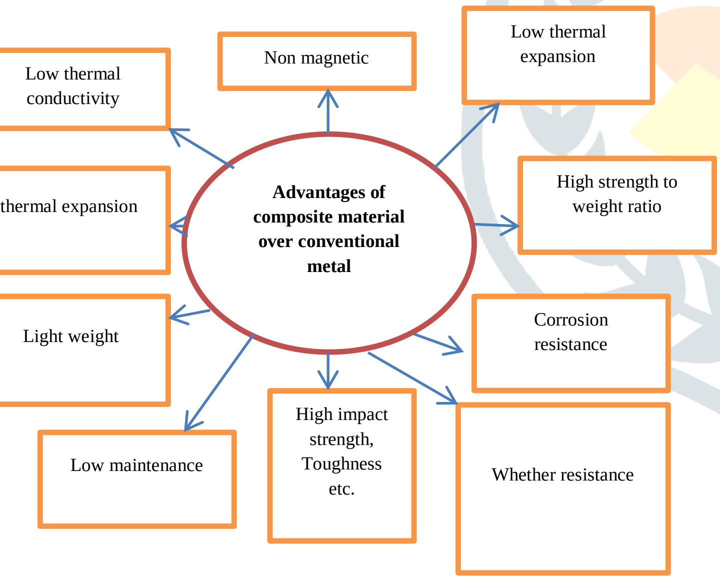
Fig (2.1) : Process depicting moulding of component from basic constituents.

3. Difference between composite and conventional metals:

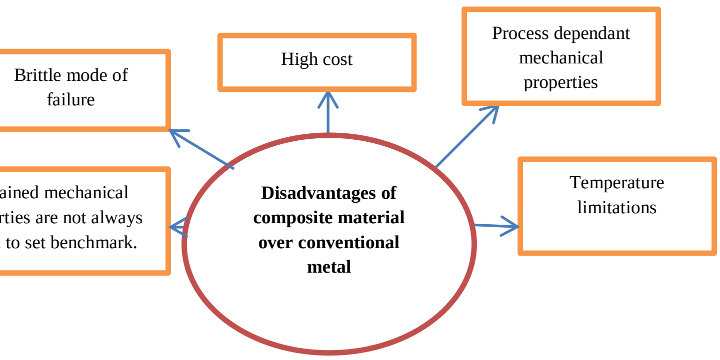
Sr. No.	Composites material	Conventional material
1	Composite structure is anisotropic in nature i.e. it exhibits different property configuration in different direction.	Similar properties in all the directions.
2	Combination of physically distinct and mechanically separable phases.	Phases can be distinguished under microscope but cannot be separated from each other.
3	No chemical bonding formation between	Chemical bonding formation followed

	elements.	by curing.
4	Light weight.	Heavy weight
5	High strength to stiffness ratio.	Low strength to stiffness ratio.
6	Constituent combined at macroscopic level.	Constituent combined at microscopic level.
7	Constituents are not soluble in each other, so can be distinguished from each other.	Constituents are mixed in each other at microscopic level so cannot be differentiate from each other neither can be separate from each other.
8	Material is anisotropic in nature.	Material is homogeneous and isotropic at macroscopic scale of observation.
9	Properties of composites depends on fibre, matrix and resin properties.	Properties of conventional alloys depends on properties of bulk which is formed after homogeneous and uniform mixing of different alloying elements added in different proportions.

4. Advantages of composite structure:



5. Dis-advantages of composite structure:



6. Structural analysis of composite material:

Load sustaining capacity of composite is the function of fibre and matrix volume fraction, for fibre volume fraction more than 0.25, fibres contributes to sustain more than 75% of total load acting. The fibre volume fraction enhances the load carrying capacity, still there is limitation for fibre packaging in matrix, beyond 80% fibre packaging is not possible, geometry alteration from any random to cylindrical would address this issue and enables packing of fibres in matrix which can be counted more than 90%.

Modular ratio (Ratio of Young's modulus of fibre in longitudinal direction to Young's modulus of matrix) load carrying capacity in respective directions also increases, provided increase in fibre volume fraction supposed to happen with every such increment in the value of Modular ratio. Transverse modulus and material shear modulus also increases with increase in percentage of fibre volume fraction. Increase in Poison's ration also can be reasoned to increase in fibre volume fraction.

The material properties are the function of fibre orientation and lamina stacking sequence. Value of longitudinal Young's Modulus decreases with change occurred in fibre orientation (From 0 to 90 degrees), it decreased up to 45 degree and again starts increasing from 45 degrees onwards till 90 degrees. Change occurred in transverse Young's Modulus is negligible, it shows little shift in value at 45 degrees and then retain constant value till 90 degrees. Shear modulus value note highest at 45 degrees and starts decline afterwards, at 90 degree value is noted lowest among all the orientations considered from 0 to 90. Poison ratio in 1-2 plane increases up to 30 degrees and starts decline and attains lowest value while reaching to 90 degrees. The poison ratio in 2-1 plane exhibits opposite behaviour than poisons ratio in 1-2 plane, the value of poisons ratio in 2-1 plane which also affected by fibre orientation starts increased from 0 degrees onwards, attains its highest value while reaching to 75 degrees and then starts decline.

6.1 Constituents of composite structure:

Sr. No.	Major constituents of composites	Types	Applicability
1	Resins	Polyester, epoxy, vinyl ester, phenolic, polyurethane etc.	Transfer stress between fibres and hold the fibre together.
2	Reinforcements	**Natural:** Cellulose, sisal, jute **Synthetic:** Carbon, aramid, glass etc.	Provide strength and stiffness in the direction of load carrying.
3	Matrix	Epoxy	Transfer the load to fibres by shear.
4	Fillers	Calcium carbonate, mica, talk, silica, calcium sulphate, kaolin etc.	Improve mechanical properties and reduces cost.
5	Additives	-	Fibre resistance, plasticizers, heat stabilizers, improve toughness, improves electrical conductivity etc.
6	Catalyst	Methylethylketo neperoxide	Enhance the speed of curing
7	Colorant	-	Impart colour to composites.
8	Releasing agent	Zinc stearate	Impart easiness in the process of removal of part from mould.
9	Thixotropic agents	-	Reduces tendencies of liquid resin to flow.
10	Adhesives	-	Helps material to stick among surface.

Table (6.1.1): Basic constituents of composite structure

6.2 Lamina and Laminate: Composite structure can well studied in two formats as discussed below,

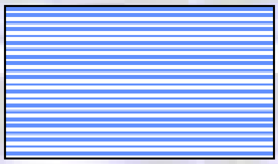
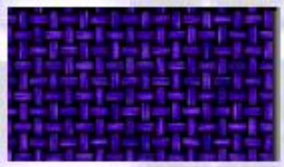
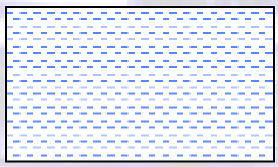
1. **Lamina:** Fibre and matrix volume fraction chosen for said percentage forms the lamina structure in which fibres with unique geometry and orientation dispersed in matrix. The orientation of fibre is the need of properties one need to achieve at the end of manufacturing.

2. **Laminate:** Several such laminas stacked for required sequence to form the laminate structure.

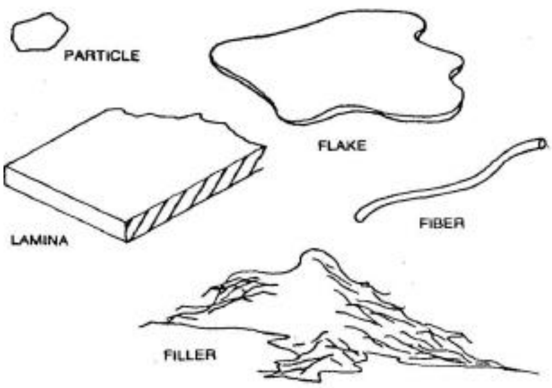
Figure below shows, laminas with different fibre orientations stacked for definite sequence to form the laminate with said property configuration. In few cases, lamina stacked one above the other though orthotropic in nature; they organized in such a way that the resultant laminates structure exhibits isotropy.

During loading, displacement through laminate noted continuous, where, laminate overall deformation is very small, which if, within permissible limit failure of structure would not happen, but as soon as deformation exceeds the permissible or yield limit crack initiate which keeps increasing with respect to applied load and brings the ultimate laminate failure. Till failure, stress-strain relationship noted linear.

6.3 Basic fibre orientations:

 Uni-directional fibres	 Bi-directional fibres
 Uni-directional discontinuous fibres	 Random discontinuous fibres

6.4 Basic structure of composite materials: The figure below depicts basic structure of composite material which imbibes with particle, flake, fibre, lamina and filler material as per the requirement.



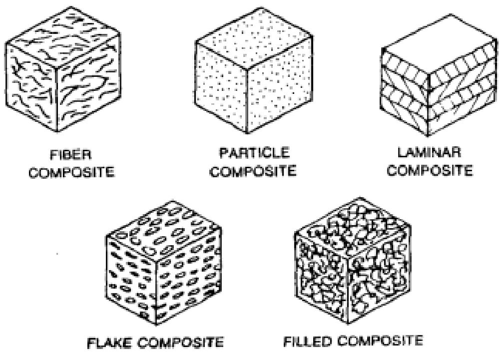


Fig (6.4.1): Basic composite structure imbibed with different filler

The layers of lamina which are provided with different fibre orientation as per the strength and other properties requiring are stacked one above the other and formation of laminate structural taken place as shown in figure below,

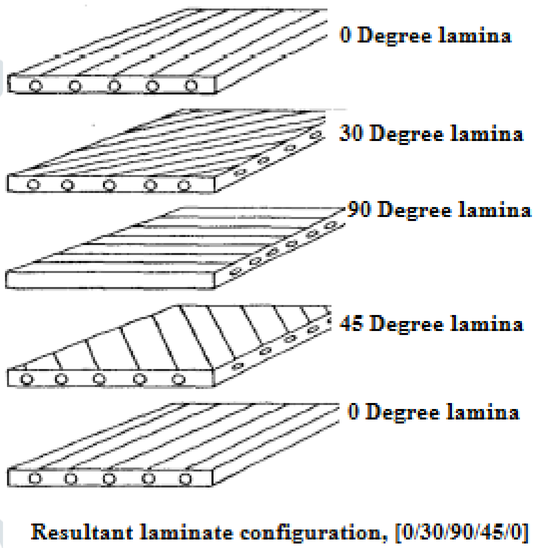


Fig: Laminate structure comprise of several lamina provided with different fibre orientations

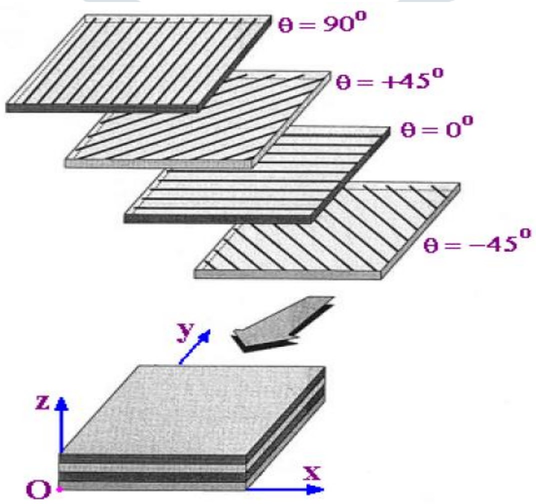


Fig (6.4.2): Laminate structure formation from lamina with unique fibre orientation stacked one above the other.

Laminate are stacked for different sequence purposefully, few of such configuration along with purpose discussed below,

Laminate	Purpose
[0/90/90/0]	**Symmetric laminate:** Eliminates the need of coupling agents and avoid bending.
[+45/-45]	**Angle ply laminates:** To impart the shear strength to avoid failure due to shear loading.
[0/90]	**Cross ply laminate:** Retain structural stability & optimum balance between deformation produced in longitudinal and transverse direction due to loading in respective directions.
$[0_G/90_k/45_c]$	**Mixed laminate:** Fibres of different materials, oriented in different direction are stacked for definite sequence to satisfy the need of required strength.

Table (6.4.1): Different laminate configurations used in final product moulding and manufacturing

6.5 Stability of composites: Strength of composites depends on fibre length, fibre shape, amount of voids and discontinuities present in to respective structure etc.

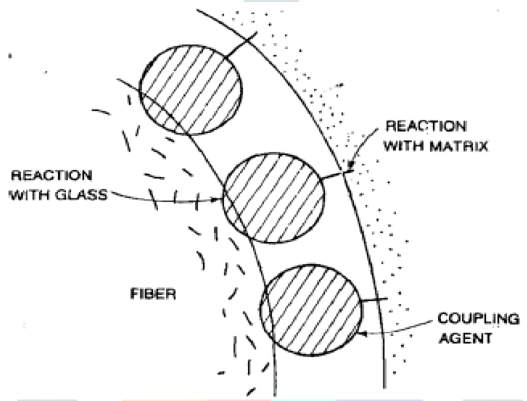


Fig (6.5.1): Coupling agent holds and retain matrix and fibre to their place after deformation vanished.

Coupling agents are connections between fibre and matrix element which retains the structural stability by maintaining unique position of structural ingredients when for a while they supposed to deform under the application of external load

The behaviour study of composite laminate can well undertake by understanding number of independent elastic constant and relativity between them. The table below represents various types of laminates and number of independent elastic constants associated with them due to their unique structure manufacturing.

Laminate Type	Description	Number of independent elastic constants.
Anisotropic	Heterogeneous material	**81**
Anisotropic with symmetric stress-strain components	Symmetry of stress-strain tensor	**36**
Anisotropic with energy consideration	Strain energy consideration reduces constant to further low value	**21**
Monoclinic material	Material having symmetry with respect to plane	**13**
Orthotropic material	Three mutually perpendicular plane of material symmetry	**9**
Transversely orthotropic material	Plane of isotropy, the point on which, the properties in all direction are same.	**5**
Isotropic material	Properties in all direction are same.	**2**

Table (6.5.1): Table shows types of material and number of independent elastic constants associated with each one of them.

Stiffness matrix namely [A], [B], [D] helps investigator to understand overall behaviour of structure under the application of load. The deformation happened under applied load is not linear always but it is of curvature shape sometime, the stiffness matrix helps to understand the behaviour of deformation for applied load and thus process of analysis continues.

- **In-plane stiffness matrix-[A]:** Considers the effect of in plane load, stresses and strains.

- **Coupling stiffness matrix-[B]:** Considers the effect of in plane load, curvature and moments to in plane strains produced.

- **Bending stiffness matrix-[C]:** Considers effect of moments to curvature produced. The laminate stacking sequence affects the matrix value.

7. Conclusion:

1. Fibre are stiff and strong element of composite which contributes approximately 80% load sharing of the total load, where matrix are flexible member which transfer load to fibres. Matrix has good damping capacity, matrix are ductile in nature and shows considerable strain before failure. Fibres are brittle in nature and show less strain by the time of failure.

2. Though fibre contributes in load sharing more compared to matrix, the increase in fibre volume fraction in matrix (Dispersion medium) is not possible beyond 80% of total volume of composites.

3. Packing of cylindrical fibres is quite easy compared to fibres with other geometry; packing of cylindrical fibres can possible up to 90% of total structure volume.

4. Strength of lamina is the function of fibre geometry, fibre volume fraction, fibre-matrix interface etc. where strength of laminate is the function of strength of various lamina stacked in to structure with different or same fibre orientation.

5. Composites are exists in physically distinct and mechanical separable phase unlike conventional material where alloys cannot be distinguished for various material components and their respective percentage.

6. Coupling agent retains structural stability and balance between constituents of composite structure.

7. Number of independent elastic constant associated with structure is the function of material isotropy or heterogeneity, constant counts are more in case of heterogeneous material, where it is found less in the case of homogeneous or isotropic material.

8. Elastic properties of composite structure are the function of fibre orientation.

9. The different phases in composites can be well distinguished if viewed under microscope.

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