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FABRICATION AND TESTING OF FRP (FIBRE-REINFORCED PLASTIC)

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ABSTRACT

The present study deals and analysis for different FRCSP has higher strength to weight ratio and exceptional buckling resistance. In addition, these structures have effective heat insulation. In this context, FRCSP i.e., fiber reinforced composite sandwich panels fabrication is taken up for aerospace applications. Significant advances in the manufacturing of the FRCSP structures themselves have given greater flexibility in various operating conditions.

The various types of composites materials are

- Matrices
  - Organic Matrix Composites (OMCs)
  - Polymer Matrix Composites (PMCs)
  - Carbon-carbon composites
  - Metal Matrix Composites (MMCs)
  - Ceramic Matrix Composites (CMCs)
- Reinforcements:
  - Fibres reinforced composites
  - Laminar composites
  - Particulate composites

Finally the project is concluded by The FRCSP can be fabricated by selecting the aluminum and glass fibre to overcome FMLs by improving bonding strengths and easy method of manufacturing along with better strengths which often requires the aerospace industry for its light weight parts.

Keywords: Composite material, Fibre Reinforced Plastic, Laminar Composites etc.

1. INTRODUCTION

In fiber reinforced composites, addition of glass fibers improves the bending load carrying capacity. Glass fibers are cheaper compared to other reinforcements like carbon fibers, moreover they are used in roofing panels of electrical and electronic devices. Due to their exceptional mechanical characteristics, glass fibers have become the predominant reinforcements in fabrication of high performance composites along with the matrix which plays a vital role in the strength threshold of the composite.

It is observed that glass fibre reinforced plastic panels that are designed for the same ballistic protection as corresponding steel panels show considerable higher post-impact load carrying capacity than the steel counterpart. The sandwich panels having truss core structure is showing good mechanical properties and domination in buckling along with improved debonding of facesheets .The CFRP with honeycombs structures used in aerospace applications and the structures having pyramidal cores are having similar mechanical performance. Thus, for any functional applications that require an open-celled architecture where cooling fluid can pass through a sandwich core, the CFRP complex cores offer a best substitution to honeycombs. Compared to traditional structures in composites hybrid core and truss topology improve specific strength, lightweight, energy absorbing and moduli when composite sandwich panels along with hybrid foam filled lattice cores of CFRP having pyramidal structure which assembled from a carbon fiber.

In view of transportation reduction in fuel consumption and improvement of safety in vehicle crashes are increasingly important along with the use of lightweight structural materials which offer appropriate impact behaviour constitutes one of the alternatives. Fibre metal laminates (FMLs) are multi-layered structures consisting of stacked metal sheets and composite thin plates, in which each constituent material is responsible for providing its best so that jointly a laminate with a good specific mechanical properties in 2024-T3 aluminium-based FML with more specific resistance and energy dissipation capacity under impact. By using filament winding machine continuous fibers can be oriented to match the direction and magnitude of stresses in a laminated structure, allowing optimal reinforcement loading.

Generally the mechanical properties of sandwich composites vary depending on the direction of the fiber arrangement; it is required to analyse them by use of an anisotropic theory. These composite materials are also usually constructed of thin layers, which may have different thickness and different +cross-ply angles. The cross-ply angle is the angle between major elastic axis of the material and reference axis. The variation in properties in the direction of the thickness implies non-homogeneity of the material and composite structures must thus be analysed according to theories, which allow for non-homogeneous anisotropic material behaviour. Some of the research work was done to evaluate the buckling load of thin FRP symmetric cross ply rectangular laminates with different orientations, which is subjected to uniaxial compression using finite-element method. The buckling load was evaluated by changing the parameters such as hole orientation, aspect ratio, thickness ratio, number of layers and boundary conditions. The effects of these five parameters are studied on buckling load. The results observed that the buckling load is more at hole orientation as 60 degrees and minimum at hole orientation as 30 degrees, decreases with the increase in an aspect ratio, decreases with an increase in the thickness ratio, increases from number of layer 4 to 12 and remains constant up to 20 . Application of lightweight materials is widely increased in aeronautical structures. Among these materials, foams with a significant weight saving have an important role, but their applications are limited by their low strength and modulus. The application of random-chopped sprayed FRP composites is impeded by the presence of voids, which are primarily formed by entrapped air in the composites and various volatile substances dissolved in the resin matrix which increases the mechanical characteristics and strengthening effectiveness.

Sandwich panels consisting of facesheets (above and below Al sheets) and glass fiber sheets of various materials have potential aeronautical applications due to their high stiffness/strength-to-weight ratio. Hexagonal honeycomb structures metallic sandwich panels are made of stochastic cores such as aluminium alloy foams. Recently many new metallic core topologies have emerged and for multifunctional purposes the combination of good properties makes it possible to fabricate sandwich structures. For lightweight attributes and potential applications, the interest in the sandwich panels with truss cores grew rapidly over the last decade. For load bearing applications, significant progress has been made recently in predicting and measuring the mechanical response of truss core sandwich structures. In this connection the selection of FRCSP is taken up with Aluminium sheet and glass fibre sheets as material and then fabricated.

1.1 Material Selection

The FRCSP is made as 90 degree orientation with 11 glass fibre layers and 2 aluminium layers to form sandwich panel. Initial and final layer is taken up as Al alloy. First Al sheet is placed and then the E-glass fibre is layed up as first level glass and then followed by unidirectional (UD), roven and Chopped strand mat (CSM). The aluminium used as Al6063-T6.

The properties of E-glass fibre are listed as tensile strength 2050MPa, Poisson ratio 0.23, Youngs Moduls 85GPa, Shear Modulus 36GPa and density 2.6 mg/m3. The chemical composition of E-glass fibre used is 54% SiO_2, 15%Al_2O_3 and 12% CaO.

The properties of Al6063-T6 are listed as tensile strength 241MPa, Poisson ratio 0.3, Youngs Moduls 68.9GPa, Shear Modulus 25.8GPa and density 2.7 mg/m^3.

1.2 Fabrication Process

In the fabrication process the layers of FRP is layed as Al sheet is taken up and on one of its side resin is applied then glass fibre is layed on it then applied resign again on other surface of the glass fibre layed up by roven then unidirectional fibre and then chopped strand fibre followed by Al sheet. The total number of layers layed up are 13. The first and last layers were Al alloy and in between the fibres were layed up. Then it is pressed and allowed for curing. The thicknesses followed for the materials used in the fabrication process are as follows: Aluminium-1.2, Glass-0.3, Roven-0.4, UD-1.1, CSM-0.75, Roven-0.4, UD-1.1, CSM-0.75, Roven-0.4, UD-1.1, CSM-0.75, Roven-0.4, Glass-0.3 and Aluminium-1.2.

The fabrication process steps were shown in the following figure:

(a) Sizing of aluminium sheet
(b) Epoxy mixing i.e., LY556=L12
(c) Hardener: HY951
(d) Mixture of Epoxy and Hardener
(e) Resin Applying on Al
(f) Layup process
(g) Last Layer of AL
(h) Cutting of Specimen
(i) Final Specimen.

Figure 1: Fabrication process of FRCSP

1.3 INTRODUCTION TO COMPOSITES

Mankind has been aware **composite materials** since several hundred years before Christ and applied innovation to improve the quality of life. Although it is not clear has to how Man understood the fact that mud bricks made sturdier houses if lined with straw, he used them to make buildings that lasted. Ancient Pharaohs made their slaves use bricks with to straw to enhance the structural integrity of their buildings, some of which testify to wisdom of the dead civilization even today.

Contemporary composites results from research and innovation from past few decades have progressed from glass fiber for automobile bodies to particulate composites for aerospace and a range other applications. Ironically, despite the growing familiarity with composite materials and ever-increasing range of applications, the term defines a clear definition. Loose terms like “materials composed of two or more distinctly identifiable constituents” are used to describe natural composites like timber, organic materials, like tissue surrounding the skeletal system, soil aggregates, minerals and rock. Composites that forms heterogeneous structures which meet the requirements of specific design and function, imbued with desired properties which limit the scope for classification. However, this lapse is made up for, by the fact new types of composites are being innovated all the time, each with their own specific purpose like the filled, flake, particulate and laminar composites. Fibers or particles embedded in matrix of another material would be the best example of modern-day composite materials, which are mostly structural. Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. Fabrics have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. Reinforcing materials generally withstand maximum load and serve the desirable properties. Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate definition, the accent is often shifted to the levels at which differentiation take place viz., microscopic or macroscopic. In matrix-based structural composites, the matrix serves two paramount purposes viz., binding the reinforcement phases in place and deforming to distribute the stresses among the constituent reinforcement materials under an applied force. The demands on matrices are many. They may need to temperature variations, be conductors or resistors of electricity, have moisture sensitivity etc. This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen. Solids that accommodate stress to incorporate other constituents provide strong bonds for the reinforcing phase are potential matrix materials. A few inorganic materials, polymers and metals have found. Applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic till failure occurs and show decreased failure strain, when loaded in tension and compression. Composites cannot be made from constituents with divergent linear expansion characteristics. The interface is the area of contact between the reinforcement and the matrix materials. In some cases, the region is a distinct added phase. Whenever there is interphase, there has to be two interphases between each side of the interphase and its adjoint constituent. Some composites provide interphases when surfaces dissimilar constituents interact with each other. Choice of fabrication method depends on matrix properties and the effect of matrix on properties of reinforcements. One of the prime considerations in the selection and fabrication of composites is that the constituents should be chemically inert non-reactive. Figure below helps to classify matrices.

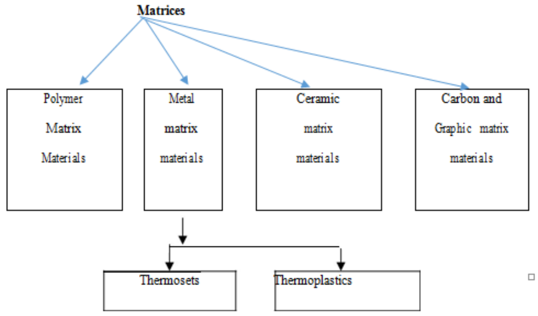

Figure: 2

1.3.1 Polymer Matrix Materials

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are thermosets and thermoplastics. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the chopped fiber composites form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins. elevated temperatures can reversed to regain its properties during cooling, facilitating applications of conventional compress techniques to mould the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The them of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the **morphology** to a considerable extent, prompting the reinforcement to empower nucleation. Whenever crystalline or amorphous, these resins possess the facility to alter their creep over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance.

A small quantum of shrinkage and the tendency of the shape to retain its original form are also to be accounted for. But reinforcements can change this condition too. The advantage of thermoplastics systems over thermosets are that there are no chemical reactions involved, which often result in the release of gases or heat. Manufacturing is limited by the time required for heating, shaping and cooling the structures.

Thermoplastics resins are sold as moulding compounds. Fiber reinforcement is apt for these resins. Since the fibers are randomly dispersed, the reinforcement will be almost isotropic. However, when subjected to moulding processes, they can be aligned directionally.

There are a few options to increase heat resistance in thermoplastics. Addition of fillers raises the heat resistance. But all thermoplastic composites tend loose their strength at elevated temperatures. However, their redeeming qualities like rigidity, toughness and ability to repudiate creep, place thermoplastics in the important composite materials bracket. They are used in automotive control panels, electronic products encasement etc.

Newer developments augur the broadening of the scope of applications of thermoplastics. Huge sheets of reinforced thermoplastics are now available and they only require sampling and heating to be moulded into the required shapes. This has facilitated easy fabrication of bulky components, doing away with the more cumbersome moulding compounds.

Thermosets are the most popular of the fiber composite matrices without which, research and development in structural engineering field could get truncated. Aerospace components, automobile parts, defense systems etc., use a great deal of this type of fiber composites. Epoxy matrix materials are used in printed circuit boards and similar areas.

kinds of thermosets:

- Thermoplastics
- Polyethylene
- Polystyrene
- Nylons
- Polypropylene

Polyamides Direct condensation polymerization followed by rearrangement reactions to form heterocyclic entities is the method generally used to produce thermoset resins. Water, a product of the reaction, in both methods, hinders production of void-free composites. These voids have a negative effect on properties of the composites in terms of strength and dielectric properties. Polyesters phenolic and Epoxies are the two important classes of thermoset resins.

Epoxy resins are widely used in filament-wound composites and are suitable for moulding prepress. They are reasonably stable to chemical attacks and are excellent adherents having slow shrinkage during curing and no emission of volatile gases. These advantages, however, make the use of epoxies rather expensive. Also, they cannot be expected beyond a temperature of 140ºC. Their use in high technology areas where service temperatures are higher, as a result, is ruled out.

Polyester resins on the other hand are quite easily accessible, cheap and find use in a wide range of fields. Liquid polyesters are stored at room temperature for months, sometimes for years and the mere addition of a catalyst can cure the matrix material within a short time. They are used in automobile and structural applications

The cured polyester is usually rigid or flexible as the case may be and transparent. Polyesters withstand the variations of environment and stable against chemicals. Depending on the formulation of the resin or service requirement of application, they can be used up to about 75ºC or higher. Other advantages of polyesters include easy compatibility with few glass fibers and can be used with verify of reinforced plastic accountrey.

Aromatic Polyamides are the most sought after candidates as the matrices of advanced fiber composites for structural applications demanding long duration exposure for continuous service at around 200-250ºC .

1.3.2 Metal Matrix Materials

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High strength, fracture toughness and stiffness are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix

- Thermosets
- Epoxy
- Phenolic polyamide
- resins
- Polyester

Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

1.3.3 Ceramic Matrix Materials

Ceramics can be described as solid materials which exhibit very strong ionic bonding in general and in few cases covalent bonding. High melting points, good corrosion resistance, stability at elevated temperatures and high compressive strength, render ceramic-based matrix materials a favourite for applications requiring a structural material that doesn't give way at temperatures above 1500ºC. Naturally, ceramic matrices are the obvious choice for high temperature applications.

High modulus of elasticity and low tensile strain, which most ceramics possess, have combined to cause the failure of attempts to add reinforcements to obtain strength improvement. This is because at the stress levels at which ceramics rupture, there is insufficient elongation of the matrix which keeps composite from transferring an effective quantum of load to the reinforcement and the composite may fail unless the percentage of fiber volume is high enough. A material is reinforcement to utilize the higher tensile strength of the fiber, to produce an increase in load bearing capacity of the matrix. Addition of high-strength fiber to a weaker ceramic has not always been successful and often the resultant composite has proved to be weaker.

The use of reinforcement with high modulus of elasticity may take care of the problem to some extent and presents pre-stressing of the fiber in the ceramic matrix is being increasingly resorted to as an option.

When ceramics have a higher thermal expansion coefficient than reinforcement materials, the resultant composite is unlikely to have a superior level of strength. In that case, the composite will develop strength within ceramic at the time of cooling resulting in microcracks extending from fiber to fiber within the matrix. Microcracking can result in a composite with tensile strength lower than that of the matrix.

1.3.4 Carbon Matrices

Carbon and graphite have a special place in composite materials options, both being highly superior, high temperature materials with strengths and rigidity that are not affected by temperature up to 2300ºC.

This carbon-carbon composite is fabricated through compaction of carbon or multiple impregnations of porous frames with liquid carboniser precursors and subsequent pyrolization. They can also be manufactured through chemical vapour deposition of pyrolytic carbon. Carbon-carbon composites are not be applied in elevated temperatures, as many composites have proved to be far superior at these temperatures. However, their capacity to retain their properties at room temperature as well as at temperature in the range of 2400ºC and their dimensional stability make them the oblivious choice in a garnut of applications related to aeronautics, military, industry and space.

Components, that are exposed to higher temperature and on which the demands for high standard performance are many, are most likely to have carbon-carbon composites used in them.

1.3.5 Glass Matrices

I n comparison to ceramics and even considered on their own merit, glass matrices are found to be more reinforcement-friendly. The various manufacturing methods of polymers can be used for glass matrices.

Glasses are meant to improve upon performance of several applications. Glass matrix composite with high strength and modulus can be obtained and they can be maintained upto temperature of the order of 650ºC.

Composites with glass matrices are considered superior in dimensions to polymer or metal system, due to the low thermal expansion behaviour. This property allows fabrication of many components in intricate shapes and their tribological characters are considered very special.

Since the elastic modulus of glass is far lower than of any prospective reinforcement materials, application of stress usually results in high elasticity modulus fiber that the tensile strength of the composite its considerably enhanced than that of the constituents, which is not case in ceramic matrices.

1.3.6 Reinforcements

Reinforcements for the composites can be fibers, fabrics particles or whiskers. Fibers are essentially characterized by one very long axis with other two axes either often circular or near circular. Particles have no preferred orientation and so does their shape. Whiskers have a preferred shape but are small both in diameter and length as compared to fibers. A reinforcement that embellishes the matrix strength must be stronger and stiffer than the matrix and capable of changing failure mechanism to the advantage of the composite. This means that the ductility should be minimum or even nil the composite must behave as brittle as possible.

1.3.7 Fiber Reinforcement

Fibers are the important class of reinforcements, as they satisfy the desired conditions and transfer strength to the matrix constituent influencing and enhancing their properties as desired.

Glass fibers are the earliest known fibers used to reinforce materials. Ceramic and metal fibers were subsequently found out and put to extensive use, to render composites stiffer more resistant to heat.

Fibers fall short of ideal performance due to several factors. The performance of a fiber composite is judged by its length, shape, orientation, composition of the fibers and the mechanical properties of the matrix.

The orientation of the fiber in the matrix is an indication of the strength of the composite and the strength is greatest along the longitudinal directional of fiber. This doesn't mean the longitudinal fibers can take the same quantum of load irrespective of the direction in which it is applied. Optimum performance from longitudinal fibers can be obtained if the load is applied along its direction. The slightest shift in the angle of loading may drastically reduce the strength of the composite.

Unidirectional loading is found in few structures and hence it is prudent to give a mix of orientations for fibers in composites particularly where the load is expected to be the heaviest.

Monolayer tapes consisting of continuous or discontinuous fibers can be oriented unidirectional stacked into plies containing layers of filaments also oriented in the same direction. More complicated orientations are possible too and nowadays, computers are used to make projections of such variations to suit specific needs. In short, in planar composites, strength can be changed from unidirectional fiber oriented composites that result in composites with nearly isotropic properties.

Properties of angle-plied composites which are not quasi-isotropic may vary with the number of plies and their orientations. Composite variables in such composites are assumed to have a constant ratio and the matrices are considered relatively weaker than the fibers. The strength of the fiber in any one of the three axes would, therefore be one-third the unidirectional fiber composite, assuming that the volume percentage is equal in all three axes.

However, orientation of short fibers by different methods is also possible like random orientations by sprinkling on to given plane or addition of matrix in liquid or solid state before or after the fiber deposition. Even three-dimensional orientations can achieved in this way.

There are several methods of random fiber orientations, which in a two-dimensional one, yield composites with one-third the strength of an unidirectional fiber-stressed composite, in the direction of fibers. In a 3-dimension, it would result in a composite with a comparable ratio, about less than one-fifth.

In very strong matrices, moduli and strengths have not been observed. Application of the strength of the composites with such matrices and several orientations is also possible. The longitudinal strength can be calculated on the basis of the assumption that fibers have been reduced to their effective strength on approximation value in composites with strong matrices and non-longitudinally orientated fiberss. It goes without saying that fiber composites may be constructed with either continuous or short fibers. Experience has shown that continuous fibers (or filaments) exhibit better orientation, although it does not reflect in their performance. Fibers have a high aspect ratio, i.e., their lengths being several times greater than their effective diameters. This is the reason why filaments are manufactured using continuous process. This finished filaments.

Mass production of filaments is well known and they match with several matrices in different ways like winding, twisting, weaving and knitting, which exhibit the characteristics of a fabric.

Since they have low densities and high strengths, the fiber lengths in filaments or other fibers yield considerable influence on the mechanical properties as well as the response of composites to processing and procedures. Shorter fibers with proper orientation composites that use glass, ceramic or multi-purpose fibers can be endowed with considerably higher strength than those that use continuous fibers. Short fibers are also known to their theoretical strength. The continuous fiber constituent of a composite is often joined by the filament winding process in which the matrix impregnated fiber wrapped around a mandrel shaped like the part over which the composite is to be placed, and equitable load distribution and favorable orientation of the fiber is possible in the finished product. However, winding is mostly confined to fabrication of bodies of revolution and the occasional irregular, flat surface.

Short-length fibers incorporated by the open- or close-mould process are found to be less efficient, although the input costs are considerably lower than filament winding.

Most fibers in use currently are solids which are easy to produce and handle, having a circular cross-section, although a few non-conventional shaped and hollow fibers show signs of capabilities that can improve the mechanical qualities of the composites.

Given the fact that the vast difference in length and effective diameter of the fiber are assets to a fiber composite, it follows that greater strength in the fiber can be achieved by smaller diameters due to minimization or total elimination of surface of surface defects.

After flat-thin filaments came into vogue, fibers rectangular cross sections have provided new options for applications in high strength structures. Owing to their shapes, these fibers provide perfect packing, while hollow fibers show better structural efficiency in composites that are desired for their stiffness and compressive strengths. In hollow fibers, the transverse compressive strength is lower than that of a solid fiber composite whenever the hollow portion is more than half the total fiber diameter. However, they are not easy to handle and fabricate.

1.3.8 Types of Fibers

Organic and inorganic fibers are used to reinforce composite materials. Almost all organic fibers have low density, flexibility, and elasticity. Inorganic fibers are of high modulus, high thermal stability and possess greater rigidity than organic fibers and not withstanding the diverse advantages of organic fibers which render the composites in which they are used.

Mainly, the following different types of fibers namely, glass fibers, silicon carbide fibers, high silica and quartz fibers, aluminina fibers, metal fibers and wires, graphite fibers, boron fibers, aramid fibers and multiphase fibers are used. Among the glass fibers, it is again classified into E-glass, A-glass, R-glass etc.

There is a greater marker and higher degree of commercial movement of organic fibers.

The potential of fibers of graphite, silica carbide and boron are also exercising the scientific mind due to their applications in advanced composites.

1.3.8.1 Glass fibers

Over 95% of the fibers used in reinforced plastics are glass fibers, as they are inexpensive, easy to manufacture and possess high strength and stiffness with respect to the plastics with which they are reinforced.

Their low density, resistance to chemicals, insulation capacity are other bonus characteristics, although the one major disadvantage in glass is that it is prone to break when subjected to high tensile stress for a long time.

However, it remains break-resistant at higher stress-levels in shorter time frames. This property mitigates the effective strength of glass especially when glass is expected to sustain loads for many months or years continuously.

Period of loading, temperature, moisture and other factors also dictate the tolerance levels of glass fibers and the disadvantage is further compounded by the fact that the brittleness of glass does not make room for prior warning before the catamorphic failure.

But all this can be easily overlooked in view of the fact the wide range of glass fiber variety lend themselves amicably to fabrication processes like matched die-moulding, filament winding lay-up and so on. Glass fibers are available in the form of mates, tapes, cloth, continuous and chopped filaments, roving and yarns.

Addition of chemicals to silica sand while making glass yields different types of glasses.

1.3.8.2 Metals fibers

As reinforcement, metal fibers have many advantages. They are easily produced using several fabrication processes and are more ductile, apart from being not too sensitive to surface damage and possess high strengths and temperature resistance. However, their weight and the tendency to react each other through alloying mechanisms are major disadvantages.

Ceramic fibers improve vastly in performance when a fine metal outline is incorporated with refractory ceramics by improving their thermal shock and impact resistance properties.

Metal wires, of the continuous version, also reinforce plastics like polyethylene and epoxy. Such combinations ensure high strength, light weight and good fatigue resistance.

Besides, continuous metal fibers are easily handled, unlike glass fibers. Better flexural properties are observed in some metal fibers reinforced plastic composites which also offer improved strength and weight, than glass fibers.

However, their poor tolerance of high temperature and the resultant steep variations of thermal expansion coefficient with the resins are a discouragement that limits their their application.

1.3.8.3 Alumina Fibers

Alumina aluminium oxide fibers, basically developed for use in metal matrices are considered a potential resin-matrix composite reinforcement. It offers good compressive strength rather than tensile strength. It’s important property is it’s high melting point of about 2000ºC and the composite can be successfully used at temperature up to about 1000ºC. Magnesium and aluminum matrices frequently use alumina fiber reinforced composites as they do not damage the fiber even in the liquid state.

1.3.8.4 Boron Fibers

They are basically composites, in which boron is coated on a substance which forms the substrate, usually made of tungsten.

Boron-tungsten fibers are obtained by allowing hot tungsten filament through a mixture of gases. Boron is deposited on tungsten and the process continued until the thickness is achieved. The tungsten however remains constant in its thickness. Properties of boron fibers generally change with the diameter, because of the changing ratio of boron to tungsten and the surface defects that change according to size. However, they are known for their remarkable stiffness and strength. Their strengths often compare with those of glass fibers, but their tensile modulus is high, almost four to five that of glass. Boron coated carbons are much cheaper to make than boron tungsten fiber. But is low modulus of elasticity often works against it.

1.3.8.5 Silicon Carbide fibers

Silicon carbide can be coated over a few metals and their room temperature tensile strengths and tensile moduli are like those boron-tungsten. The advantages of silicon carbide-tungsten are several and are more desirable than uncoated boron tungsten fibers. Elevated temperature performance and the fact that they reported only a 35% loss of strength at 1350ºC are their best qualities. Silicon carbide-tungsten and silicon carbide-carbon have both been seen to have very high stress-rupture strength at 1100ºC and 1300ºC. Uncoated boron-tungsten fibers do not react with molten aluminum, unlike uncoated boron and they also withstand high temperatures used in hot-press titanium matrices.

However, Silicon carbide-tungsten fibers are dense compared to boron-tungsten fibers of the same diameters. They are prone to surface damage and need careful, delicate handling, especially during fabrication of the composite. Further, above 930ºC weakening reactions occur between tungsten and silicon carbide, making it different to maintain balance in high-temperature matrix formations.

Silicon carbide on carbon substrates have several advantages, viz. no reaction at high temperature, being lighter than silicon carbide tungsten and possessing tensile strengths and modulus that is are often better than those of silicon carbide-tungsten and boron fibers.

1.3.8.6 Aramid Fibers

Aramid fibers are made aromatic polyamides which are long polymeric chains and aromatic rings. They are structures in which six carbon s\atoms are bonded to each other and to combinations of hydrogen atoms. In aramid fibers, these rings occur and reoccur to form the fibers. They were initially used to reinforce automobile tires. Since then, they have also found other uses like bullet proof vests. As high strength applications, their use in power boats is not uncommon.

Aramids have high tensile strength, high modulus and low weight. Impact-resistant structures can be produced from aramids. The density of aramid fibers is less than that of glass and graphite fibers. They are fire resistant apart from being high-temperature resistant and unaffected by organic solvents fuels. But their resistance in acid and alkaline media is poor. They are supple and allow themselves to be woven into matrices by simple processes. Aramid fibers have a negative coefficient of thermal expansion in the fiber direction and failure of aramid fibers is unique. When they fail, the fibers break into small fibers, which are like fibers within the fibers. This unique failure mechanism is responsible for high strength.

1.3.8.7 Quartz and Silica Fibers

The glass-types typically contain about 50 to 70% silica. Silica glass is a purer glass fiber that can be made by treating fiberglass in an acid bath, which removes all impurities without affecting the silica. The final product contains 93 to 99% silica. Quartz is even more pure, and quartz fibers are made from natural quartz crystals that contain 99.9% silica, possessing nearly all the properties of pure solid quartz.

Ordinary fiberglass, high silica and quartz fibers share several characteristics and can be produced in a range of fiber diameter. Roving or yarns and other forms of fibers can be made from high silica as well as quartz too.

They differ from glass in many factors, however, especially in heat-related properties.

Although quartz crystals are commonly available, pure crystals are hard to come by. On the other hand, high silica comes from the same material as glass fibers and is easily accessible. However, quartz makes up for its rarity with its capacity to withstand high temperatures, which silica is incapable of.

Barring this difference, silica and quartz are similar in other respects. They are highly elastic and can be stretched to 1% of their length before break point. Both silica and quartz are not affected by acid attacks and are resistant to moisture.

Owing to their thermal properties, silica and quartz are the natural choice as fibers in several applications. They have good insulting properties and do not melt at temperature up to 1600ºC.

In addition, they have a low thermal expansion coefficient which makes them withstand high temperatures.

1.3.8.8 Graphite Fibers

While use of the term carbon for graphite is permissible, there is one basic difference between the two. Element analysis of poly-acrylo-nitrile (PAN) base carbon fibers show that they consist of 91 to 94% carbon. But graphite fibers are over 99% carbon. The difference arises from the fact that the fibers are made at different temperatures.

PAN-based carbon cloth or fiber is produced at about 1320ºC, while graphite fibers and cloth are graphitised at 1950 to 3000ºC.

The properties of graphite remain unchanged even at high temperatures, but its willingness to react readily with most metals at the fabrication stage or during use at very high temperatures is often a stumbling block, as seen in aluminium matrices when carbides are produced at the interface. These carbides react with moisture with disastrous effects on the composite material.

Graphite fibers are some of the stiffer fibers known. The stiffness of the fiber is as high as the graphite content. But a major drawback is that stiffness and strength are inversely proportional to each other.

Forbidding costs make the use of graphite fibers prohibitive. The best glass fibers are far less expensive than the cheapest, lowest quality of graphite, and in PAN-base fibers, other raw materials too are equally expensive. The carbonization and graphitisation are time-consuming, apart from demanding excessive energy, materials and close controls throughout the process.

Cheaper pitch base fiber are now being developed, with greater performance potential and there are possibilities of the increased use of graphite fibers.

1.3.8.9 Multiphase Fibers

Spoolable filaments made by chemical vapour deposition processes are usually the multiphase variety and they usually comprise materials like boron, silicon and their carbides formed on surface of a very fine filament substrate like carbon or tungsten. They are usually good for high temperature applications, due to their reduced reaction with higher melting temperature of metals than graphite and other metallic fibers. Boron filaments are sought after for structural and intermediate-temperature composites.

A poly-phase fiber is a core-sheath fiber consisting of a poly-crystalline core.

1.3.9 Whiskers

Single crystals grown with nearly zero defects are termed whiskers. They are usually discontinuous and short fibers of different cross sections made from several materials like graphite, silicon carbide, copper, iron etc. Typical lengths are in 3 to 55 N.M. ranges. Whiskers differ from particles in that, whiskers have a definite length to width ratio greater than one. Whiskers can have extraordinary strengths upto 7000 MPa.

Whiskers were grown quite incidentally in laboratories for the first time, while nature has some geological structures that can be described as whiskers. Initially, their usefulness was overlooked as they were dismissed as incidental by-products of other structure. However, study on crystal structures and growth in metals sparked off an interest in them, and also the study of defects that affect the strength of materials, they came to be incorporated in composites using several methods, including power metallurgy and slip-casting techniques.

Metal-whisker combination, strengthening the system at high temperatures, has been demonstrated at the laboratory level. But whiskers are fine, small sized materials not easy to handle and this comes in the way of incorporating them into engineering materials to come out with a superior quality composite system.

Early research has shown that whisker strength varies inversely with effective diameter. When whiskers were embedded in matrices, whiskers of diameter upto 2 to 10µm yielded fairly good composites.

Ceramic material's whiskers have high moduli, useful strengths and low densities. Specific strength and specific modulus are very high and this makes ceramic whiskers suitable for low weight structure composites. They also resist temperature, mechanical damage and oxidation more responsively than metallic whiskers, which are denser than ceramic whiskers. However, they are not commercially viable because they are damaged while handling.

1.3.10 Laminar Composites

Laminar composites are found in as many combinations as the number of materials. They can be described as materials comprising of layers of materials bonded together. These may be of several layers of two or more metal materials occurring alternately or in a determined order more than once, and in as many numbers as required for a specific purpose.

Clad and sandwich laminates have many areas as it ought to be, although they are known to follow the rule of mixtures from the modulus and strength point of view. Other intrinsic values pertaining to metal-matrix, metal-reinforced composites are also fairly well known.

Powder metallurgical processes like roll bonding, hot pressing, diffusion bonding, brazing and so on can be employed for the fabrication of different alloys of sheet, foil, powder or sprayed materials. It is not possible to achieve high strength materials unlike the fiber version. But sheets and foils can be made isotropic in two dimensions more easily than fibers. Foils and sheets are also made to exhibit high percentages of which they are put. For instance, a strong sheet may use over 92% in laminar structure, while it is difficult to make fibers of such compositions. Fiber laminates cannot over 75% strong fibers.

The main functional types of metal-metal laminates that do not posses high strength or stiffness are single layered ones that endow the composites with special properties, apart from being cost-effective. They are usually made by pre-coating or cladding methods.

Pre-coated metals are formed by forming by forming a layer on a substrate, in the form of a thin continuous film. This is achieved by hot dipping and occasionally by chemical plating and electroplating. Clad metals are found to be suitable for more intensive environments where denser faces are required.

There are many combinations of sheet and foil which function as adhesives at low temperatures. Such materials, plastics or metals, may be clubbed together with a third constituent. Pre-painted or pre-finished metal whose primary advantage is elimination of final finishing by the user is the best known metal-organic laminate. Several combinations of metal-plastic, vinyl-metal laminates, organic films and metals, account for upto 95% of metal-plastic laminates known. They are made by adhesive bonding processes.

1.3.11. Flake Composites

Flakes are often used in place of fibers as can be densely packed. Metal flakes that are in close contact with each other in polymer matrices can conduct electricity or heat, while mica flakes and glass can resist both. Flakes are not expensive to produce and usually cost less than fibers.

But they fall short of expectations in aspects like control of size, shape and show defects in the end product. Glass flakes tend to have notches or cracks around the edges, which weaken the final product. They are also resistant to be lined up parallel to each other in a matrix, causing uneven strength. They

are usually set in matrices, or more simply, held together by a matrix with a glue-type binder. Depending on the end-use of the product, flakes are present in small quantities or occupy the whole composite.

Flakes have various advantages over fibers in structural applications. Parallel flakes filled composites provide uniform mechanical properties in the same plane as the flakes. While angle-plying is difficult in continuous fibers which need to approach isotropic properties, it is not so in flakes. Flake composites have a higher theoretical modulus of elasticity than fiber reinforced composites. They are relatively cheaper to produce and be handled in small quantities.

1.3.12 Filled Composites

Filled composites result from addition of filer materials to plastic matrices to replace a portion of the matrix, enhance or change the properties of the composites. The fillers also enhance strength and reduce weight.

Another type of filled composite is the product of structure infiltrated with a second-phase filler material. The skeleton could be a group of cells, honeycomb structures, like a network of open pores. The infiltrant could also be independent of the matrix and yet bind the components like powders or fibers, or they could just be used to fill voids. Fillers produced from powders are also considered as particulate composite.

In the open matrices of a porous or spongy composite, the formation is the natural result of processing and such matrices can be strengthened with different materials. Metal impregnates are used to improve strength or tolerance of the matrix. Metal casting, graphite, powder metallurgy parts and ceramics belong to this class of filled composites.

In the honeycomb structure, the matrix is not naturally formed, but specifically designed to a predetermed shape. Sheet materials in the hexagonal shapes are impregnated with resin or foam and are used as a core material in sandwich composites.

Fillers may be the main ingredient or an additional one in a composite. The filler particles may be irregular structures, or have precise geometrical shapes like polyhedrons, short fibers or spheres.

While their purpose is far from adding visual embellishment to the composites, they occasionally impart colour or opacity to the composite which they fill.

As inert additives, fillers can change almost any basic resin characteristic in all directions required, to tide over the many limitations of basic resins as far as composites are concerned. The final composite properties can be affected by the shape, surface treatment, blend of particle types, size of the particle in the filler material and the size distribution.

Filled plastics tend to behave like two different constituents. They do not alloy and accept the bonding. They are meant to develop mutually; they desist from interacting chemically with each other. It is vital that the constituents remain in co-ordination and do not destroy each others desired properties.

Matrix in a few filled composites provides the main framework while the filler furnishes almost all desired properties. Although the matrix forms the bulk of the composite, the filler material is used in such great quantities relatively that it becomes the rudimentary constituent.

The benefits offered by fillers include increase stiffness, thermal resistance, stability, strength and abrasion resistance, porosity and a favorable coefficient of thermal expansion.

However, the methods of fabrication are very limited and the curing of some resins is greatly inhibited. They also shorten the life span of some resins and are known to weaken a few composites.

1.3.13 Particulate Reinforced Composites

Microstructures of metal and ceramics composites, which show particles of one phase strewn in the other, are known as particle reinforced composites. Square, triangular and round shapes of reinforcement are known, but the dimensions of all their sides are observed to be more or less equal. The size and volume concentration of the dispersoid distinguishes it from dispersion hardened materials.

The dispersed size in particulate composites is of the order of a few microns and volume concentration is greater than 28%. The difference between particulate composite and dispersion strengthened ones is, thus, oblivious. The mechanism used to strengthen each of them is also different. The dispersed in the dispersion-strengthen materials reinforces the matrix alloy by arresting motion of dislocations and needs large forces to fracture the restriction created by dispersion.

In particulate composites, the particles strengthen the system by the hydrostatic coercion of fillers in matrices and by their hardness relative to the matrix.

Three-dimensional reinforcement in composites offers isotropic properties, because of the three systematical orthogonal planes. Since it is not homogeneous, the material properties acquire sensitivity to the constituent properties, as well as the interfacial properties and geometric shapes of the array. The composite's strength usually depends on the diameter of the particles, the inter-particle spacing, and the volume fraction of the reinforcement. The matrix properties influence the behaviour of particulate composite too.

1.3.14 Cermets

Cermets are one of the premier groups of particle strengthened composites and usually comprises ceramic grains of borides, carbides or oxides. The grains are dispersed in a refractory ductile metal matrix, which accounts for 20 to 85% of the total volume. The bonding between ceramic and metal constituents is the result of a small measure of mutual solutions.

Metal oxide systems show poor bonding and require additional bonding agents. Cermet structures are usually produced using power metallurgy techniques. Their potential properties are several and varied depending on the relative volumes and compositions and of the metal and ceramic constituents. Impregnation of a porous ceramic structure with a metallic matrix binder is another method used to produce cermets. Cermets may be employed as coating in a power form. The power is sprayed through a gas flame and fused to a base material. A wide variety of cermets have been produced on a small scale, but only a few have appreciable value commercially.

1.3.15 Microspheres

Microspheres are considered to be some of the most useful fillers. Their specific gravity, stable particle size, strength and controlled density to modify products without compromising on profitability or physical properties are its their most-sought after assets.

Solid glass Microspheres, manufactured from glass are most suitable for plastics. Solid glass Microspheres are coated with a binding agent which bonds itself as well as the sphere's surface to the resin. This increases the bonding strength and basically removes absorption of liquids into the separations around the spheres.

Solid Microspheres have relatively low density, and therefore, influence the commercial value and weight of the finished product. Studies have indicated that their inherent strength is carried over to the finished moulded part of which they form a constituent.

Hollow microspheres are essentially silicate based, made at controlled specific gravity. They are larger than solid glass spheres used in polymers and commercially supplied in a wider range of particle sizes. Commercially, silicate-based hollow microspheres with different compositions using organic compounds are also available. Due to the modification, the microspheres are rendered less sensitive to moisture, thus reducing attraction between particles. This is very vital in highly filled liquid polymer composites where viscosity enhancement constraints the quantum of filler loading.

Formerly, hollow spheres were mostly used for thermosetting resin systems. Now, several new strong spheres are available and they are at least five times stronger than hollow microspheres in static crush strength and four times long lasting in shear.

Recently, ceramic alumino silicate microspheres have been introduced in thermoplastic systems. Greater strength and higher density of this system in relation to siliceous microspheres and their resistance to abrasions and considerable strength make then suitable for application in high pressure conditions.

Hollow microspheres have a lower specific gravity than the pure resin. This makes it possible to use them for lightning resin dominant compounds. They find wide applications in aerospace and automotive industries where weight reduction for energy conservation is one of the main considerations.

But their use in systems requiring high shear mixing or high-pressure moulding is restricted as their crush resistance is in no way comparable to that of solid spheres. Fortunately, judicious applications of hollow spheres eliminate crazing at the bends in the poly-vinyl chloride plastisol applications, where the end component is subjected to bending stresses.

Microspheres, whether solid or hollow, show properties that are directly related to their spherical shape let them behave like minute ball bearing, and hence, they give better flow properties. They also distribute stress uniformly throughout resin matrices.

In spherical particles, the ratio of surface area to volume is minimum. In resin-rich surfaces of reinforced systems, the microspheres which are free of orientation and sharp edges are capable of producing smooth surfaces.

1.3.16 Solidification of Composites

Directional solidification of alloys is adopted to produce in-situ fibers. They are really a part of the alloy being precipitated from the melt, while the alloy is solidifying. This comprises eutectic alloys wherein the molten material degenerates to form many phases at a steady temperature. When the reaction is carried out after ensuring the solidifying phases, directionally solidified eutectics result.

During the solidification of alloy, crystals nucleate from the mould or some relatively cooler region. A structure with many crystalline particles or grains results from this and grows into each other. When unidirectionallly solidified, random coalescing is not allowed to occur.

1.4 CLASSIFICATION OF COMPOSITES

1.4.1 Classification

Composite materials are commonly classified at following two distinct levels:

- The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.
- The second level of classification refers to the reinforcement form - fibre reinforced composites, laminar composites and particulate composites. Fibre reinforced composites can be further divided into those containing discontinuous or continuous fibres.
- Fibre Reinforced Composites are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.
- Laminar Composites are composed of layers of materials held together by matrix. Sandwich structures fall under this category.
- Particulate Composites are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category.

1.4.2 COMPARISON WITH METALS

Requirements governing the choice of materials apply to both metals and reinforced plastics. It is, therefore, imperative to briefly compare main characteristics of the two.

- Composites offer significant weight saving over existing metals. Composites can provide structures that are 25-45% lighter than the conventional aluminium structures designed to meet the same functional requirements. This is due to the lower density of the composites.

Depending on material form, composite densities range from 1260 to 1820 kg/in3 (0.045 to 0.065 lb/in3) as compared to 2800 kg/in3 (0.10 lb/in3) for aluminium. Some applications may require thicker composite sections to meet strength/stiffness requirements, however, weight savings will still result.

- Unidirectional fibre composites have specific tensile strength (ratio of material strength to density) about 4 to 6 times greater than that of steel and aluminium.
- Unidirectional composites have specific -modulus (ratio of the material stiffness to density) about 3 to 5 times greater than that of steel and aluminium.
- Fatigue endurance limit of composites may approach 60% of their ultimate tensile strength. For steel and aluminium, this value is considerably lower.

- Fibre composites are more versatile than metals, and can be tailored to meet performance needs and complex design requirements such as aero-elastic loading on the wings and the vertical & the horizontal stabilisers of aircraft.
- Fibre reinforced composites can be designed with excellent structural damping features. As such, they are less noisy and provide lower vibration transmission than metals.
- High corrosion resistance of fibre composites contributes to reduce life- cycle cost.
- Long term service experience of composite material environment and durability behavior is limited in comparison with metals.

2 . Basic Constituent materials in Composites

2.1 Matrix Materials

2.1.1 Introduction

Although it is undoubtedly true that the high strength of composites is largely due to the fibre reinforcement, the importance of matrix material cannot be underestimated as it provides support for the fibres and assists the fibres in carrying the loads. It also provides stability to the composite material. Resin matrix system acts as a binding agent in a structural component in which the fibres are embedded. When too much resin is used, the part is classified as resin rich. On the other hand if there is too little resin, the part is called resin starved. A resin rich part is more susceptible to cracking due to lack of fibre support, whereas a resin starved part is weaker because of void areas and the fact that fibres are not held together and they are not well supported.

2.1.2 Functions of a Matrix

In a composite material, the matrix material serves the following functions:

- Holds the fibres together.
- Protects the fibres from environment.
- Distributes the loads evenly between fibres so that all fibres are subjected to the same amount of strain.
- Enhances transverse properties of a laminate.
- Improves impact and fracture resistance of a component.
- Helps to avoid propagation of crack growth through the fibres by providing alternate failure path along the interface between the fibres and the matrix.
- Carry interlaminar shear.

The matrix plays a minor role in the tensile load-carrying capacity of a composite structure. However, selection of a matrix has a major influence on the interlaminar shear as well as in-plane shear properties of the composite material. The interlaminar shear strength is an important design consideration for structures under bending loads, whereas the in-plane shear strength is important under torsion loads. The matrix provides lateral support against the possibility of fibre buckling under compression loading, thus influencing to some extent the compressive strength of the composite material. The interaction between fibres and matrix is also important in designing damage tolerant structures. Finally, the processability and defects.

2.1.3 Properties of a Matrix

The needs or desired properties of the matrix which are important for a composite structure are as follows:

- Reduced moisture absorption.
- Low shrinkage.
- Low coefficient of thermal expansion.
- Good flow characteristics so that it penetrates the fibre bundles completely and eliminates voids during the compacting/curing process
- Reasonable strength, modulus and elongation (elongation should be greater than fibre).
- Must be elastic to transfer load to fibres.
- Strength at elevated temperature (depending on application).
- Low temperature capability (depending on application).
- Excellent chemical resistance (depending on application).
- Should be easily processable into the final composite shape.
- Dimensional stability (maintains its shape).

As stated above, the matrix causes the stress to be distributed more evenly between all fibres by causing the fibres to suffer the same strain. The stress is transmitted by shear process, which requires good bonding between fibre and matrix and also high shear strength and modulus for the matrix itself. One of the important properties of cured matrix system is its glass transition temperature (Tg) at which the matrix begins to soften and exhibits a decrease in mechanical properties. The glass transition temperature is not only an important parameter for dimensional stability of a composite part under influence of heat, but it also has effect on most of the physical properties of the matrix system at ambient temperature.

As the load is primarily carried by the fibres, the overall elongation of a composite material is governed by the elongation to failure of the fibres that is usually 1-1.5%. A significant property of the matrix is that it should not crack. The function of the matrix in a composite material will vary depending on how the composite is stressed. For example, in case of compressive loading, the matrix prevents the fibres from buckling and is, therefore, a very critical part of the composite since without it, the reinforcement could carry no load. On the contrary, a bundle of fibres could sustain high tensile loads in the direction of the filaments without a matrix. Some of the physical properties of the matrix which influence the behaviour of composites are:

- Shrinkage during cure,
- Modulus of elasticity,
- Ultimate elongation,
- Strength (tensile, compressive and shear), and
- Fracture toughness.

The fibres are saturated with a liquid resin before it cures to a solid. The solid resin is then said to be the matrix for the fibres.

2.1.4 General types of Matrix Materials

In general, following general following types of matrix materials are available:

- Thermosetting material;
- Thermoplastic material;
- Carbon;
- Metals;
- Ceramics;
- Glass Matrix.

A thermosetting material is the one which when cured by heat or chemical reaction is changed into an infusible and insoluble material. Thermosetting resins undergo irreversible chemical cross-linking reaction upon application of heat. On the other hand, thermoplastics do not undergo a chemical reaction on application of heat. They simply melt on application of heat and pressure to form a component. Thermoplastics can be softened and they undergo large and rapid change in viscosity with variation in temperature. Thermoplastics can be repeatedly softened by heating and hardened by cooling.

Some of the significant differences between thermosets and thermoplastics are given below:

TABLE 1

Thermosets	**Thermoplastics**
Resin cost is low.	Resin cost is slightly higher.
Thermosets exhibit moderate shrinkage.	Shrinkage of thermoplastics is low
Interlaminar fracture toughness is low.	Interlaminar fracture toughness is high.
Thermosets exhibit good resistance	Thermoplastics exhibit poor resistance

2.1.4.1 Thermosetting Materials

The major group of materials used today in the aircraft industry contains thermosetting matrix resins.

Thermoset Resin

Polyesters, epoxy and other resins in liquid form contain monomers (consisting of simple molecules), which convert into polymers (complex cross-linked molecules) when the resin is cured. The resulting solid .is called thermosets, which is tough, hard, insoluble and infusible. The property of infusibility distinguishes thermosets from the thermoplastics. Cure and polymerisation refer to the chemical reactions that solidify the resin. Curing is accomplished by heat, pressure and by addition of curing agents at room temperature.

Thermosetting materials can be further divided into two groups depending on how they react to form their network structure. For example, epoxies and polyesters react to form a network structure without formation of a volatile by-product. Phenolics react to form a volatile by-product i.e., water. The fact that some thermosets form volatile by-products means that high pressure laminating techniques must be used to prevent the formation of voids or other defects. Epoxies and polyesters can be cured at atmospheric pressures and also at ambient temperatures.

Polyester matrices have been in use for the longest period in the widest range of structures. Polyesters cure with the addition of a catalyst (usually a peroxide) resulting in an exothermic reaction, which can be initiated at room temperature. The most widely used matrices for advanced composites have been the epoxy resins. These resins cost more than polyesters and do not have the high temperature capability of the Bismaleimides or Polyimides. However, they are widely used due to the following advantages.

- No by-products formed during cure;
- Low shrinkage during cure;
- High or low strength and flexibility;
- Resistance to solvents and chemicals;
- Resistance to creep and fatigue;
- Wide range of curative options;
- Adjustable curing rate;
- Good electrical properties.

Epoxies do have few inherent disadvantages also, viz.

- Resins and curatives are somewhat toxic in uncured form;
- Moisture absorption resulting into change in dimensions and physical properties;
- Limited to about 200°C (392°F) upper temperature use;
- Difficult to combine toughness and high temperature resistance;
- High thermal coefficient of expansion;
- High degree of smoke liberation in a fire;
- May be sensitive to ultraviolet light degradation;
- Slow curing.

There are two resin systems in common use for higher temperatures, bismaleimides and polyimides. New designs of aircraft demand a 177°C (350°F) operating temperature requirement not met with by other common structural resin systems. Bismaleimides, with higher modulus values and established higher thermal ratings, earned a strong position for use in military aircraft primary structures with recent selection for the F-22 fighter. Bismaleimides offer mechanical properties higher than those of epoxies at elevated temperature resulting in either lower weight or increased safety margins; epoxy-like processing using standard autoclave cure processes; and cost comparable to epoxy parts.

Polyimides are the highest temperature polymers in advanced composite use with a long-term upper temperature limit (Tg) of 232°C (450°F) or 316°C (600°F).

The Cyanate ester resins have shown superior dielectric properties and much lower moisture absorption than any other structural resin for use in composites. The dielectric properties have enabled their use as adhesives in multilayer microwave printed circuit boards and the low moisture absorbance have caused them to be the resin of universal choice for structurally stable spacecraft components. The phenolic triazine resins also have superior elevated temperature properties along with excellent properties at cryogenic temperature. Both Bismaleimide and Cyanate ester resins have been evolved as easy-to-process thermosetting resins qualified for 177°C (350°F) hot-wet service. Vinyl ester resins are the most recent addition to the family of thermosetting polymers. There are two basic types of vinyl esters having commercial significance, viz., the general-purpose lower molecular weight vinyl esters and the higher heat resistant vinyl esters. General-purpose vinyl esters have excellent mechanical properties and outstanding chemical resistance to acids, bases and many solvents. Heat resistant vinyl esters increase the heat resistance of composites by 17-27°C (30-50°F) over the general-purpose type. This often translates into higher useful operating temperatures for vinyl esters based reinforced plastics even in corrosive environment. Resins of this type are more reactive and more caution is required in fabrication of composite laminates.

2.1.4.2 Typical Properties of Thermosetting Materials

2.1.4.2.1 Phenolics

- Low cost,
- Capability to be B-Staged,
- Excellent high temperature resistance up to 205-260°C (400-500°F),
- Good mechanical strength,
- Dimensional and thermal stability,
- Good laminate properties,
- Hot molding (cold molding very rarely),
- Good fire resistance and very low smoke emission,
- Curing temperature is 175°C (350°F),
- High chemical resistance, and
- Good dielectric properties. Some of the disadvantages are: by-products are produced during curing, there is high shrinkage on cure, and phenolic laminates are porous.

2.1.4.2.2 Polyesters

- Low cost,
- Good handling characteristics,
- Low viscosity and versatility,
- Good mechanical strength,
- Good electrical properties,
- Good heat resistance,
- Cold and hot molding,
- Flame resistant with fire proof additive ,and
- Curing temperature is 120°C (250°F).

Some of the disadvantages are: interlaminar shear is less than that of epoxies, lower strength than that of epoxies, fair weatherability, high curing shrinkage, and poor chemical resistance.

2.1.4.2.3 Vinyl Ester

- Vinyl ester combines inherent toughness with outstanding heat and chemical resistance,
- Corrosion-resistance, and
- Possesses low ester content and low unsaturation resulting in greater resistance to hydrolysis and less shrinkage during cure. Some of the disadvantages are: vinyl esters are not as good as epoxy resins with regard to bondability to other surfaces and high cost. 2.1.4.2.4 Polyimides
- Excellent strength retention for long term in 260-315°C (500-600°F) range and short term in 370°C (700°F) range,
- Excellent electrical properties,
- Excellent mechanical strength,
- Good fire resistance and low smoke emission,
- Hot molding under pressure, and
- Curing temperature is 175°C (350°F) and 315°C (600°F). Some of the disadvantages are: laminates are porous, volatile by-products are given off during cure, and long post cure is required

2.1.4.2.4 Epoxies

- Make an excellent matrix material because of their versatility,
- Good handling characteristics,
- Low shrinkage,
- Excellent adhesive properties,
- Flame resistant,
- Good chemical resistance,
- Good mechanical properties including toughness,
- Offer considerable variety for formulating Prepreg resins,
- Hot molding (cold molding rarely),
- High smoke emission,
- Curing temperature is 120-175°C (250-3500F), and
- No by-products formed during cure.

Some of the disadvantages are: require 4.4°C (40°F) storage and shipment, service temperature is only 93-1O7°C (200-225°F) and laminate displays light brittleness.

2.1.4.2.5 Bismaleimide

- Superior to epoxy in maximum hot-wet use temperature.
- In comparison to conventional epoxies, bismaleimides have higher temperature resistance.
- Damage tolerance is generally comparable to that of commercial aerospace epoxy resins.

One factor that limits wider use of Bismaleimide is that they require higher curing temperatures than used for epoxies.

2.1.4.3 Thermoplastic Resin

As stated earlier, thermoplastics can be repeatedly softened by heating, and hardened by cooling. Thermoplastics possess several advantages over the thermosets, one of the most. important being that they do not need storing under refrigeration. They also possess improved damage tolerance, environmental resistance, fire resistance, recyclability and potential for fast processing. Primary reason for the use of thermoplastics is their cost effective processing. Increased use for thermoplastics is also due to three different reasons, viz.

- First - Processing can be faster than that of thermoset composites since no curing reaction is required. Thermoplastic composites require only heating, shaping and cooling.
- Second - The properties are attractive, in particular, high delamination resistance and damage tolerance, low moisture absorption and the excellent chemical resistance of semi-crystalline polymers.
- Third- In the light of environmental concerns, thermoplastic composites offer other advantages also. They have low toxity since they do not contain reactive chemicals (therefore storage life is infinite).

Because it is possible to remelt and dissolve thermoplastics, their composites are also easily recycled or combined with other recycled materials in the market for molding compounds. Since the release of gases during processing and inherent brittleness is serious disadvantage of some thermoset resins, thermoplastic composites are of great interest. Thermoplastics usually require high temperature and pressure during processing and generally lack good solvent resistance. Process conditions for high performance thermoplastics are temperature in the range of 300 to 400°C (570 to 750°F) and pressure between atmospheric pressure for thermofolding process to 20 times the atmospheric pressure for high performance press forming. Due to their high strains to failure, thermoplastics are the only matrices currently available that are suited to thermo-forming and other forms of rapid manufacture.

Thermo-loading is the most straight forward thermoplastic forming technique where a straight line is heated and folded. The process is used in volume applications like aircraft floor boards. Thermofolding operations can be carried out on solid laminate materials as well as on sandwich panels.

Press forming process for thermoplastic composites is related to that used for metals, the difference being that the blank material is heated to a high temperature and processed within a very short time span. Applications for press forming are reinforcement ribs.

Composites have ranged from small, simple, structural details such as ribs or spars up to relatively large structure.

Table given below lists some of these applications in aircraft industry.

Table 2

Polymer Type	Applications
• PEEK	• Airbus A320 vertical stabilizer brackets • EH-101 helicopter floor • F-117 rudder assembly • F-22 weapons bay doors • F-22 access covers • OH-58d helicopter horizontal stab
• Poly-phenylene-sulphide	• Airbus A320-200 rudder nose ribs • Airbus A340 aileron ribs

2.1.4.4 Thermosetting Materials

The major group of materials used today in the aircraft industry contains thermosetting matrix resins.

Thermoset Resin

Polyesters, epoxy and other resins in liquid form contain monomers (consisting of simple molecules), which convert into polymers (complex cross-linked molecules) when the resin is cured. The resulting solid .is called **thermosets**, which is tough, hard, insoluble and infusible. The property of infusibility distinguishes thermosets from the thermoplastics. Cure and **polymerisation** refer to the chemical reactions that solidify the resin. Curing is accomplished by heat, pressure and by addition of curing agents at room temperature.

Thermosetting materials can be further divided into two groups depending on how they react to form their network structure. For example, epoxies and polyesters react to form a network structure without formation of a volatile by-product. Phenolics react to form a volatile by-product i.e., water. The fact that some thermosets form volatile by-products means that high pressure laminating techniques must be used to prevent the formation of voids or other defects. Epoxies and polyesters can be cured at atmospheric pressures and also at ambient temperatures.

Polyester matrices have been in use for the longest period in the widest range of structures. Polyesters cure with the addition of a catalyst (usually a peroxide) resulting in an exothermic reaction, which can be initiated at room temperature. The most widely used matrices for advanced composites have been the epoxy resins. These resins cost more than polyesters and do not have the high temperature capability of the Bismaleimides or Polyimides. However, they are widely used due to the following advantages.

- Adhesion to fibres and to resin;
- No by-products formed during cure;
- Low shrinkage during cure;
- High or low strength and flexibility;
- Resistance to solvents and chemicals;
- Resistance to creep and fatigue;
- Wide range of curative options;
- Adjustable curing rate;
- Good electrical properties.

Epoxies do have few inherent disadvantages also, viz.

- Resins and curatives are somewhat toxic in uncured form;
- Moisture absorption resulting into change in dimensions and physical properties;
- Limited to about 200°C (392°F) upper temperature use;
- Difficult to combine toughness and high temperature resistance;
- High thermal coefficient of expansion;
- High degree of smoke liberation in a fire;
- May be sensitive to ultraviolet light degradation;
- Slow curing.

+ There are two resin systems in common use for higher temperatures, bismaleimides and polyimides. New designs of aircraft demand a 177°C (350°F) operating temperature requirement not met with by other common structural resin systems. Bismaleimides, with higher modulus values and established higher thermal ratings, earned a strong position for use in military aircraft primary structures with recent selection for the F-22 fighter. Bismaleimides offer mechanical properties higher than those of epoxies at elevated temperature resulting in either lower weight or increased safety margins; epoxy-like processing using standard autoclave cure processes; and cost comparable to epoxy parts.

Polyimides are the highest temperature polymers in advanced composite use with a long-term upper temperature limit (Tg) of 232°C (450°F) or 316°C (600°F).

The Cyanate ester resins have shown superior dielectric properties and much lower moisture absorption than any other structural resin for use in composites. The dielectric properties have enabled their use as adhesives in multilayer microwave printed circuit boards and the low moisture absorbance have caused them to be the resin of universal choice for structurally stable spacecraft components. The phenolic triazine resins also have superior elevated temperature properties along with excellent properties at cryogenic temperature. Both Bismaleimide and Cyanate ester resins have been evolved as easy-to-process thermosetting resins qualified for 177°C (350°F) hot-wet service. Vinyl ester resins are the most recent addition to the family of thermosetting polymers. There are two basic types of vinyl esters having commercial significance, viz., the general-purpose lower molecular weight vinyl esters and the higher heat resistant vinyl esters. General-purpose vinyl esters have excellent mechanical properties and outstanding chemical resistance to acids, bases and many solvents. Heat resistant vinyl esters increase the heat resistance of composites by 17-27°C (30-50°F) over the general-purpose type. This often• First - Processing can be faster than that of thermoset composites since no curing reaction is required. Thermoplastic composites require only heating, shaping and cooling.

- Second - The properties are attractive, in particular, high delamination resistance and damage tolerance, low moisture absorption and the excellent chemical resistance of semi-crystalline polymers.
- Third- In the light of environmental concerns, thermoplastic composites offer other advantages also. They have low toxity since they do not contain

reactive chemicals (therefore storage life is infinite).

Because it is possible to remelt and dissolve thermoplastics, their composites are also easily recycled or combined with other recycled materials in the market for molding compounds. Since the release of gases during processing and inherent brittleness is serious disadvantage of some thermoset resins, thermoplastic composites are of great interest.

Thermoplastics usually require high temperature and pressure during processing and generally lack good solvent resistance. Process conditions for high performance thermoplastics are temperature in the range of 300 to 400°C (570 to 750°F) and pressure between atmospheric pressure for thermofolding process to 20 times the atmospheric pressure for high performance press forming. Due to their high strains to failure, thermoplastics are the only matrices currently available that are suited to thermo-forming and other forms of rapid manufacture.

Thermo-loading is the most straight forward thermoplastic forming technique where a straight line is heated and folded. The process is used in volume applications like aircraft floor boards. Thermofolding operations can be carried out on solid laminate materials as well as on sandwich panels.

TABLE: 3

Material	Hydraulic Fluid	Chlorinated Hydro-carbons	Ketones	Esters	H_2O absorption (%)
Polyamide	-	No effect	No effect	No effect	8
PEEK	No effect	No effect	No effect	No effect	0.5
PES	Absorbed	Dissolved	Absorbed	Absorbed	0.3
PEI	No effect	Dissolved	Absorbed	Absorbed	1.2

Due to the above advantages, PEEK is a widely used thermoplastic. As stated above, it possesses glass transition temperature of 143°C (290°F).Above this temperature, as expected, there is a drop in mechanical properties but it maintains useful properties up to its melting point of 343°C (650°F).The polymer can be reinforced to further improve properties and maintain them up to a *higher temperature. Glass or carbon fibres are the commonly used reinforcements. Some of the significant properties of PEEK are as follows:

- Retention of useful mechanical properties at temperatures up to 315°C (600°F).
- PEEK exhibits a high fatigue resistance. It is also resistant to thermal fatigue when the temperature cycle is less than 150°C (300°F).
- PEEK has higher impact strength as compared to other thermoplastics but lower than most metals.
- Although there is drop in mechanical properties after glass transition temperature, PEEK is significantly stronger than most of other thermoplastics at higher temperatures.
- Many thermoplastics are vulnerable to continuously applied loads as they are susceptible to creep. PEEK exhibits higher creep over a wide range of temperature.
- Fracture toughness of PEEK is about 50-100 times higher than epoxies.
- It exhibits low water absorption characteristics, which is less than 0.5% at 23°C (73°F) compared to 4-5% for conventional aerospace epoxies.
- It offers resistance to a wide range of process chemicals.
- PEEK offers good resistance to wear and chemicals.
- It shows good resistance to gamma radiation thereby offering its use as wire covering material for control cabling within the containment area of nuclear reactors.

One of the major advantages of using thermoplastics is their ability to produce parts to finished shape and tolerance .The most common processing technique employed for thermoplastics is injection molding. However, for larger parts and short production, compression molding has proved cost effective. It is frequently possible to produce thermoplastic parts, which function more efficiently than conventionally manufactured parts. By using a thermoplastic, which can be molded to almost any shape, it is possible to produce parts to the optimum design in a single step.

2.1.4.5 Carbon matrices

Carbon fibre reinforced carbon is a high strength composite material, which is also resistant to high temperature in a non-oxidising atmosphere. It is composed of a carbon matrix into which reinforcing carbon fibres are embedded. Such a material was first used under extreme thermal and mechanical loads in space technology. The criteria for selection of carbon-carbon composites as a thermal protection system are based on the following requirements:

- Maintenance of reproducible strength levels at 1650°C (3002°F).
- Sufficient stiffness to resist flight loads and large thermal gradients.
- Low coefficient of thermal expansion to minimize induced thermal stresses.
- Tolerance to impact damage.

Carbon-carbon composites are used in many applications due to their

Following properties:

- Low specific weight.
- High heat absorption capacity.
- Resistance to thermal shock.
- High resistance to damage.
- Exceptional frictional properties at high energy levels.
- Resistance to high temperatures.
- Chemical inertness.

The disadvantages of carbon-carbon composites are the lack of resistance to oxidation at temperatures in excess of 500°C (930°F) and economic problems namely long manufacturing time and high production cost.

To allow the use of carbon-carbon composites in an oxidising atmosphere, they must be compounded with materials that produce oxidation protective coatings through thermo-chemical reaction with oxygen above 2000°C (3630°F). Important areas of use of carbon-carbon composites are aircraft brakes, brake system for high-speed trains and racing cars. Its application as braking material is due to high-energy absorption capacity, low specific weight and the fact that it does not contain any environmentally harmful elements like asbestos. Some other examples of its use include heavy duty clutches, tools for high temperature production of alloys like titanium, etc.

There are two production methods to obtain a carbon matrix reinforced with carbon fibres.

1. Chemical vapour impregnation - where a preform is compressed by deposition of carbon from a gaseous phase.
2. The liquid phase impregnation - where a carbon preform is compressed by means of multiple impregnations with resin and intermediate carbonisation steps.

Carbon-Carbon Brakes

As we know, conventional aircraft landing gear brakes are made up of three principal parts:

1. A torque tube,
2. A loading system for the heat sink, and
3. A heat sink.

The heat sink is made of rotors and stators. The stators are located around the torque tube while the rotors are fitted to the wheel. The object of the heat sink is to transform kinetic energy to thermal energy through the friction between stators and rotors. Consequently, the performance of brakes depends almost completely upon the heat sink material. The material, which can be used for a heat sink, should have the following properties:

- Very high specific heat - the higher the specific heat, the greater the amount of kinetic energy absorbed and better will be the brake efficiency.
- Good mechanical properties at high temperature - since the temperature of the heat sink can be very high, the mechanical properties of the rotors and stators should stay good enough so as to ensure a good brake torque transmission.
- Good resistance to thermal shock - at the beginning of the braking, the heat sink material is very cold and within a few seconds reaches a very high temperature due to large amount of absorbed energy. Therefore, the heat sink material should have good resistance to thermal shock.
- Good frictional characteristics at high temperatures - the brake torque should stay as smooth as possible all along the braking process-even at the end when the temperature is very high.
- Low thermal expansion to avoid deformation.
- As light as possible so as to save on weight.

Due to the above mentioned properties of these composites, carbon-carbon brakes are able to meet the brake requirements in normal and overweight landing conditions and also during rejected take-offs. The performance of carbon-carbon brakes, therefore, is superior to that of brakes made of conventional materials. In case of a normal landing, the maximum temperature allowed is limited by the metallic parts, which are in the heat sink environment. They must not be damaged if we want to reuse the brake, which is the case after normal landing .In case of rejected take-off, the only requirement is to stop the aircraft and, therefore, the maximum allowed temperature is dependent on the heat sink material. The limit for steel is about 1000°C (1830°F) beyond which it exhibit mechanical frictional properties will no longer. Steel brakes absorb, rather than release, a great deal of heat. This eventually melt the brakes and poses safety problems. The brakes can overheat and leave an aircraft stranded on the runway after landing. On the other hand, carbon can handle 3-4 times the amount of heat, as compared to steel, without melting. For carbon-carbon, the maximum allowed temperature is about 2000°C (3630°F). Thus if carbon-carbon brakes are used in place of steel brakes, we will have, for the same weight, a much more efficient and secure system or in other words for the same efficiency, the system will be much lighter.

Disk brakes for aircraft are the representation of a heat sink. They are composed of a number of disks ,half of which are keyed to the non-rotating brake mechanism (stators), and the other half rotate with the wheel to which they are keyed (rotors). Braking is accomplished by forcing the disks together, at which time friction is converted into heat that must be dissipated. This requires a material that is resistant to thermal shock, stable at very high temperatures, and has low thermal expansion as well as good thermal conductivity. In addition, the material should have a friction coefficient of about0.3 to 0.5 to ensure good stopping performance.

Carbon-carbon composites have all of these properties, which provide nearly four times the stopping power of copper or steel brakes. In conclusion, the advantages of the carbon-carbon brakes may be summarised as:

- Smooth braking,
- Lighter brake (carbon brakes weigh approximately 1/3rd less than the steel brakes),
- High efficiency brake,
- Increased life (nearly 2-3 times), and
- Cost effectiveness.

Carbon-carbon brakes are presently being used in number of aircraft viz. Concord, Airbus and Boeing family, etc. As an example, the weight saving by using carbon-carbon brakes on Boeing family of aircraft is as follows:

TABLE.4

Aircraft	Weight Saving (Kg)
B-747	635
B-757	272
B-767	408

Life projection of carbon-carbon brakes and steel brakes is as follows:

TABLE.5

	Estimated Loading	
Aircraft	Carbon-carbon	Steel
B-747	2000	800
B-757	3000	1500
B-767	3000	1500

Other application of carbon-carbon composites is the one piece, bladed turbine rotor that is coated to prevent oxidation. The rotor offers higher temperature performance without cooling. Gas turbine engine applications using carbon-carbon composites include exhaust nozzle flaps and seals, augmenters, combustors and acoustic panels. Carbon-carbon composite are being used in products such as the nozzle in the F-l00 jet engine afterburner, turbine wheels operating at a speed more than 40000 rpm, leading edges for missiles and for the space shuttle. Pushing the state of the art in carbon-carbon composite is the piston for internal combustion engines. The carbon-carbon pistons have exhibited reduction in weight and increase in mechanical and thermal efficiencies of the engine. The carbon-carbon piston concept features a low piston-to-cylinder wall clearance. Carbon-carbon material maintains its strength at elevated temperatures. Allowing the piston to operate at higher temperatures and pressures than those of a comparable metal piston. The high emittance and low thermal conductivity of the carbon-carbon piston should improve the thermal efficiency of the engine because less heat energy is lost to the piston and cooling system. The elimination of rings reduces friction, thus improving mechanical efficiency. Besides being lighter than conventional pistons, the carbon-carbon piston can produce cascading effects that could reduce weight of other reciprocating components such as the crankshaft, connecting rods, flywheels and balances, thus improving specific engine performance.

2.1.4.6 Metallic Matrices

Metallic matrices are essential constituents for fabrication of Metal Matrix Composites (MMC), which have potential for structural materials at high temperatures. Metal matrix has the advantage over polymeric matrix in applications requiring a long-term resistance to severe environments, such as high temperature. The yield strength and modulus of most metals are higher than those for polymers, which is an important consideration for applications requiring high transverse strength and modulus as well as compressive strength for the composite. Another advantage of using metals is that they can be plastically deformed and strengthened by a variety of thermal and mechanical treatments. However, metals have a number of disadvantages, namely, they have high specific gravities, high melting points (therefore, high process temperatures), and a tendency toward corrosion at the fibre/matrix interface.

While a variety of matrix materials has been used for making MMCs, the major emphasis has been on the development of lighter MMCs using aluminum and titanium alloys, due to the significant potential of improvement in the thrust to-weight ratio for the aerospace, space and automotive engines. Aluminium and titanium have comparatively low specific gravities and are available in a variety of alloy forms. Although magnesium is even lighter, its great affinity toward oxygen promotes atmospheric corrosion and makes it less suitable for many applications.

Beryllium is the lightest of all structural metals and has a tensile modulus higher than that of steel. However, it suffers from extreme brittleness, which is the reason for its exclusion as a potential matrix material. Nickel-and cobalt-based super alloys have also been used as matrix, however, the alloying elements in these materials tend to accentuate the oxidation of fibres at

Aluminium and its alloys have attracted the most attention as matrix material in metal matrix composites. Commercially, pure aluminium has been used for its good corrosion resistance. Aluminium alloys, such as 201, 6061, and 1100, have been used for their higher tensile strength to weight ratios. Carbon fibre is used with aluminium alloys, however, at typical fabrication temperatures of 500°C (932°F) or higher, carbon reacts with aluminium to form aluminium carbide, which severely degrades the mechanical properties of the composite.

Protective coatings of either titanium boride or sodium are used on carbon fibres to reduce the problem of fibre degradation as well as to improve their wetting with the aluminium alloy matrix. Carbon fibre reinforced aluminium composites are inherently prone to galvanic corrosion, in which carbon fibres act as a cathode owing to a corrosion potential of one volt higher than that of aluminium. Amore common reinforcement for aluminium alloys is Silicon Carbide (SiC).

Titanium alloys that are most useful in metal matrix composites are alpha, beta alloys (e.g. Ti-6Al-4V) and metastable beta alloys (e.g. Ti-lOV-2Fe-3Al). These titanium alloys have higher tensile strength to weight ratios as well as better strength retention at 400-500°C (752-932°F) over those of aluminium alloys. The thermal expansion coefficient of titanium alloys is closer to those for reinforcing fibres, which reduces the thermal mismatch between them. One of the problems with titanium alloys is their high reactivity with boron fibres at normal fabrication temperatures. **Borsic** (boron fibres coated with silicon carbide) and SiC fibres

Show less reactivity with titanium. Improved tensile strength retention is obtained by coating boron and SiC fibres with carbon-rich layers.

Continuous silicon carbide fibre reinforced metals have been successfully applied on aerospace development programs fulfilling primary design objective of high specific strength over conventional monolithic materials. The high specific strength of silicon carbide metal matrix composites has generated significant interest for the' aircraft industry. The principal areas of interest are for high performance structures such as aircraft, missiles and engines. Some of the materials in this category under consideration are:

Silicon carbide/aluminium	Development of missile body casings. Wing structural elements
Silicon carbide/titanium	Drive shaft for core of the engine requiring increased stiffness and increased critical vibratory speed ranges. Disks for turbine engine. Hollow fan blades.
Silicon carbide/Copper	For high temperature missile application
Silicon carbide/bronze	Propellers for naval application

TABLE.6

MMC production technology is complicated and requires satisfaction of the following conditions, of which the most significant are as follows:

- Maintaining the reinforcing fibres strength.
- Ensuring a strong bond of fibres with matrices and between the matrix layers.
- Providing the correct fibre length, greater than the critical length.
- Even distribution of fibres in the matrix.
- Orientation of fibres in the direction of the applied load.
- Achieving the required shape and dimensions of the MMC.
- Obtaining MMC strength reasonably near to theoretical.

2.1.4.7 Ceramic Matrices

While ceramic matrix composites are still in the early stages of component design, fabrication and testing, these materials, with their damage' tolerant mechanical behaviour, are considered as prime candidates for application of futuristic aircraft gas turbine engines. The selection of matrix materials for ceramic composites is strongly influenced by thermal stability and processing considerations. These include oxides, carbides, nitrides, borides and **silicides**. All these materials have melting temperatures above 1600°C (2912°F).

2.1.5 Curing of Resins

Thermoset resin like polyester is cured by adding a catalyst, which causes a chemical reaction without changing its own composition. The catalyst initiates the chemical reaction of the unsaturated polyester and monomer ingredient from liquid to a solid state. When used as

Epoxy resin is cured by adding hardener. Unlike the catalytic hardeners used for curing polyester resin, epoxy resin hardener contains monomers, which contribute to the curing reaction. Proper care is required to be taken while handling the epoxy resin liquids and hardeners as they give off potentially harmful vapour causing skin rashes.

After curing, low shrinkage is desirable in order to minimise in-built stressing and distortion of the fibres and matrix. Desirable qualities for a matrix are that it should be tough, durable and thermally stable over a wide range of temperatures and that it should resist cracking, chemical attack, ultra violet light and moisture.

2.1.5.1 Ingredients and Additives used in Manufacturing of Resins

Manufacturers of all types of resins use various ingredients and additives, in different proportions, to give their resins differing properties and characteristics suited to particular applications. Some general classes of additives used are as follows:

Catalysts, Promoters, Inhibitors

In polyesters, the most important additive is catalyst or initiator. Typically, organic peroxide such 3SMEKP (Methyl Ethyl Ketone Peroxide) is used for room temperature cured processes, or benzoyl peroxide is added to the resin for heat cured molding. When triggered by heat, or used in conjunction with a promoter (such as cobalt napthenate), peroxides convert to a reactive state (exhibiting free radicals), causing the unsaturated resin to react (cross-link) and become solid. Some additives such as TBC (Tertiary Butyl Catechol) are used to slow the rate of reaction and are called inhibitors. They are used in polyester resins to extend their shelf life. Accelerators such as DMA (Dimethyl Aniline) speed up curing process.

Additives and Modifiers

A wide variety of additives are used in composites to modify materials properties and tailor the laminates performance. Although these materials are generally used in relatively low quantity by weight compared to resins, reinforcements and fillers, they perform critical functions. Additive used in thermoset and thermoplastic composites exhibits the following properties:

- **Low shrink/low profile** - When parts with smooth surfaces are required, a special thermoplastic resin, which moderates resin shrinkage, can be added to thermoset resins.
- **Fire resistance** –Combustion resistance is improved by proper choice of resin, use of fillers or flame retardant additives. Included in this category are materials containing antimony trioxide, bromine, chlorine, borate and phosphorus.
- **Air release**- Most laminating resins, gel coats and other polyester resins might entrap air during processing and application. This can cause air voids and improper fibre wet-out. Air release additives are used to reduce such air entrapment and to enhance fibre wet-out. a curing agent, catalysts are referred to as catalytic hardeners. Proper care is required to be taken while handling the catalysts as they can cause skin burning and permanent eye damage. • **Emission control** - In open mold applications, styrene emission suppressants are used to lower emissions for air quality compliance.
- **Viscosity control**-In many composite types, it is critical to have a low, workable viscosity during production. Lower viscosity in such filled systems is usually achieved by use of wetting and dispersing additives. These additives facilitate the wet-out and dispersion of fillers resulting in lower viscosity.
- **Electrical conductivity**- Most composites do not conduct electricity. It is possible to obtain a degree of electrical conductivity by the addition of metal, carbon particles or conductive fibres. Electromagnetic interference shielding can be achieved by incorporating conductive materials.
- **Toughness**- Toughness can be enhanced by the addition of reinforcements. It can also be improved by special additives such as certain rubber or other **elastomeric** materials.
- **Antioxidants** - Plastics are sometimes modified with antioxidants, which retard or inhibit polymer oxidation and the resulting degradation of the polymer.
- **Antistatic agents** – Antistatic agents are added to polymers to reduce their tendency to attract electrical charge. Control of static electricity is essential in processing and handling operation of certain plastics, as well as in finished products. Static charges on plastics can produce shocks, present fire hazard and attract dust. The effect of static charge in computer/data processing applications, for example, is particularly detrimental.
- **Foaming agents**- Foaming agents are added to polymers during processing to form minute cells throughout the resin. Foamed plastics exhibit lower density, decrease material costs, improves electrical and thermal insulation, increase strength to weight ratio and reduce shrinkage and part warping.
- **Plasticisers**- Plasticisers are added to compounds to improve processing characteristics and offer a wide range of physical and mechanical properties. Slip and blocking agents - They provide surface lubrication. This results in reduced coefficient of friction on part surfaces and enhances release of parts from the mold.
- **Heat stabilisers**- They are used in thermoplastic resins to inhibit polymer degradation that results from exposure to heat.
- **Ultraviolet Stabilisers**- Both thermoset and thermoplastic composites use special materials which are added to prevent loss of gloss, crazing, chalking, discoloration, changes in electrical characteristics, embrittlement and disintegration due to ultraviolet (UV) radiation. Additives, which protect composites by absorbing the UV, are called ultraviolet absorbers. Materials, which protect the polymer in some other manner, are known as ultraviolet stabilisers.

2.1.5.2 Fillers

Fillers are inert substances added to reduce the resin cost and/or improve its physical properties, viz., hardness, stiffness and impact strength.

Commonly used fillers are calcium carbonate, hydrated alumina and clay.

Calcium carbonate is the most widely used inorganic filler. It is available in a variety of particle sizes and treatments, especially for composite applications. They assist in reducing

2.2 Total Lay-up code

Fibre orientation of all the plies is sequentially written. Subscript 'T' outside the bracket denotes total laminate definition code, and ± sign denotes fibre orientation.

TABLE.7

Laminate Lay-up	Code
• 45º	[45/0/-60$_2$/30]$_T$
-0º	
-60º	
-60º	
30º	
• 45º	[±45/-30/+30/0]$_T$
-45º	
-30º	
30º	
0º	

2.2.1 Symmetric Lay-up Code

In a laminate with symmetric lay-up code, every ply above the mid-plane has an identical ply below the mid-plane. One half of the laminate, from the first ply to the mid-plane, is written sequentially within brackets. A subscript 'S' outside the bracket denotes symmetrical laminate definition code. When the laminate mid-plane divides a physical ply into case of symmetric laminate with odd number of plies.

2.2.2 Hybrid Laminate Code

A hybrid laminate includes plies of different materials within its lay-up. In this case, every ply is identified by its fibre orientation angle and a subscript on the angle identified the type or material.

TABLE.8

Laminate Lay-up	Code
0º$_B$	[0$_B$ /±45$_{GR}$ /90$_{GR}$]$_S$
45º$_{GR}$	
-45º$_{GR}$	
90º$_{GR}$	
90º$_{GR}$	
-45º$_{GR}$	
-45º$_{GR}$	
0º$_B$	

2.2.3 Quasi Symmetric Lay-up Code

A laminate lay-up is quasi symmetric when every ply above the mid-plane has a correspondence ply below the mid-plane, with a change in the sign of its fibre orientation angle.

TABLE.9

Laminate Lay-up	Code
45º	[45/0/90]$_{2S}$
0º	
0º	
-45º	

2.2.4 Set Identification Code

In this case, sets of plies repeat within a laminate lay-up. These are identified by including them within parenthesis. An integer prefix to the subscript 'S' refers to the laminate mid-plane.

TABLE.10

Laminate Lay-up	Code
45º	[45/0/90]$_{2S}$
0º	
90º	
45º	
0º	
90º	
90º	
0º	
45º	
90º	
0º	
45º	

In addition to the above, following additional stacking sequences are also used design consideration points of view:

2.2.5 Special classification of Laminates

The laminates also classified based on the symmetricity of Reinforced fibres, viz:

- Symmetric laminates
- Anti-symmetric laminates
- Non-symmetric laminates

2.2.5.1 Symmetric laminates (Simplification of Analysis)

2.2.5.1.2 Mid-plane Symmetric laminates

The geometric mid-plane is the reference surface for determining if a laminate is symmetrical or not. In a mid-plane symmetric laminate, identical plies are located is above and below the mid-plane, at locations that are mirror reflections of each about the fibre orientation. In general, in order to reduce out-of-plane strains, coupled bending and stretching of the laminate and complexity of analysis; laminates should be used. The in-plane response and the bending response of a mid-plane symmetric laminate are uncoupled or independent of each other because all the B_{ij} terms are zero. This means that there is no coupling between in-plane loads and curvature nor between the bending loads and in-plane deformations. The in-plane load ($N_{x,}$ $N_{y,}$ and N_x) will only cause in-plane strains ($\varepsilon^\circ_{x,}$ $\varepsilon^\circ_{y,}$ $\gamma^\circ_{xy)}$, and will not cause the laminate to bend (the mid-plane curvature is equal to zero). A laminate that is not mid-plane symmetric has non-zero B_{ij} $_{\text{terms}}$ that couple the membrane and bending response. In this case, an in-plane load will cause the laminate to bend (a response that is unique in laminates and is not seen in metals). Likewise, an applied bending moment will cause the laminate mid-plane to be strained. Almost all the structural laminates are designed to be mid-plane symmetric so as to avoid the generally undesirable coupling between membrane and bending reactions.

2.2.5.1.3 Balanced Laminates

All laminates should be balanced to achieve in-plane orthotropic behaviour. A laminate is considered balanced when there are equal number of off-axis plies in the +θ and –θ directions with equal thickness and same material properties. If the laminate contains only 0º and/or 90º layers, it satisfies the requirements for balance. Laminates may be mid-plane symmetric but not balanced and vice versa. In a balanced laminate, A_{16}=A_{26}=0. In this case, an in-plane (membrane) normal load will only induce mid-plane normal strains and will not induce any mid-plane shear strains. Likewise, an applied shear load will only induce a mid-plane shear strain with no accompanying normal strain. Thus, there is no coupling between extension loads and shear strain. If, in addition, these +θ and –θ plies are at the same distance from the mid-plane, then the corresponding B and D-matrix coefficients tend towards zero. When the balanced laminate is also mid-plane symmetric, its response emulates the behaviour of metals.

2.2.5.1.4 Angle Ply Laminates

An angle ply laminate has a lay-up where successive plies alternate between + θ and- θ in fibre orientation. Based on this definition, angle ply laminates with an odd number of plies are mid-plane symmetric but are not balanced and angle ply laminates with an even number of alternating + θ and – θ plies above the mid-plane. A $[\pm 45]_s$ lay-up is an example. The mechanical response of angle ply laminates provides an explanation for the use of ±45º plies at structural locations that require large shear stiffness. A set of ±45º plies increase the shear stiffness to a great extent. In the axial stiffness, 90º, plies are selected to maximize the transverse stiffness and ±45º plies are selected to maximize the shear stiffness of the laminates.

2.2.5.1.5 cross-ply Laminates

Cross-ply laminates contain only 0º and 90º plies. In a cross-ply laminate, A_{16}=A_{26}=B_{16}=B_{26}=D_{26}=0. Mid-plane symmetric cross-ply laminates are also referred to as orthotropic laminates. Their in-plane normal and shear behaviours are uncoupled and their pure bending and twisting behaviours are also uncoupled. This means that N_x and N_y induce only $\varepsilon^\circ_{x,}$ ε°_y (γ°_{xy}=0) and M_x and M_y induce only K_x and K_y (K_{xy}=0). Likewise, N_{xy} induce only γ°_{xy} ($\varepsilon^\circ_{x,}$ ε°_y =0) and K_{xy} (K_x = K_y =0)

2.2.5.1.6 Quasi-Isotropic Laminates

Quasi-isotropic laminates behave like isotropic materials at the laminate level though their individual plies are orthotropic or anisotropic with respect to the reference coordinates. In case of quasi-isotropic laminates, only the elastic in-plane properties are isotropic. The strength properties, however, will vary with direction.

The goal of composite design is to achieve the lightest as well as most efficient structure by aligning most of the fibres in the direction of the load. Many times there is a need; however, to produce a composite, which has some isotropic properties, similar to metal, because of multiple or unified load paths. A quasi-isotropic laminates lay-up accomplishes this for the x- and y-planes only; the z- or through-the-laminate-thickness plane is quite different and lower. Laminates with plies distributed every 45º are called Π/4 laminates (plies can be in the 0º, 45º, 90º and -45º directions). Another class of laminates (plies can be in the 0º, 60º, or -60º directions). In both cases, an equal percentage of plies in each of the pre-selected orientations result in a quasi-isotropic laminate. Most laminates produced for aircraft applications have been, with few exceptions, quasi-isotropic. For a quasi-isotropic laminate, the following are the main design requirements:

- It must have three layers or more.
- Individual layers must have identical stiffness matrices and thickness.

The layers must be oriented at equal angles. For example, if total number of layers is 'n', the angle between two adjacent layers should be 360º/n. If a laminate is constructed from identical sets of three or more layers each, the condition on orientation must be satisfied by the layers in each set, for example, $(0º±60º)_S$ or(0º/±45º/90º).

2.2.5.1.7 Anti-symmetric Laminates

Symmetry of a laminate about the mid-plane is often desirable to avoid coupling between bending and extension. However, many physically applications design requirements. An even number of plies may be necessary at orientations that alternate from ply to ply i.e. –θ/+ θ/ θ/+ θ. Thus, symmetry about the mid-planes is destroyed and the characteristics of a laminate can be changed from that of the symmetric case. The laminate is not symmetric but Most laminates used today are symmetric so as to eliminate or reduce any tendency of the structure to warp unexpectedly. Most laminates are also balanced, often because it is erroneously thought to be preventing the structure from warping. A balanced laminate is really necessary in situations with reversible shear loading conditions. antisymmetric about the mid-plane. The general class of antisymmetric laminates must have an even number of plies. Further, each ply should have same thickness.

An antisymmetric cross-ply laminate consists of an even number of plies with principal material directions alternating at 0º and at 90º to the laminate axes. The thickness of the plies is also the same.

An antisymmetric angle ply laminate has plies orientated at + θº to the laminate coordinate axes on one side of the mid-plane and corresponding equal thickness ply orientated at - θº on the other side.

Antisymmetric Laminates

The general class of antisymmetric laminates must have a number of layers. In such laminates, $A_{16}=A_{26}=D_{16}=D_{26}=0$. The coupling stiffness B_{ij} vary for different classes of antisymmetric laminates.

In case of antisymmetric cross-ply laminates, $A_{16}=A_{26}=B_{16}=B_{26}=D_{16}=D_{26}=0$. As the number of layers in a laminate increases, coupling stiffness B_{11} also approaches zero.

In case of antisymmetric angle ply laminates, $A_{16}=A_{26}=B_{11}=B_{12}=B_{66}=D_{16}=D_{26}=0$. As the number of layers in a laminate increases, coupling stiffness B_{16} and B_{26} also approaches zero.

The designer should, therefore, take advantage of the orthotropic nature of the fibre composite ply in order to –

- Orient the individual plies as per the above criteria.
- Intersperse the ply orientation. If a design requires a laminate with 16 plies at ±45°, 16 plies at 0°, and 16 plies at 90°, use the intersperse design $(90_2/±45_2/0_2)_{4S}$ rather than $(90_8/±45_8/0_8)_S$ design. Concerning plies at nearly the same angle provides the opportunity for large matrix cracks to form thereby producing lower laminate allowable. Even if a design requires all 0º plies, some 90º plies and some off-angle plies should be interspersed in the laminate to provide some biaxial strength and stability and also to accommodate unplanned loads. This improves handling characteristics of the laminates and serves to prevent large matrix cracks from forming. Ensure that the laminate has sufficient fibre orientations to avoid dependence on the matrix for stability.
- Use multiple ply angles. Typical composites are constructed from multiple unidirectional or fabric layers which are positioned at angular orientations in a specified stacking sequence. The multiple layers are usually oriented in at least two different

angles, and possibly three or four; (±θ°/0°/±θ°) or (0°/±θ°/90°) cover most of the applications with θ between 30° and 60°. Unidirectional laminates are rarely used except when the basic composite material is only mildly orthotropic or when the load path is absolutely known or carefully oriented parallel to the reinforcement.

2.2.5.2 Spirally Stacked Laminates/Nonsymmetric laminates

It has been shown by experiments that interlaminar stresses are less in a spirally stacked laminate as composed to any other laminate with similar fibre orientation. Interlaminar stresses arise out the difference between the angles of two adjacent plies- smaller difference is better than larger difference.

3. MANUFACTURING PROCESSES

3.1 Fabrication/Manufacturing Techniques

3.1.1 Tooling of Composites

The manufacture of composite detailed parts and assemblies requires that some kind of accurate repeatable tool surface be provided, which is capable of withstanding repeated exposures to the cure cycle environment of high temperature sand pressures. Individual composite parts or details will require a variety of support tooling-beyond the initial cure tool, which are as follows:

- Master model reference patterns,
- Trim or router tools,
- Precision hole location drill tools,
- Assembly fixtures,
- Ply locating templates, and
- Associated shop aids.

The primary objective of any tool for composite fabrication is to make an accurate repeatable part within the confines of the process parameters defined by the manufacturer/designer and the detail performance characteristics meeting the requirements of the end user. Design of the initial tool becomes the most pressing initial issue of tooling for composites.

Factors, which govern the basic tool design, are as follows:

- Coefficient of thermal expansion (CTE). One of the most critical parameters in the design of tooling for composites is the difference between the CTE of the problems. The greater the difference between the CTE of the composite detail and the tool, the more pronounced the effect would be. One of the effects that occurs as a function of these dimensional differences is called spring back Composite details, when cured, hold the specific molded shape, as defined by the tool, as a result of the cured combination of resin and reinforcement. The spring back, or more accurately defined as a warpage condition, occurs when the composite detail is cured into a tool, that at a specific temperature has one definite dimensional tolerance and then upon cooling to ambient temperature, contracts to its original ambient dimensions. Warpage occurs when stresses are induced to the composite as the tool begins to return to the ambient dimensions. This condition will become predominant as the temperature difference between ambient and cure temperature increases and the dimensional size of tool increases. A common method of minimising the effect of spring back or warpage of a composite detail during and after cure cycle is to determine the CTE of the composite part being fabricated and the CTE of the tooling material selected. During the design of tooling, CTE of the tooling material should be matched to that of the composite detail. Another condition leading to warpage of the laminate includes an unbalanced laminate orientation where the numbers of plies of material are more dominant in one direction than other.
- Using CTE in the design of tooling for composites. Following two methods are commonly used to minimise the effect of CTE when designing tooling for the fabrication of composite details:

Careful selection of the appropriate tooling material. Difference between CTE of tooling material and composite detail to be fabricated should be as close as possible.

- Choice of material in the design of tooling. Careful selection of the appropriate material for tool use must include review of the following criteria:

1. Anticipated tool usage i.e. expected life of tool. The life expectancy of any tool fabricated for the lay-up and cure of composite details is dependent on a variety of factors. Material selection, shop handling procedures and cure cycle

time all affect the ability of tool to withstand long usage.

2. Cost available for tool fabrication. Cost of tool fabrication is difficult to quantify due to variable factors such as material and manpower cost.

3. Material available for tool construction.

Available methods for tool fabrication. Methods of manufacturing vary depending on equipment and personnel resources available. Plaster type master models and wet lay-up type molds take minimum facility requirements and basic shop skills. Use of prepreg materials requires additional skill levels and expenditure on account of sophisticated ovens and autoclaves.

Level of dimensional tolerances required from composite details. Based on the type of manufacturing method and the type of material selected, different levels of dimensional tolerances are possible. Initially, the dimensional tolerance for the composite detail to be fabricated is determined. Compliance to this tolerance is critical in meeting structural demands and conformance to any form, fit or functional requirements.

- Designing tools for resistance to failure. Due to the abusive environment experienced by tooling during the fabrication of composite details, life expectancy of the tooling is always short of anticipated value. Repetitive cycling from ambient to over 177°C (350°F),inadequate care and handling procedures, incorrect fabrication techniques have lead to a variety of defects resulting in premature, temporary or permanent failure of the tool. Failure modes common to composite lay-up tools fabricated by both wet lay-up and prepreg methods generally involve fibre separation and delamination. This is due to a of delamination between layers of prepreg tooling is the use of resin systems with glass transition temperature values at or slightly above the maximum usable temperature. For example, if the tool is intended to be cycled repeatedly at 177°C (350°F), glass transition temperature value of the resin system in the 220°C (425°F) range will allow more cycles.

3.1.2 Template Method

There are several techniques of building a plaster master determined by the shape of the part. If the part is not symmetrical and does not have a constant cross-section or the size is large, the master model is made from a series of templates secured to a flat base to form a 3D full-scale model of the part. Space between the templates is relative to the degree of abruptness of the contour. For normal gentle contours, a space of 15-20mm is common. Templates are usually made of aluminium to prevent corrosion. For temporary masters, steel is sometimes used, however, because of the amount of moisture present during mixing and application of the plaster, steel templates may rust. A schematic of typical template plaster master .

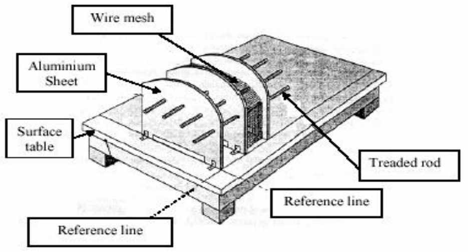

FIGURE.3

If electronic data is available, the templates can be NC-machined or cut with water or laser jet directly from the flat pattern generated by the data. Except for NC-method, deburring is generally required to remove spurs or sharp edges from the templates prior to use. Holes are drilled to the templates for threaded rod spacer sand screen support rods. For large models, air passages are cut into the bottom of the template to allow for even curing of the plaster. Once sufficient templates have been prepared, bluing is applied to a flat-ridged steel table and scribed with a pointed tool to denote the location of each template. Flatness of the table is critical and should be within0.127mm. Tooling balls, which indicate the x-, y- and z-direction are some times placed on the table corners as reference points for the system. Each template is attached 90° to the base table with angles. Threaded rods are secured with nuts on each side of the template to provide rigidity to the template face. Wire mesh is placed between the templates and secured to the threaded rod. This is used to hold plaster in place. Slurry of plaster is poured between the templates; surface is made even and left to dry to forma smooth and accurate surface. Because of the tendency of plaster to absorb moisture, it should be sealed after the surface has had adequate time to cure. Commercially available lacquers can be used to seal the surface and provide a suitable protection within the shop environment.

3.1.3 Follow Board Method

A method widely used when a constant cross-section is required to be built is the follow board. A flat surface is required with an accurate side surface to act as a guide rail. A template of the contour is prepared from sheet of aluminium or steel and attached to a wooden guide support. Plaster is mixed and built up on the surface to within 3mm of the final contour. Partial drying is recommended before the final plaster mix is applied. This will prevent shrinking and cracking of the plaster surface which otherwise would affect accuracy. Using the template and guide support, the plaster contour is formed by pushing the template evenly over the surface.

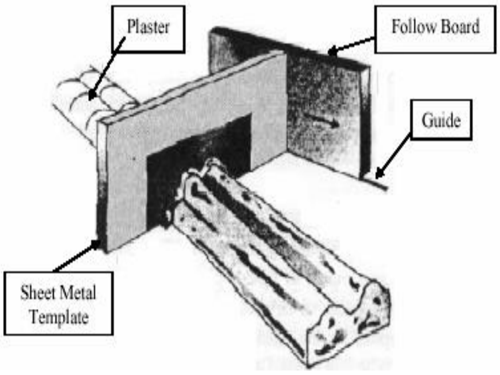

FIGURE.4

3.1.4 Prepreg Method

There is considerable number of prepregs available as epoxy 'B' staged glass or carbon reinforced cloth. The first step prior to prepreg application on the master surface is to ensure that the prepreg and the master surface are absolutely clean and free from debris and that the surface is smooth and without pin holes. A quick vacuum check is always a good idea at a minimum of 6.2 kPa. A loss of 500 Pa within 5 minutes with the pump non-operating is acceptable. Apply masking tape around the tool periphery for later application of the sealant tape. It is absolutely necessary that the, master surface can be released with a suitable hard wax or other release agents. After the cleaning and releasing processes have been completed, release coated tooling pins should be placed into the holes of the master. Series of steps followed after the above processes are:

- Carefully lay each ply onto the surface and work out wrinkles or air bubbles and maintain the warp direction of each ply in the 0ºdirection.
- An overlap between the plies should be preferably 3-6 mills.
- Debulking should be done to ensure that no air is entrapped at the interface and the smooth surface on the tool. It is accomplished by application of a peel ply net to the edge of the laminate and working out wrinkles and air bubbles.
- Sealant tape should be placed around the periphery to prevent resin flow. Adequate precautions should be taken to allow for resin bleed.
- The orientation for each ply should be such that a balanced system is maintained to minimise stress build up in the laminate.
- As a rule of thumb, debulking should be done after every 4-5 plies. Final build up of the laminate should be at least 9.5 mm.
- Final vacuum bagging is performed with a layer of peel ply, perforated Teflon, polyester breather and vacuum bag.
- Recommended heat up rate and cure temperature should be followed. Most systems can be initially cured at up to 63°C (145°F) and 586-689 kPa of pressure for 14 hours.
- After the autoclave cycle, carefully remove the bag and films .from the laminate to avoid lift up from the master surface. Attachment of support or back up structure (e.g. egg crate) to the laminate is very important to minimise

any potential residual stresses built into the laminate. • Separation of the tool from the master should be done carefully to avoid damage to the master or the tool itself. Tooling pins should be removed prior to separation. Once the tool is separated, the surface should be inspected for pin holes or -roughness. Pin holes can be filled with resin and the roughness can be smoothened with fine grit sandpaper. Care must be taken that no fibres are lifted by sanding along1he length of the fibres.

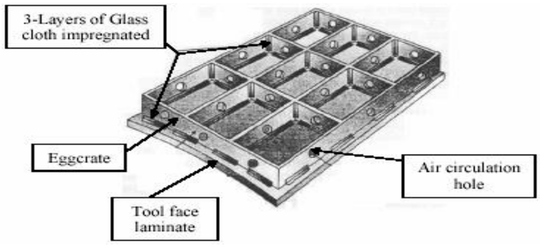

FIGURE.5

Another aspect considered important for composite fabrication is appropriate lay-up techniques along with composite cure control.

Some of the considerations for choosing lay-up techniques are given below:

TABLE.11

Consideration	Manual	Flat Tape	Contoured Tape
Orientation accuracy	Least accurate	Automatic	somewhat accuracy dependent on tape accuracy and computer programme
Ply count	Dependent on operator	Dependent on operator	Programme records
Release film retention	Up to operator	Automatic	Automatic
Tape lengths	Longer tapes more difficult	Longer tape is more economical	Longer tape is more economical
Cutting waste	Scrap on cutting	Less scrap	Least scrap
Compaction pressure	No pressure	Less voids	Least voids
Programming	N/A	N/A	Necessary

4. ANALYSIS OF FRP

(FIBER-REINFORCED PLASTIC)

The recent researches are still trying prove the FRP (Fiber-reinforced plastic) has much strength rather than alluminium.

4.1 MATERIAL USED

4.1.1 Glass Fiber-reinforced composites

The manufacturing process for glass fibers suitable for reinforcement uses large furnaces to gradually melt the silica sand, limestone, kaolin clay, fluorspar, colemanite, dolomite and other minerals to liquid form. Then it is extruded through bushings, which are bundles of very small orifices (typically 5–25 micrometres in diameter for E-Glass, 9 micrometres for S-Glass).

Glass-fiber reinforced plastic, or GFRP is a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers of glass. Fiberglass is a lightweight, extremely strong, and robust material. Although strength propertiesare somewhat lower than carbon fiber and it is less stiff, the material is typically far less brittle, and the raw materials are much less expensive. Its bulk strength and weight properties are also very favorable when compared to metals, and it can be easily formed using molding processes. The plastic matrix may be epoxy, a thermosetting plastic (most often polyester or viny lester) or thermoplastic. Common uses of fiberglass include boats, automobiles, baths, hot tubs, water tanks, roofing and pipes.

4.2 Preparation of specimen

The composite materials used for the present investigation is fabricated by hand layup process. Chopped fibers of 50 mm length were used to prepare the specimen. The composite specimen consists of total three layers in which glass fiber layers are fixed in top middle and bottom of the specimen. The layers of fibers are fabricated by adding the required amount of epoxy resin. Initially the glass fibers plastic.

4.3 Example of Sisal Fiber

4.3.1. Size of laminate

Initially we take the alkaline treatment of sisal fiber and it's chopped into 50mm. Then the chopped sisal fiber is compressed in the compression molding machine into the form of sheet 1.2mm. The dimension of compressed sisal fiber is, Width = 290mm, Length = 290mm, Thick = 1.2mm Then the glass fiber (Woven Roving Mat) is cutting into the required shape, Length = 290mm, width = 290mm

4.3.2. Fabrication details

GLASS = 272g

NATURAL FIBER = 75+75g

GLASS FIBER TO RESIN = 1:1

NATURAL FIBER TO RESIN = 1:2

EPOXY WITH HARDENER = 570g

PRESSURE OF COMPRESSION = 10bar

TEMPERATURE REQUIRED = 80°c

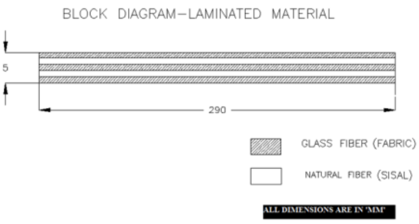

FIGURE.6

4.4. Impact test

The impact test specimens are prepared according to the required dimension following the ASTM-

A370 standard. During the testing process, the specimen must be loaded in the testing machine and allows the pendulum until it fractures or breaks. Using the impact test, the energy needed to break the material can be measured easily and can be used to measure the toughness of the material and theyield strength.

FIGURE.7

FIGURE.8

FIGURE.9

Length = 11.5mm, width = 10.5 mm, thick = 5mm.

FIGURE.10

FIGURE.12

Length = 12.5mm, width = 10.5mm, thick = 5mm.

FIGURE.13

4.5. Impact properties

The impact test carried out for the present investigation is Charpy impact test. The results indicated that the maximum impact strength is obtained for Fiber reinforced material is 12J. The specimen size of impact test is 11.5mmx10mm2x5mm.

4.6 RESULT OF FRP

Thus the FRP composite samples are fabricated and tested. The composite are subjected to mechanical testing such as impact test. Based on the results, the following conclusions are drawn. The maximum impact strength is obtained for the fiber composite and has the value of 12 joules The occurred result is compared with other metals the values are as below.FRP has much strength when compared with other individual metal

Aluminium

TENSILE	FRACTURE	SHEAR
224-MPA	303-MPA	72-MPA
2289.00-kgf/sqcm	3099.56-kgf/sqcm	741.14-kgf/sqcm

FRP

TENSILE	FRACTURE	SHEAR
241-MPA	434-MPA	152-MPA
2457.52-kgf/sqcm	4425.57-kgf/sqcm	1549.97-kgf/sqcm

Resin

TENSILE	FRACTURE	SHEAR
93-MPA	135-MPA	77-MPA
948.33-kgf/sqcm	1376.62-kgf/sqcm	785.18-kgf/sqcm

Average - (Composites)

TENSILE	FRACTURE	SHEAR
186-MPA	290-MPA	200-MPA
1898.28-kgf/sqcm	2967.25-kgf/sqcm	1025.43-kgf/sqcm

5. ADVANTAGES AND DISADVANTAGE OF COMPOSITES

5.1 ADVANTAGES

_Summary of the advantages exhibited by composite materials, which are of significant use in aerospace industry are as follows:

- High resistance to fatigue and corrosion degradation.
- High 'strength or stiffness to weight' ratio. As enumerated above, weight savings are significant ranging from 25-45% of the weight of conventional metallic designs.
- Due to greater reliability, there are fewer inspections and structural repairs.
- Directional tailoring capabilities to meet the design requirements. The fibre pattern can be SZlaid in a manner that will tailor the structure to efficiently sustain the applied loads.
- Fibre to fibre redundant load path.
- Improved dent resistance is normally achieved. Composite panels do not sustain damage as easily as thin gage sheet metals.
- It is easier to achieve smooth aerodynamic profiles for drag reduction. Complex double-curvature parts with a smooth surface finish can be made in one manufacturing operation.
- Composites offer improved torsional stiffness. This implies high whirling speeds, reduced number of intermediate bearings and supporting structural elements. The overall part count and manufacturing & assembly costs are thus reduced.
- High resistance to impact damage.
- Thermoplastics have rapid process cycles, making them attractive for high volume commercial applications that traditionally have been the domain of sheet metals. Moreover, thermoplastics can also be reformed.
- Like metals, thermoplastics have indefinite shelf life.
- Composites are dimensionally stable i.e. they have low thermal conductivity and low coefficient of thermal expansion. Composite materials can be tailored to comply with a broad range of thermal expansion design requirements and to minimise thermal stresses.
- Manufacture and assembly are simplified because of part integration (joint/fastener reduction) thereby reducing cost.
- The improved weatherability of composites in a marine environment as well as their corrosion resistance and durability reduce the down time for maintenance.
- Close tolerances can be achieved without machining.
- Material is reduced because composite parts and structures are frequently built to shape rather than machined to the required configuration, as is common with metals.
- Excellent heat sink properties of composites, especially Carbon-Carbon, combined with their lightweight have extended their use for aircraft brakes.
- Improved friction and wear properties.
- The ability to tailor the basic material properties of a Laminate has allowed new approaches to the design of aeroelastic flight structures.

The above advantages translate not only into airplane, but also into common implements and equipment such as a graphite racquet that has inherent damping, and causes less fatigue and pain to the user.

5.2 DISADVANTAGES

Some of the associated disadvantages of advanced composites are as follows:

a). High cost of raw materials and fabrication.
b). Composites are more brittle than wrought metals and thus are more easily damaged.
c). Transverse properties may be weak.
d). Matrix is weak, therefore, low toughness.
e). Reuse and disposal may be difficult.
f). Difficult to attach.

g). Repair introduces new problems, for the following reasons:

- Materials require refrigerated transport and storage and have limited shelf life.
- Hot curing is necessary in many cases requiring special tooling.
- Hot or cold curing takes time.

h). Analysis is difficult.

i). Matrix is subject to environmental degradation.

However, proper design and material selection can circumvent many of the above disadvantages.

New technology has provided a variety of reinforcing fibres and matrices those can be combined to form composites having a wide range of exceptional properties. Since the advanced composites are capable of providing structural efficiency at lower weights as compared to equivalent metallic structures, they have emerged as the primary materials for future use.

In aircraft application, advanced fibre reinforced composites are now being used in many structural applications, viz. floor beams, engine cowlings, flight control surfaces, landing gear doors, wing-to-body fairings, etc., and also major load carrying structures including the vertical and horizontal stabiliser main torque boxes.

Composites are also being considered for use in improvements to civil infrastructures, viz., earthquake proof highway supports, power generating wind mills, long span bridges, etc.

6. FUTURE SCOPE

The future scope of this paper is to test the FRCSP as per standards and comparing with other composite material categories. Also the best possible orientations can be evaluated by using the design of experiments in fabrication. Optimum process parameters can be suggested by considering the Taguchi techniques. the experimental data can be modelled and analyzed using other modelling techniques , such as fuzzy logic .

The other properties of composites such as moisture absorption, fatigue and tribological behaviour may be determined using extensive experimentation.

7. REVIEW

The Project proved an interesting challenge for a class in design of composites. The study of FRP provided a challenge as it was a different composites compare to other metals like aluminum, titanium…etc. the most of the background material related to composites were available over a half century ago. The historic development proved that is possible to design a frp composites which are capable of combining kinds of materials functionality of aircrafts.

Compare the results of the final analysis of the FRP composite to the current / earlier composite proved it is satisfactory the calculation was done manually.

This concept is being considered by many developed countries to develop the various kinds composites of materials in the report. The project is huge achievement for me to study FRP structures

8. CONCLUSION

From the analytical and experimental investigation on glass fibers reinforced plastic composite the following conclusions have been arrived

- The maximum impact strength of 12 Joules is observed for sample S1 with an energy of 400 Newton's.

Fiber reinforced plastics (FRP) have been widely accepted as materials for structural and non-structural applications in recent years.Glass, carbon,Kevlar and boron fibres are commonly used for reinforcement

Infact the uses of carbon and Kevlar is limited mainly to aerospace applications due to their very high costs

This work has conclusively proven that the Glass fiber impact capability for FRP laminate to self-heal after low velocity impact damage.

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