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# Design and Analysis of Fiber Reinforced Plastic

**Banda Anil Yadav**
M.Tech Student, Aerospace,
MLRIT, Hyderabad.

**Dr. M Satyanarayana Gupta**
Professor & HOD, Aero Dept,
MLRIT, Hyderabad.

**Mr. Khallel**
Assistant Professor, Aero Dept,
MLRIT, Hyderabad.

## ABSTRACT

***A Fiber Reinforced Plastic (FRP) is a polymer matrix that is reinforced with a fiber material with a sufficient aspect ratio (length to thickness) to provide a reinforcing function in one or more directions fiber reinforced plastics have been widely used in the aerospace industry as materials for structural components. During recent years the focus has been on perform Resin transfer molding materials with the aim of improving material properties and reducing costs. Harnessing the full potential of these materials requires a model for assessing the properties and in particular long-term behavior such a model needs to take into account the special conditions of these materials basic failure mechanisms have to be analyzed in order to develop this kind of model.***

***FRP composites are apparent in the direction of the applied load whereas steel or aluminum is isotropic, that is uniform properties in all directions, independent of applied load. The purpose of the present study is to give strength equal to metal and lighter in weight by using Glass Fiber Reinforced Plastic materials.***

***Aim is to design Fiber reinforced plastic component with composite materials using Laminating Resin and Hardener. The structure is analyzed in ANSYS for understanding the effects of the loading conditions on the structure, externally applied forces, temperatures and axial stiffness of the reinforced body.***

## INTRODUCTION

This module introduces basic concepts of stiffness and strength underlying the mechanics of fiber-reinforced advanced composite materials. This module will deal primarily with unidirectional-reinforced continuous-fiber composites and with properties measured along and transverse to the fiber direction.

## Composite Materials

The term composite usually refers to a “matrix" material that is reinforced with fibers. For instance, the term “FRP" (for Fiber Reinforced Plastic) usually indicates a thermosetting Polyester matrix containing glass fibers and this particular composite has the lion's share of today's commercial market. The figure shows a laminate fabricated by “cross plying" unidirectional reinforced layers.

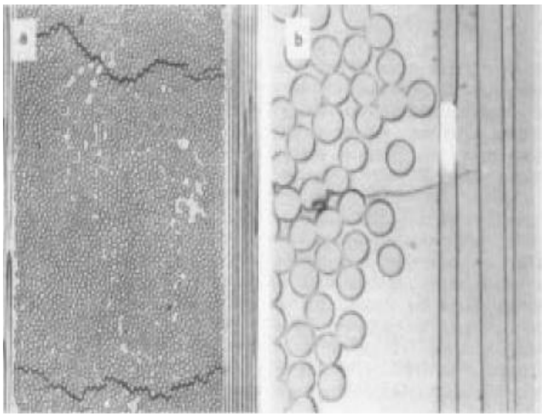

Figure 1: A cross-plied FRP laminate, showing non-uniform fiber packing and micro-cracking.

The matrix dilutes the properties to some degree, but even so very high specific (weight-adjusted) properties are available from these materials. Metal and glass are available as matrix materials, but these are currently very expensive and largely restricted. The Fibers may be oriented randomly within the material, but it is also possible to arrange for them to be oriented preferentially in the direction expected to have the highest stresses. Such a material is said to be anisotropic (different properties in different directions), and control of the anisotropy is an

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important means of optimizing the material for specific applications.

Many composites used today are at the leading edge of materials technology, with performance and costs appropriate to ultra demanding applications such as spacecraft. But heterogeneous materials combining the best aspects of dissimilar constituents have been used by nature for millions of years. Ancient society, imitating nature, used this approach as well: the Book of Exodus speaks of using straw to reinforce mud in brick making, without which the bricks would have almost no strength.

Materials are selected for a given application based principally on the materials properties. Most engineering structures are required to bear loads, so the material property of greatest interest is very often its *strength*. Strength alone is not always enough; however, as in aircraft or many other structures a great penalty accompanies weight. It is obvious an aircraft must be as light as possible, since it must be able to fly. As another example, a bicyclist wants her bicycle to be light, since that makes it easier to climb hills (and to carry it upstairs to keep it from being stolen). In some other applications, the importance of light weight is not so obvious: consider an energy-storage flywheel, which can store energy in a kinetic form via the inertia of a rotating mass. Some subway cars use this approach in regenerative braking: as the car brakes to a stop at the station, motor/generators driving the wheels are used in a generator mode to supply current to the flywheel motor. This causes the generator shaft to apply a braking resistance to the wheel, and the generated current speeds up the flywheel and raises its kinetic energy.

Composites bring many performance advantages to the designer of structural devices,
Among which we can list:

• Composites have high stiffness, strength, and toughness, often comparable with structural metal alloys. Further, they usually provide these properties at substantially less weight than metals: their "specific" strength and modulus per unit weight is near five times that of steel or aluminum. This means the overall structure may be lighter, and in weight-critical devices such as airplanes or spacecraft this weight savings might be a compelling advantage.

• Composites can be made anisotropic, i.e. have different properties in different directions and this can be used to design a more efficient structure. In many structures the stresses are also different in different directions; for instance in closed-end pressure vessels – such as a rocket motor case – the circumferential stresses are twice the axial stresses. Using composites, such a vessel can be made twice as strong in the circumferential direction as in the axial.

• Many structures experience fatigue loading, in which the internal stresses vary with time. Axles on rolling stock are examples; here the stresses vary sinusoidal from tension to compression as the axle turns. These fatigue stresses can eventually lead to failure, even when the maximum stress is much less than the failure strength of the material as measured in a static tension test. Composites of then have excellent fatigue resistance in comparison with metal alloys, and often shows evidence of accumulating fatigue damage, so that the damage can be detected and the part replaced before a catastrophic failure occurs.

• Materials can exhibit damping, in which a certain fraction of the mechanical strain energy deposited in the material by a loading cycle is dissipated as heat. This can be advantageous, for instance in controlling mechanically-induced vibrations. Composites generally offer relatively high levels of damping, and furthermore the damping can often be tailored to desired levels by suitable formulation and processing.

• Composites can be excellent in applications involving sliding friction, with tribological ("wear") properties approaching those of lubricated steel.

• Composites do not rust as do many ferrous alloys, and resistance to this common form of environmental degradation may offer better life-cycle cost even if the original structure is initially more costly.

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• Many structural parts are assembled from a number of subassemblies, and the assembly process adds cost and complexity to the design. Composites offer a lot of flexibility in processing and property control, and this often leads to possibilities for part reduction and simpler manufacture. Of course, composites are not perfect for all applications, and the designer needs to be aware of their drawbacks as well as their advantages.

• Not all applications are weight-critical. If weight-adjusted properties not relevant, steel and other traditional materials may work fine at lower cost.

• Even after several years of touting composites as the "material of the future," economies of scale are still not well developed. As a result, composites are almost always more expensive – often much more expensive – than traditional materials, so the designer must look to composites' various advantages to offset the extra cost.

• During the energy-crisis period of the 1970's, automobile manufacturers were so anxious to reduce vehicle weight that they were willing to pay a premium for composites and their weight advantages. But as worry about energy efficiency diminished, the industry gradually returned to a strict lowest-cost approach in selecting materials. Hence the market for composites in automobiles returned to a more modest rate of growth.

• Although composites have been used extensively in demanding structural applications for a half-century, the long-term durability of these materials is much less certain than that of steel or other traditional structural materials. The well-publicized separation of the tail fin of an American Airlines A300-600 Airbus after takeoff from JFK airport on November 12, 2001 is a case in point. It is not clear that this accident was due to failure of the tail's graphite-epoxy material, but NASA is looking very hard at this possibility and these points up the uncertainty designers must consider in employing composites.


Fig .3 Composites in A300

One of the prime considerations in the selection and fabrication of composites is that the constituents should be chemically inert non-reactive. This can be explained with the help of following diagram.

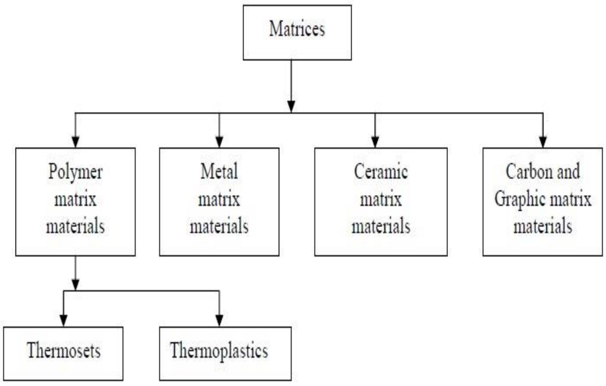


Fig .4 Composites matrix

### 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.

The advantage of thermoplastics systems over thermosets are that there are no chemical reactions

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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.

Following figure shows some kinds of thermosets.

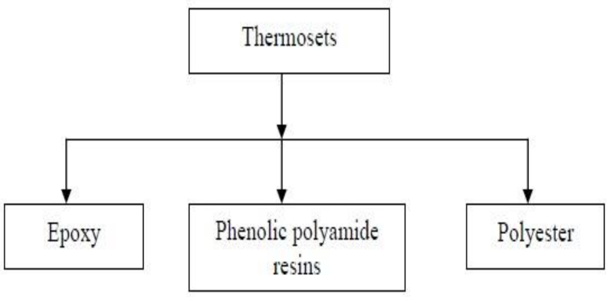


Fig .5 Thermosets

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.

## 2. CLASSIFICATION OF FRP

### 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 carbonize and subsequent pyrolization 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. Their dimensional stability makes them the 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.

### Glass Matrices

In 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 up to 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 behavior. This property allows fabrication of many components in intricate shapes and their tribological characters are considered very special.

### Resin Systems

The resin is an important constituent in composites. The two classes of resins are the thermoplastics and thermoset. A thermoplastic resin remains a solid at room temperature. It melts when heated and solidifies when cooled. The long chain polymers do not form strong covalent bond. That is why they do not harden permanently and are undesirable for structural application.

### Epoxies

The epoxies used in composites are mainly the glycidyl ethers and amines. The material properties and cure (hardening) rates can be formulated to meet the required performance. Epoxies are generally found in aeronautical, marine, automotive and electrical device applications. Although epoxies can be expensive, it may be worth the cost when high performance is required. It also has some disadvantages, which are its toxicity and complex

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processing requirements. Most of the epoxy hardeners cause various diseases.

### Vinyl Esters

The vinyl ester resins were developed to take advantage of both the workability of the epoxy resins and the fast curing of the polyesters. The vinyl ester has better physical properties than polyesters but costs less than epoxies. A composite product containing a vinyl ester resin can withstand high toughness demand and offer excellent corrosion resistance.

### Polyurethanes

Polyurethanes are mainly used without reinforcements or in some case with fiber reinforcement. They are desired due their low cost, low viscosity and rapid hardening. They have less mechanical and less temperature tolerance as compared to the above mentioned thermoset resins. Polyurethanes are also related with resin toxicity. Most of their applications are in the car industry.

### Fiber Reinforcement

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.

### Glass fibers

Glass fiber reinforcements were produced for the first time in 1893. Now it is one of the most appealing reinforcements due to its high performance, good properties and low cost. It is made up of silicon oxide and some other oxide. Glass fibers are resistant to high temperatures and corrosive environments and they also have radar transparency. There are two main types of glass fibers: E-glass and S-glass. The first type is the most widely used, and takes its name from its good electrical properties but is prone to fractures in case of acoustic emissions, The second type is very strong (S-glass), stiff, and temperature resistant. Reinforced glass fibers composite are an ideal material to make boat hulls, swimming pool linings, and car bodies, roofing and furniture.

Fig .6 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.

### Various applications

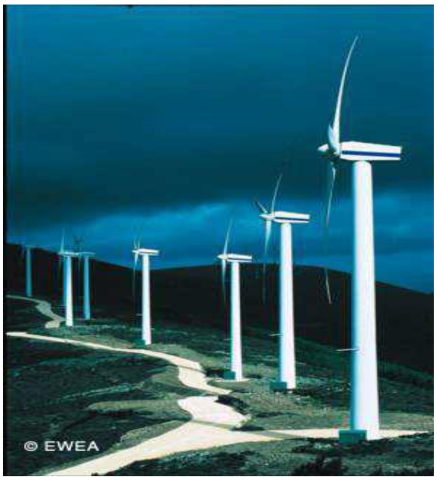

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Fig .7 Used in fuselages

Fig .8 A380

Fig 9 Used in UAVs

## 3. MANUFACTURING PROCESS

The most common manufacturing process for fiberglass is the wet lay-up process using an open mold. The shape of the part is determined by the shape of the mold, and the mold surface is typically in contact with the exterior of the part. Mold release is first applied to the mold to prevent the fiberglass part from adhering to the mold. Then gel coat, which is pigmented resin, is applied to the mold to give the part color. Fiberglass and resin are then deposited on to the mold and the fiberglass is compressed by rollers, which evenly distributes the resin and removes air pockets. Multiple layers of fiberglass are deposited until the desired thickness is achieved. When the resin is cured, the part is removed from the mold.

Excess material is trimmed off, and the part is ready for paint and assembly. With the exception of filament winding structures, high-quality, continuous fibre-reinforced components are currently being industrially manufactured with the prepreg method. However, due to rising production costs, research on the so-called liquid resin infusion method (LRI) has intensified lately since this method promises a significant reduction in manufacturing cost.

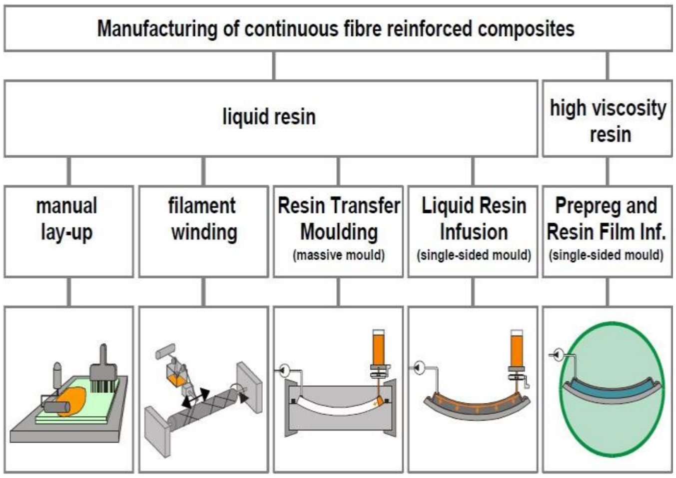


Fig .10 Composite Manufacturing Technologies

### The Prepreg Autoclave Technology

At present, the prepreg autoclave method is primarily being used for the manufacture of high-quality composite components since it provides a very high and reproducible component quality while requiring a moderate investment of tools. The high component quality is attained by compacting and curing the prepregs (resin impregnated, continuous fibre products), in the autoclave under specified conditions. Simple tools are required because only single-sided supporting tools are needed which have a flexible

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vacuum cover. However, prepregs are costly due to their specialized preparation process. In addition the lay-up process with prepreg is more complicated than with dry fibre material because the applied resin film is already activated and therefore difficult to handle.

### The Resin-Transfer-Moulding Method

The Resin-Transfer-Moulding (RTM) method has become established in the past few years as an alternative to the Prepreg Autoclave technology. In this method, a cost-effective, non impregnated fibre perform is placed in a massive mould to which a low-viscous resin system is injected under pressure. The considerably lower costs of the semi-finished products are advantageous here when the manufactured quantity warrants the enormous investment costs for the vacuum-tight, temperature-adjustable, pressure-loaded, and often very complex and heavy moulds. Since a compacting of the laminate in all directions is not possible in massive RTM moulds, a reduction in the quality of the laminate and fibre content must be expected

### LRI / SCRIMP Technology

A promising subtype of the LRI (Liquid Resin Infusion) technology is the SCRIMP method. In the SCRIMP (Seeman Composites Resin Infusion Moulding Process) method a flow aid is applied to the dry fibre perform that enables a quick distribution of the resin over the parts surface during infiltration. As opposed to RTM and autoclave methods, the infusion and curing process take place at ambient pressure. In contrast to classical LRI methods, the infiltration of the resin takes place perpendicular to the flat fibre reinforcement. Normally, a single sided mould is also used here which is sealed with a vacuum bag. Because of the low fibre compacting as well as uncontrolled resin distribution, the quality of the laminate is usually considerably lower than with the Prepreg autoclave method.

### The Single Line Injection (SLI) Method

Since the quality and economical manufacture of fibre composite components play decisive roles in their successful introduction into the market, a manufacturing process was developed at the Institute of Structural Mechanics with the goal of producing high-quality fibre composite components with the best possible laminate and surface quality in a cost-optimised production process. The process was to be optimised for the production of small series and prototype components with a quantity of up to about 500 pieces per year since a great market potential is developing in the areas of aircraft, railway, and vehicle prototype construction

### The Principle of the SLI Method

The approach for the development of the SLI method essentially is to combine the advantages of the raw material of the liquid resin technology with the laminate quality of the Prepreg autoclave technology. The advantage of this method in comparison to the LRI method is that the resin is injected under pressure and that the laminate can be compacted by the autoclave pressure. The name of the method is an indication that the evacuation of the fibre perform as well as the injection of the resin system is carried out with the same resin transfer line. This resin transfer line can be arranged on the fibre perform in any arrangement to shorten the flow path and, with that, the injection time. With the SLI method, it is possible to combine cost-effective and dry semi-finished fibre products such as fabrics, weaves, and warp knitted fabrics with the optimal matrix resin for each application. In addition to the standard epoxy resins, vinyl ester resins, polyisocyanurats (Blendur), heat-resistant resins such as bismalimide, cyanate ester and even phenolic resins can be processed. The excellent and void-free laminate quality achieved by the autoclave process leads to a superb component quality which almost reaches the status of a Class a surface.

### Variation of the Fibre Volume Content

An additional characteristic of the SLI method is the possibility to directly influence the fibre content by means of the process parameters. This is possible because the flexible side of the mould enables the autoclave pressure to be in equilibrium with the inner resin pressure of the component and the restoring force of the fibre material. If the autoclave pressure is

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adjusted to be the same as the inner resin pressure, the fibre preform can relax in the thickness direction and can support the impregnation due to greater permeability. If the fibre preform is completely impregnated, the autoclave pressing on the fibre material can be selectively increased by reducing the injection pressure until the desired fibre volume content of typically 60% is reached.

### The Sandwich Principle

The basic prerequisite for high-performance structural component parts as used in aerospace applications is light-weight design wherever possible. An essential component of these light-weight structures is load-bearing and buckling optimized shell elements. The classical method to obtain improved buckling properties is using monolithic stringers, although sandwich structures have also prove their worth in a number of fields. The performance of a sandwich structure depends primarily upon the efficiency of surface skins and the distance between them. A great distance between the surface skins produces a correspondingly great geometrical moment of inertia, thus leading to high bending stiffness.

### Core Materials

While the most important thing with the surface skins is stiffness and strength, the major factor with the core is keeping the mass down to a minimum. The core stress results from having to keep the surface skins at a distance to one another and providing buckling stability to the skins. This means that the core is primarily stressed from shear and sometimes compression. Honeycomb core materials made of aluminum or Nomex have the greatest potential for performance with regard to weight because they have an amazing compression modulus with minimum material use. Honeycomb core materials have established themselves firmly in aerospace applications and are generally used in combination with prepreg products. Some typical structural components are leading edges on the wing and empennage, landing gear doors and other access doors and all kind of fairings.

In spite of the excellent potential for performance of honeycomb core sandwich structures, there is increasing demand among airlines for alternatives because of the high maintenance costs caused by honeycomb cores in various applications. The reason for these higher maintenance costs is related to the fact that honeycomb cores may fill up with water under certain circumstances, for instance if the surface skins are porous. The water in the full honeycomb cells freezes and expands at low temperatures, which in terms damages adjacent honeycomb cells.

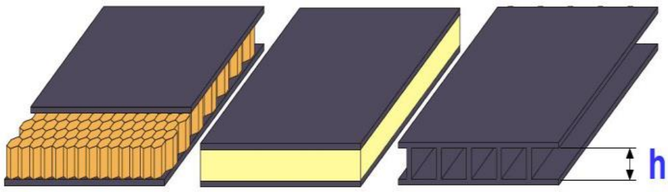


Fig 11 Honey comb

For maintenance activities that mean that the honeycomb core components have to be inspected more frequently because they sometimes carry very significant amounts of water. The costs of servicing and repairing these components can diminish the positive aspects of the low structural weight to the extent that a heavier foam-core construction can be more economical over the component's total life cycle. A comparison shows the benefits and shortcomings of the various core materials.

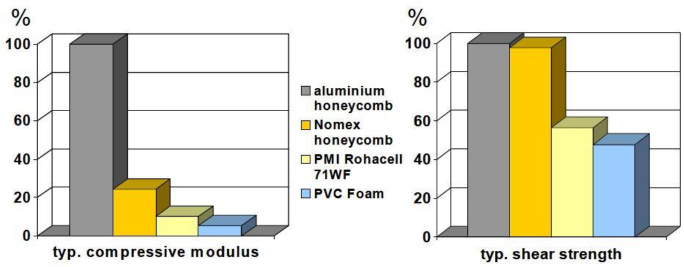


Fig .12 Stress vs. shear strength

### Aluminium honeycomb

Aluminium honeycomb cores have excellent compression stiffness with regard to weight because it can be manufactured with extremely thin walls.

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However, these thin walls may also lead to local buckling in the honeycomb surfaces especially with large honeycombs. Beyond this, the combination of aluminium and carbon fibres can produce contact corrosion if both elements are not electrically insulated. Honeycomb corrosion is a serious problem because inspecting the inside of a honeycomb component involves enormous expenditures. However, tapping the surface skins provides initial indications of the condition of a honeycomb core-sandwich component.

### Nomex honeycomb

Nomex honeycomb cores consist of aramid "paper" impregnated with phenolic resin and can be found in a wide variety of applications. There is less of a problem with local cell buckling than with aluminium honeycomb because of the greater wall thickness. Furthermore, there is also no problem with contact corrosion because nomex honeycomb does not conduct electricity. However, a negative characteristic of aramide semifinished products is the fact that they are not resistant to UV light, although this is not a problem with honeycomb cores in lightproof casing. It also has positive FST characteristics because of its phenolic resin sealing.

### PMI foams

PMI (**P**oly**m**ethacryl**i**mide) foams are also used extensively in aviation because they can be worked in 180°C production processes after being appropriately tempered. The high degree of compressive strength of medium weight PMI foams makes it possible to apply autoclave cycles with more than 0.5 MPas at temperatures of 180°C, meaning they are suited to standard prepreg production cycles. The PMI foams approved for aviation have a very even distribution of closed-celled pores with their size remaining extensively constant. Its moisture absorption can be as much as 9% with unsealed foams, which is very detrimental. Moisture can produce great problems notably in production when the foam cores are not sufficiently dried. When working resins containing isocyanate (such as Blendur) moisture may even lead to matrix decomposition.

### PVC foams

The main feature of PVC (polyvinyl chloride) foams is the fact that they are comparably inexpensive. They are mostly used in aviation for building small aircraft where production strategies are mainly without autoclaves at process temperatures below 140° C. Gas exhalation should also be observed with PVC foams used in RTM Processes, because it may lead to porosities in the laminate of the surface skins. The fact that it has low moisture absorption and the great impact strength of untempered PVC foams has a positive effect.

Fig .13 Manufacturing Process

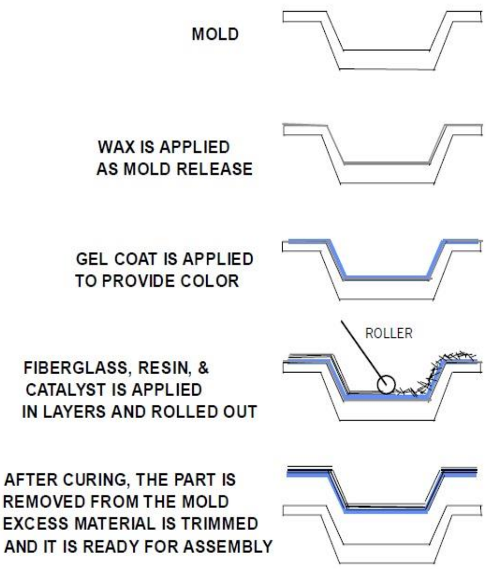


Fig .14 Molding Process

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## 4. DESIGN AND ANALYSIS

### FEA Structural Analysis on a Wing Rib(composite structure)

- In an aircraft, ribs are forming elements of the structure of a wing, especially in traditional construction.

- By analogy with the anatomical definition of "rib", the ribs attach to the main spar, and by being repeated at frequent intervals, form a skeletal shape for the wing.

- Usually ribs incorporate the airfoil shape of the wing, and the skin adopts this shape when stretched over the ribs.

### DESIGNED RIB COMPONENT

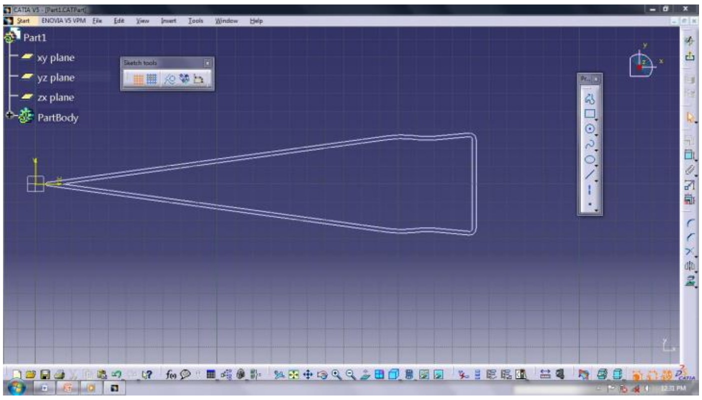
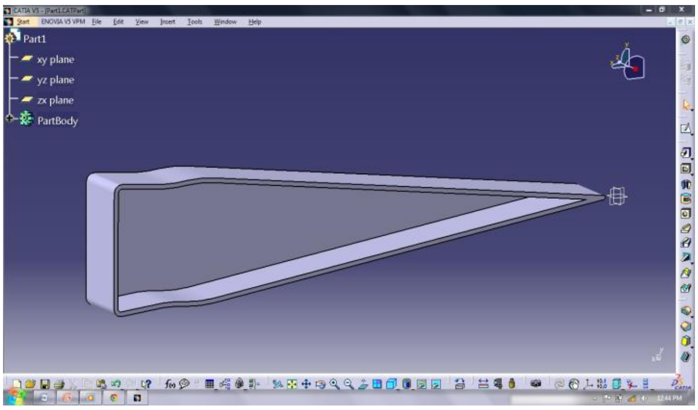



Fig .15 Designing part in Catia



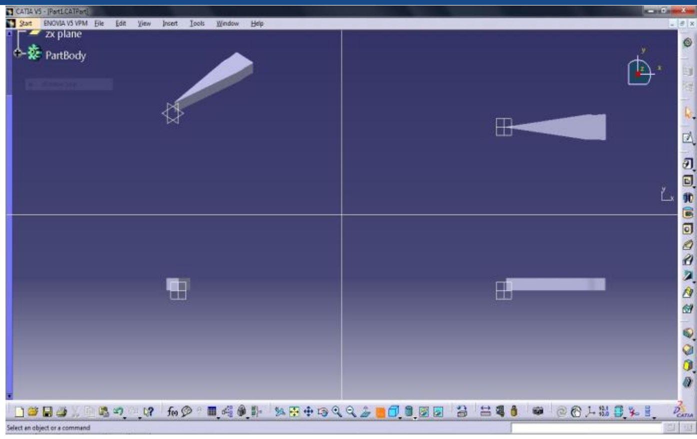
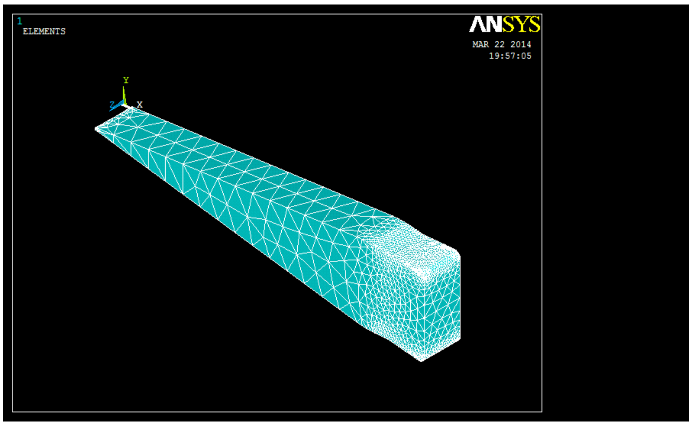




Fig .16 Designed wing rib component

### AFTER MESHING




### MATERIAL PROPERTIES

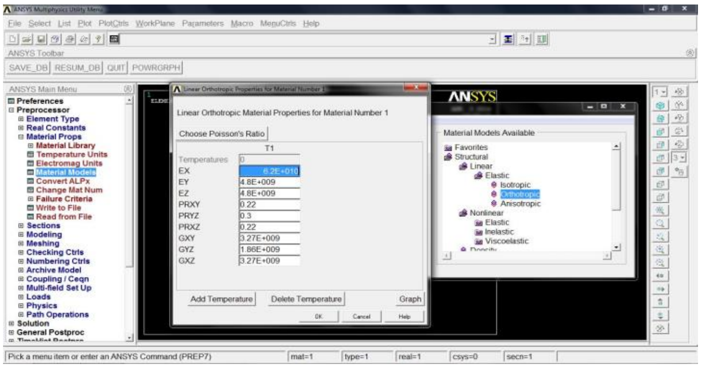



Fig .17 Meshed and material properties of cfrp wing rib

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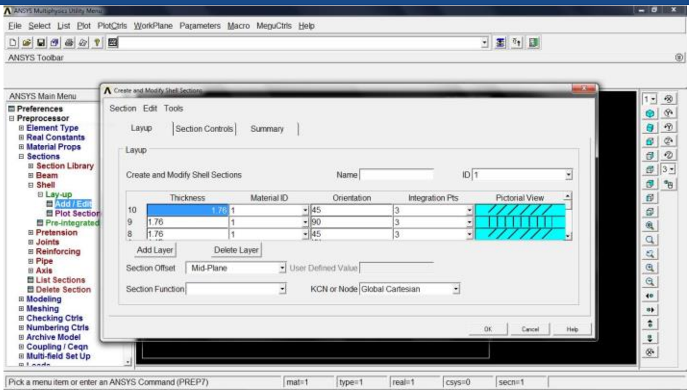



Fig.18 Shell layers

## LAYER STACKING

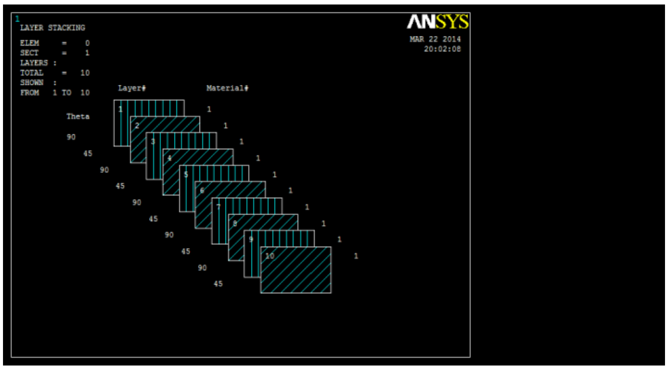
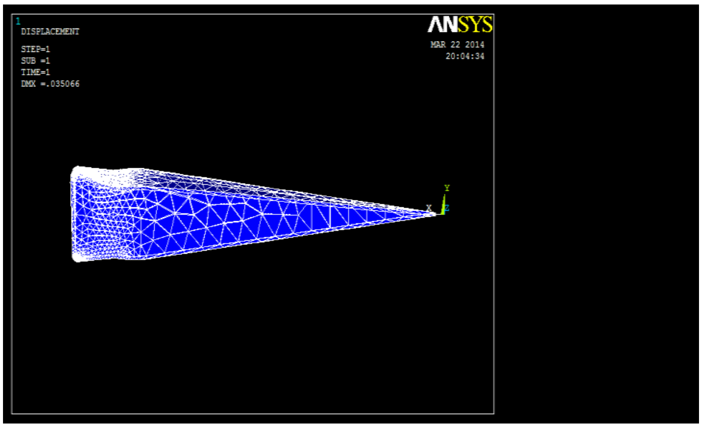
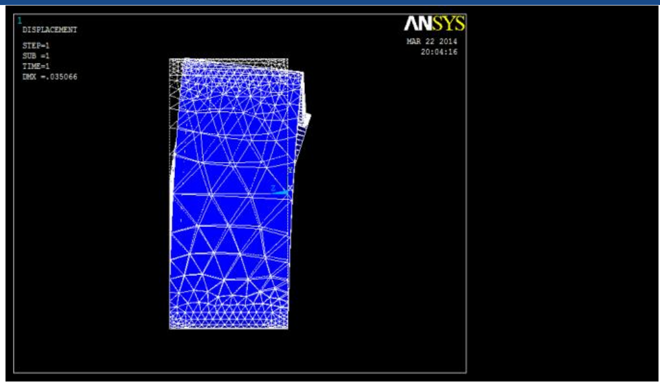



Fig .19 .Layer stacking

## RESULTS



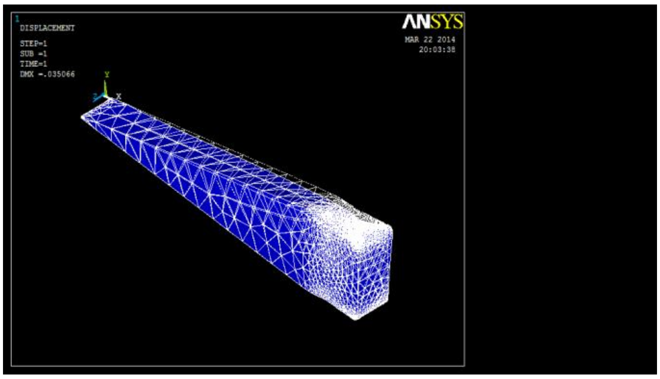




Fig . 20. Deformation of wing rib structure

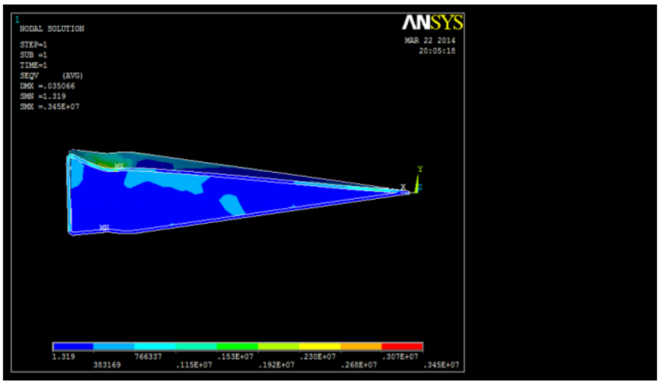



Fig. 21. Stresses in wing rib structure

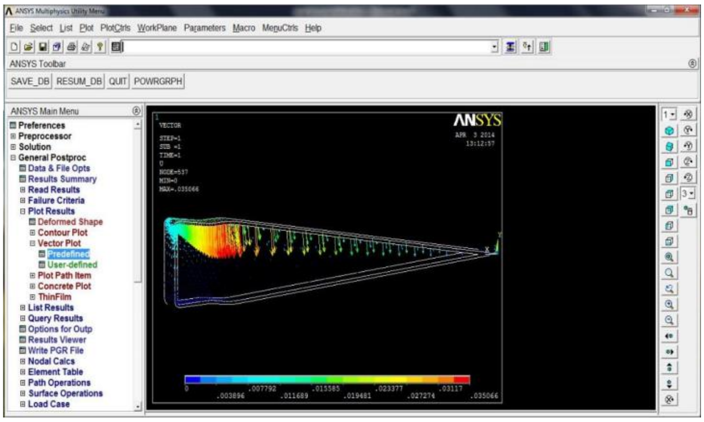



Fig .22. Vector Displacement of wing rib

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### SPECIMEN DATA
Thickness = 2 mm
Highest diameter (Base) = 55 mm
Central length = 236 mm + 2mm= 238 mm
Overall length = 241 mm
Cross sectional area = 241 * 27.5 = 6627.5 $mm^2$
Load applied = 20000 Newton= 20 KN
Depth of specimen = 26 mm

### MATERIAL PROPERTIES
$E_x$ = 6.2 E010
$E_y$ = 4.8 E009
$E_z$ = 4.8 E009
$PR_{xy}$ =0.22
$PR_{yz}$ =0.3
$PR_{xz}$ =0.22
$G_{xy}$ =3.27 E009
$G_{yz}$ =1.86 E009
$G_{xz}$ =3.27 E009

### RESULTS AND DISCUSSION
Load applied = 20 kn
Ultimate stress = load/ area = 20000/6627.5 =3.0177 $N/mm^{2\backslash}$
Stress maximum = 0.345 E007
Stress minimum = 1.319
Displacement = 0.035066 mm
Original length = 57 mm
After testing = 56.9634 mm
Strain = 0.03606 mm

### 5 CONCLUSION
Material properties that would be used in specific environment such as underground or airborne should have firm specific properties, and therefore the materials used should not add any more fuel to the fire or emit toxic gases to the surroundings. Therefore, the regulations should then specify stern material properties according to their electrical, chemical and flammability resistance as well as toxicity requirements. The research introduces the variety of composite resins and fibre reinforcements to choose from. Therefore the material chosen was the Carbon fiber for the reinforcement and Epoxy for the matrix. The material is oriented by $90^0$ off axis and $45^0$ for the plies orientations. Throughout the analysis the deformation was within the limits but high for the expected values therefore the following section will analyse some further work for solving the deformation condition, while the stresses were within the limits, and were acceptable in the design analysis initial stage.

The Carbon fiber reinforced plastic components have high mechanical properties compared to glass fiber reinforced plastic components except temperature resistance because GFRP has high Thermal resistance than CFRP The wing rib designed with composites is tested and could withstand high mechanical stresses compared to other metals the research in these fields is active and with further introduction of different composites we can achieve high strength to weight ratio with less manufacturing costs than conventional metals. Finite element analysis using non-linear constitutive models of cracked concrete, steel bars and FRP is used to predict the behavior of FRP strengthened beam. It is verified that the finite element analysis can accurately predict the load deformation, load capacity and failure mode of the beam. It can also capture cracking process for the shear-flexural peeling and end peeling failures, similar to the experiment.

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