

# Study of Advanced Composite Materials in Aerospace Application

A. Kalaiyarasan, P. Ramesh, P. Paramasivam

Assistant Professor, Department of Mechanical Engineering, Muthayammal Engineering College, Rasipuram,  
Tamil Nadu, India

## ABSTRACT

Composite materials are becoming more important in the construction of aerospace structures. Aircraft parts made from composite materials, such as fairings, spoilers, and flight controls, were developed during the 1960s for their weight savings over aluminum parts. New generation large aircraft are designed with all composite fuselage and wing structures and the repair of these advanced composite materials requires an in-depth knowledge of composite structures, materials, and tooling. The primary advantages of composite materials are their high strength, relatively low weight, and corrosion resistance.

**Keywords:** Aluminium, Aerospace

## I. INTRODUCTION

When two or more different materials are combined, the result is a "composite. The first uses of composites date back to the 1500 B.C. when early Egyptians and Mesopotamian settlers used a mixture of mud and straw to create strong and durable buildings. Straw continued to provide reinforcement to ancient composite products including pottery and boats. Later, in 1200 AD, the Mongols invented the first composite bow. Using a combination of wood, bone, and "animal glue," bows were pressed and wrapped with birch bark. These bows were powerful and accurate. Composite Mongolian bows helped to ensure Genghis Khan's military dominance. Laminating resins are formulated from components including

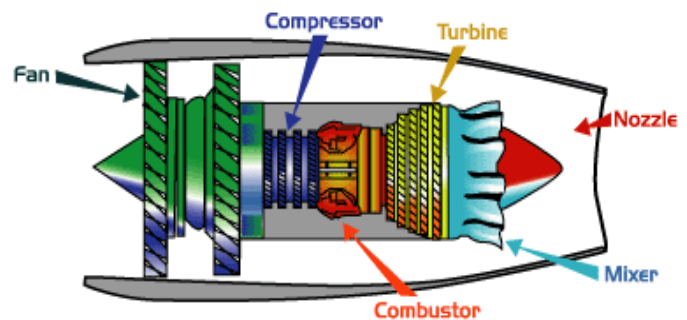


Figure 1. a turbofan color

1. Polymer Reactive monomer
2. Thyrotrophic agents
3. Promoters
4. Inhibitors

Processing requirements include:

1. Spray ability
2. We tout
3. Sag
4. Working time



**Figure 1.** b aircraft structure

## II. LAMINATED STRUCTURES

Composite materials consist of a combination of materials that are mixed together to achieve specific structural properties. The individual materials do not dissolve or merge completely in the composite, but they act together as one. Normally, the components can be physically identified as they interface with one another. The properties of the composite material are superior to the properties of the individual materials from which it is constructed.

An advanced composite material is made of a fibrous material embedded in a resin matrix, generally laminated with fibers oriented in alternating directions to give the material strength and stiffness. Fibrous materials are not new; wood is the most common fibrous structural material known to man.

Applications of composites on aircraft include:

- ✓ Fairings
- ✓ Flight control surfaces
- ✓ Landing gear doors

- ✓ Leading and trailing edge panels on the wing and stabilizer
- ✓ Interior components
- ✓ Floor beams and floor boards
- ✓ Vertical and horizontal stabilizer primary structure on large aircraft
- ✓ Primary wing and fuselage structure on new generation large aircraft
- ✓ Turbine engine fan blades
- ✓ Propellers

### Major Components of a Laminate

An isotropic material has uniform properties in all directions. The measured properties of an isotropic material are independent of the axis of testing. Metals such as aluminum and titanium are examples of isotropic materials.

A fiber is the primary load carrying element of the composite material. The composite material is only strong and stiff in the direction of the fibers. Unidirectional composites have predominant mechanical properties in one direction and are said to be anisotropic, having mechanical and/or physical properties that vary with direction relative to natural reference axes inherent in the material. Components made from fiber-reinforced composites can be designed so that the fiber orientation produces optimum mechanical properties, but they can only approach the true isotropic nature of metals, such as aluminum and titanium.

A matrix supports the fibers and bonds them together in the composite material. The matrix transfers any applied loads to the fibers, keeps the fibers in their position and chosen orientation, gives the composite environmental resistance, and determines the maximum service temperature of a composite.

### Strength Characteristics

Structural properties, such as stiffness, dimensional stability, and strength of a composite laminate, depend on the stacking sequence of the plies. The stacking sequence describes the distribution of ply

orientations through the laminate thickness. As the number of plies with chosen orientations increases, more stacking sequences are possible. For example, a symmetric eight-ply laminate with four different ply orientations has 24 different stacking sequences.

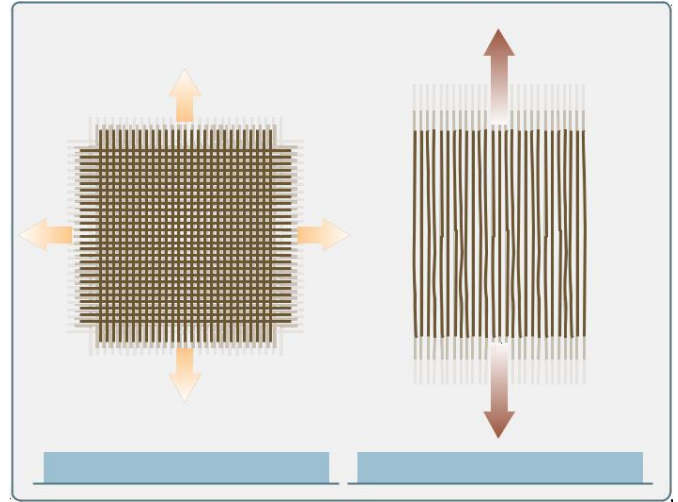
### Fiber Orientation

The strength and stiffness of a composite buildup depends on the orientation sequence of the plies. The practical range of strength and stiffness of carbon fiber extends from values as low as those provided by fiberglass to as high as those provided by titanium. This range of values is determined by the orientation of the plies to the applied load. Proper selection of ply orientation in advanced composite materials is necessary to provide a structurally efficient design. The part might require  $0^\circ$  plies to react to axial loads,  $\pm 45^\circ$  plies to react to shear loads, and  $90^\circ$  plies to react to side loads. Because the strength design requirements are a function of the applied load direction, ply orientation and ply sequence have to be correct. It is critical during a repair to replace each damaged ply with a ply of the same material and ply orientation.

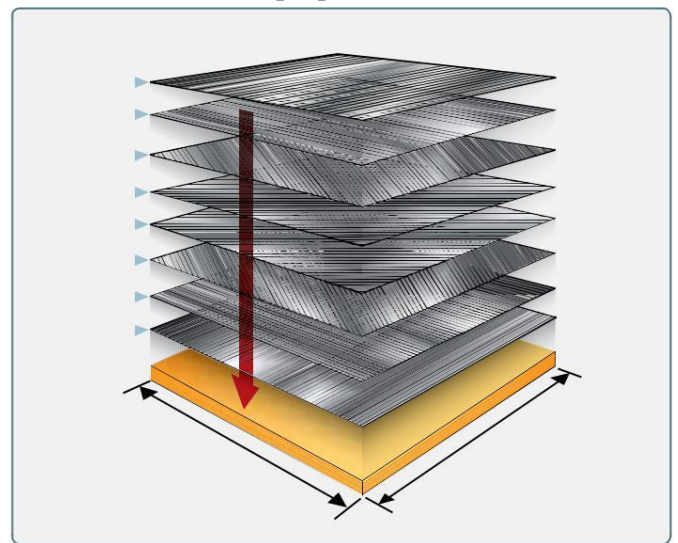
The fibers in a unidirectional material run in one direction and the strength and stiffness is only in the direction of the fiber. Pre-impregnated (prepreg) tape is an example of a unidirectional ply orientation.

The fibers in a bidirectional material run in two directions, typically  $90^\circ$  apart. A plain weave fabric is an example of a bidirectional ply orientation. These ply orientations have strength in both directions but not necessarily the same strength. [Figure -1]

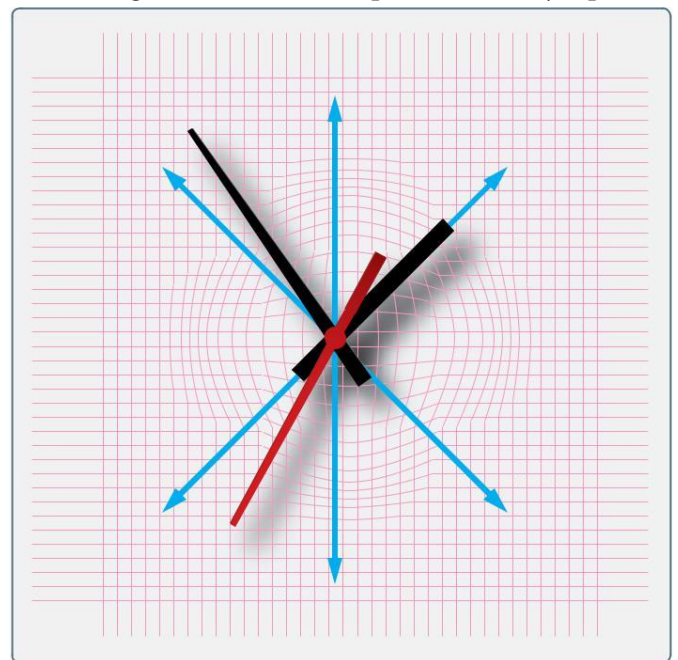
The plies of a quasi-isotropic layup are stacked in a  $0^\circ$ ,  $-45^\circ$ ,  $45^\circ$ , and  $90^\circ$  sequence or in a  $0^\circ$ ,  $-60^\circ$ , and  $60^\circ$  sequence. [Figure -2] These types of ply orientation simulate the properties of an isotropic material. Many aerospace composite structures are made of quasi-isotropic materials.



**Figure 1.** Bidirectional and unidirectional material properties.



**Figure 2.** Quasi-isotropic material lay-up.



**Figure 3.** A warp clock.

## Roving

A roving is a single grouping of filament or fiber ends, such as 20-end or 60-end glass rovings. All filaments are in the same direction and they are not twisted. Carbon rovings are usually identified as 3K, 6K, or 12K rovings, K meaning 1,000 filaments. Most applications for roving products utilize mandrels for filament winding and then resin cure to final configuration.

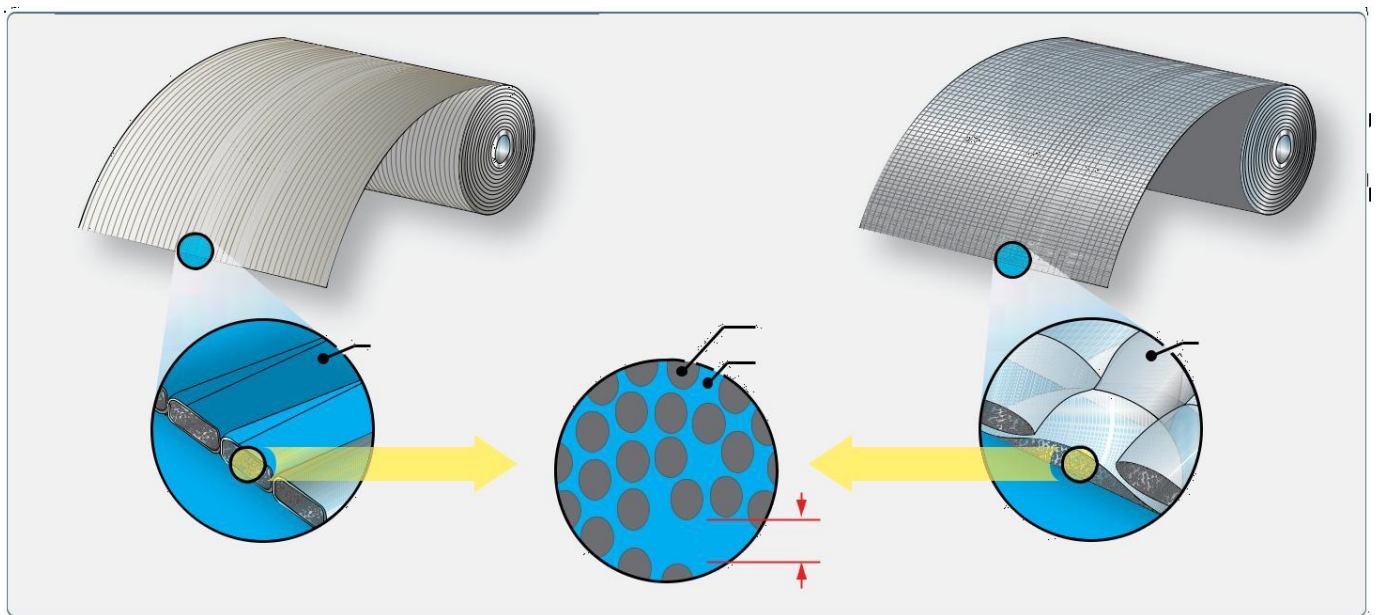
## Unidirectional (Tape)

Unidirectional prepreg tapes have been the standard within the aerospace industry for many years, and the fiber is typically impregnated with thermosetting resins. The most common method of manufacture is to draw collimated raw (dry) strands into the impregnation machine where hot melted resins are combined with the strands using heat and pressure. Tape products have high strength in the fiber

direction and virtually no strength across the fibers. The fibers are held in place by the resin. Tapes have a higher strength than woven fabrics. [Figure-4]

## Bidirectional (Fabric)

Most fabric constructions offer more flexibility for layup of complex shapes than straight unidirectional tapes offer. Fabrics offer the option for resin impregnation either by solution or the hot melt process. Generally, fabrics used for structural applications use like fibers or strands of the same weight or yield in both the warp (longitudinal) and fill (transverse) directions. For aerospace structures, tightly woven fabrics are usually the choice to save weight, minimizing resin void size, and maintaining fiber orientation during the fabrication process.



**Figure 4.** Tape and fabric products.

Woven structural fabrics are usually constructed with reinforcement tows, strands, or yarns interlocking upon themselves with over/under placement during the weaving process. The more common fabric styles are plain or satin weaves. The plain weave construction results from each fiber alternating over and then under each intersecting strand (tow, bundle,

or yarn). With the common satin weaves, such as 5 harness or 8 harness, the fiber bundles traverse both in warp and fill directions changing over/under position less frequently.

These satin weaves have less crimp and are easier to distort than a plain weave. With plain weave fabrics



and most 5 or 8 harness woven fabrics, the fiber strand count is equal in both warp and fill directions. Example: 3K plain weave often has an additional designation, such as 12 x 12, meaning there are twelve tows per inch in each direction. This count designation can be varied to increase or decrease fabric weight or to accommodate different fibers of varying weight. [Figure -5]

### Nonwoven (Knitted or Stitched)

Knitted or stitched fabrics can offer many of the mechanical advantages of unidirectional tapes. Fiber placement can be straight or unidirectional without the over/under turns of woven fabrics. The fibers are held in place by stitching with fine yarns or threads after preselected orientations of one or more layers of dry plies. These types of fabrics offer a wide range of multi-ply orientations. Although there may be some added weight penalties or loss of some ultimate reinforcement fiber properties, some gain of interlaminar shear and toughness properties may be realized. Some common stitching yarns are polyester, aramid, or thermoplastics. [Figure -6]

### Types of Fiber

#### Fiberglass

Fiberglass is often used for secondary structure on aircraft, such as fairings, radomes, and wing tips. Fiberglass is also used for helicopter rotor blades. There are several types of fiberglass used in the aviation industry. Electrical glass, or E-glass, is identified as such for electrical applications. It has high resistance to current flow. E-glass is made from borosilicate glass. S-glass and S2-glass identify structural fiberglass that have a higher strength than E-glass. S-glass is produced from magnesia-alumina-silicate. Advantages of fiberglass are lower cost than other composite materials, chemical or galvanic corrosion resistance, and electrical properties (fiberglass does not conduct electricity). Fiberglass has a white color and is available as a dry fiber fabric or prepreg material.

#### Kevlar

Kevlar is DuPont's name for aramid fibers. Aramid fibers are light weight, strong, and tough. Two types of Aramid fiber are used in the aviation industry. Kevlar 49 has a high stiffness and Kevlar 29 has a low stiffness. An advantage of aramid fibers is their high resistance to impact damage, so they are often used in areas prone to impact damage. The main disadvantage of aramid fibers is their general weakness in compression and hygroscopy. Service reports have indicated that some parts made from Kevlar absorb up to 8 percent of their weight in water. Therefore, parts made from aramid fibers need to be protected from the environment. Another disadvantage is that Kevlar is difficult to drill and cut. The fibers fuzz easily and special scissors are needed to cut the

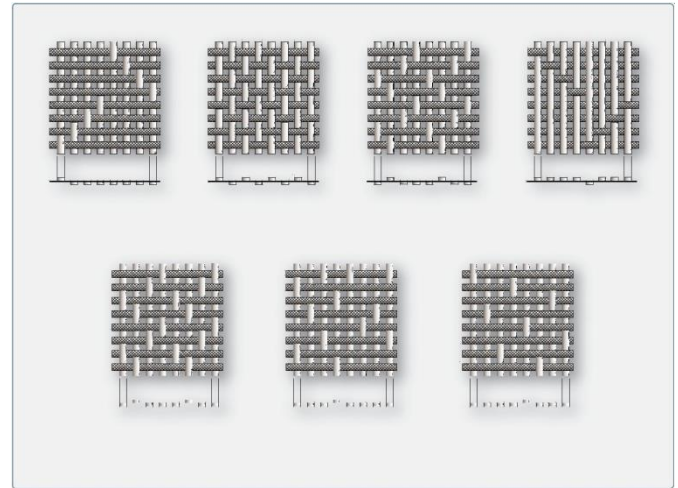


Figure 5. Typical fabric weave styles.

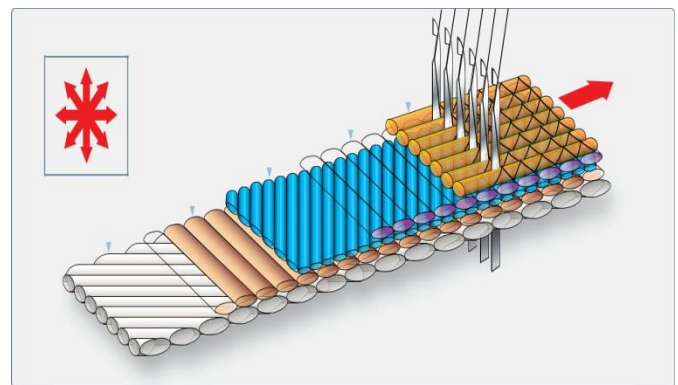


Figure 6. Nonwoven material (stitched).

#### Carbon/Graphite

One of the first distinctions to be made among fibers is the difference between carbon and graphite fibers, although the terms are frequently used interchangeably. Carbon and graphite fibers are based

on graphene (hexagonal) layer networks present in carbon. If the graphene layers, or planes, are stacked with three dimensional order, the material is defined as graphite. Usually extended time and temperature processing is required to form this order, making graphite fibers more expensive. Bonding between planes is weak. Disorder frequently occurs such that only two-dimensional ordering within the layers is present. This material is defined as carbon.

Carbon fibers are very stiff and strong, 3 to 10 times stiffer than glass fibers. Carbon fiber is used for structural aircraft applications, such as floor beams, stabilizers, flight controls, and primary fuselage and wing structure. Advantages include its high strength and corrosion resistance. Disadvantages include lower conductivity than aluminum; therefore, a lightning protection mesh or coating is necessary for aircraft parts that are prone to lightning strikes. Another disadvantage of carbon fiber is its high cost. Carbon fiber is gray or black in color and is available as dry fabric and prepreg material. Carbon fibers have a high potential for causing galvanic corrosion when used with metallic fasteners and structures.

[Figure 7-7]



**Figure 7.** Fiberglass (left), Kevlar (middle), and carbon fiber material (right).

### **Boron**

Boron fibers are very stiff and have a high tensile and compressive strength. The fibers have a relatively large diameter and do not flex well; therefore, they are available only as a prepreg tape product. An

epoxy matrix is often used with the boron fiber. Boron fibers are used to repair cracked.

potential. The boron fiber is difficult to use if the parent material surface has a contoured shape. The boron fibers are very expensive and can be hazardous for personnel. Boron fibers are used primarily in military aviation applications.

### **Ceramic Fibers**

Ceramic fibers are used for high-temperature applications, such as turbine blades in a gas turbine engine. The ceramic fibers can be used to temperatures up to 2,200 °F.

### **Lightning Protection Fibers**

An aluminum airplane is quite conductive and is able to dissipate the high currents resulting from a lightning strike. Carbon fibers are 1,000 times more resistive than aluminum to current flow, and epoxy resin is 1,000,000 times more resistive (i.e., perpendicular to the skin). The surface of an external composite component often consists of a ply or layer of conductive material for lightning strike protection because composite materials are less conductive than aluminum. Many different types of conductive materials are used ranging from nickel-coated graphite cloth to metal meshes to aluminized fiberglass to conductive paints. The materials are available for wet layup and as prepreg.

In addition to a normal structural repair, the technician must also recreate the electrical conductivity designed into the part. These types of repair generally require a conductivity test to be performed with an ohmmeter to verify minimum electrical resistance across the structure. When repairing these types of structures, it is extremely important to use only the approved materials from authorized vendors, including such items as potting compounds, sealants, adhesives, and so forth. [Figures 7-8 and 7-9]



**Figure 8.** Aluminum meshes lightning protection material.



**Figure 9.** Aluminum meshes lightning protection material.

### III. MATRIX MATERIALS

#### Thermosetting Resins

Resin is a generic term used to designate the polymer. The resin, its chemical composition, and physical properties fundamentally affect the processing, fabrication, and ultimate properties of a composite material. Thermosetting resins are the most diverse and widely used of all man-made materials. They are easily poured or formed into any shape, are compatible with most other materials, and cure readily (by heat or catalyst) into an insoluble solid. Thermosetting resins are also excellent adhesives and bonding agents.

#### Polyester Resins

Polyester resins are relatively inexpensive, fast processing resins used generally for low cost applications. Low smoke producing polyester resins are used for interior parts of the aircraft. Fiber-reinforced polyesters can be processed by many methods. Common processing methods include matched metal molding, wet layup, press (vacuum bag) molding, injection molding, filament winding, pultrusion, and autoclaving.

#### Vinyl Ester Resin

The appearance, handling properties, and curing characteristics of vinyl ester resins are the same as those of conventional polyester resins. However, the corrosion resistance and mechanical properties of vinyl ester composites are much improved over standard polyester resin composites.

#### Phenolic Resin

Phenol-formaldehyde resins were first produced commercially in the early 1900s for use in the commercial market. Urea-formaldehyde and melamine-formaldehyde appeared in the 1920–1930s as a less expensive alternative for lower temperature use. Phenolic resins are used for interior components because of their low smoke and flammability characteristics.

#### Epoxy

Epoxies are polymerizable thermosetting resins and are available in a variety of viscosities from liquid to solid. There are many different types of epoxy, and the technician should use the maintenance manual to select the correct type for a specific repair. Epoxies are used widely in resins for prepreg materials and structural adhesives. The advantages of epoxies are high strength and modulus, low levels of volatiles, excellent adhesion, low shrinkage, good chemical resistance, and ease of processing. Their major disadvantages are brittleness and the reduction of properties in the presence of moisture. The processing or curing of epoxies is slower than polyester resins. Processing techniques include autoclave molding, filament winding, press molding, vacuum bag

molding, resin transfer molding, and pultrusion. Curing temperatures vary from room temperature to approximately 350 °F (180 °C). The most common cure temperatures range between 250° and 350 °F (120–180 °C). [Figure 7-10]



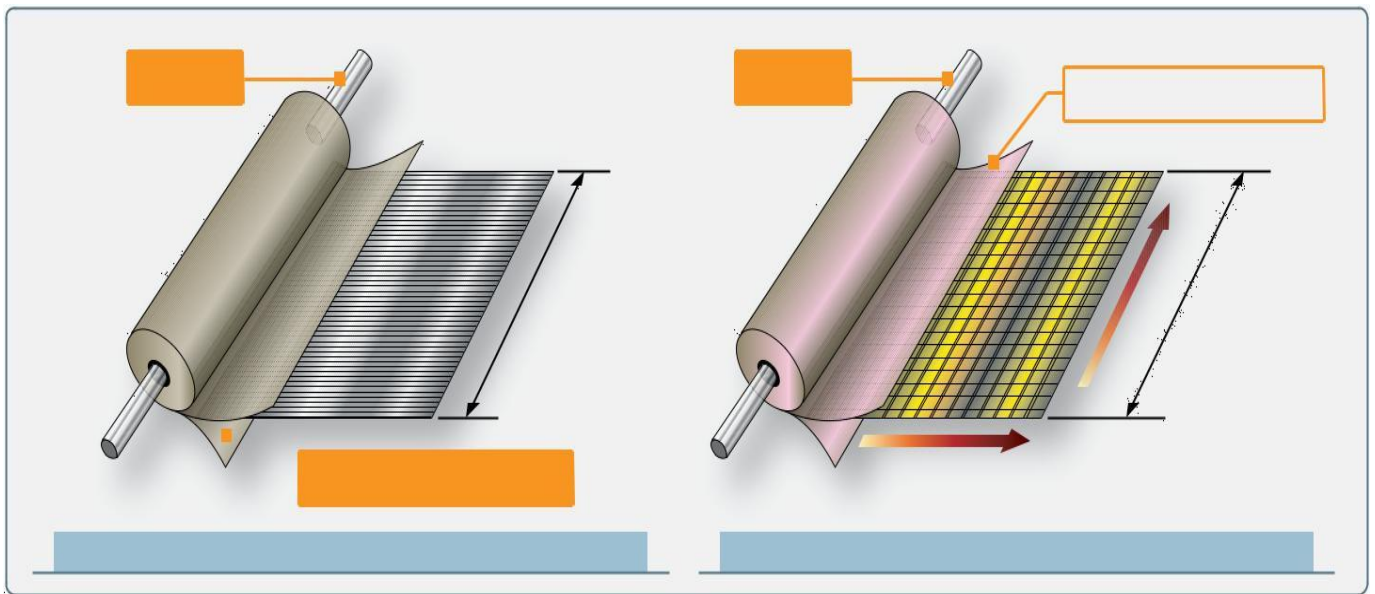
**Figure 10.** Two part wet layup epoxy resin system with pump dispenser.

### Polyimides

Polyimide resins excel in high-temperature environments where their thermal resistance,

oxidative stability, low coefficient of thermal expansion, and solvent resistance benefit the design. Their primary uses are circuit boards and hot engine and airframe structures. A polyimide may be either a thermo set resin or a thermoplastic. Polyamides require high cure temperatures, usually in excess of 550 °F (290 °C). Consequently, normal epoxy composite bagging materials are not usable, and steel tooling becomes a necessity. Polyimide bagging and release films, such as Kapton are used. It is extremely important that Upilex replace the lower cost nylon bagging and polytetrafluoroethylene (PTFE) release films common to epoxy composite processing. Fiberglass fabrics must be used for bleeder and breather materials instead of polyester mat materials due to the low melting point of polyester.

and chemical stability. The stability results in unlimited shelf life, eliminating the cold storage requirements of thermo set prepress.



**Figure 11.** Tape and fabric prepare materials.

### Dry Fiber Material

Dry fiber materials, such as carbon, glass, and Kevlar, are used for many aircraft repair procedures. The dry fabric is impregnated with a resin just before the repair work starts. This process is often called wet layup. The main advantage of using the wet layup process is that the fiber and resin can be stored for a long time at room temperature. The composite can be

cured at room temperature or an elevated temperature cure can be used to speed up the curing process and increase the strength. The disadvantage is that the process is messy and reinforcement properties are less than prepare material properties. [Figure -12]





**Figure 12.** Dry fabric materials (top to bottom: aluminum lightning protection mess, Kevlar, fiberglass, and carbon fiber).

## Adhesives

### Film Adhesives

Structural adhesives for aerospace applications are generally supplied as thin films supported on a release paper and stored under refrigerated conditions ( $-18^{\circ}\text{C}$ , or  $0^{\circ}\text{F}$ ). Film adhesives are available using high temperature aromatic amine or catalytic curing agents with a wide range of flexibilizing and toughening agents. Rubber-toughened epoxy film adhesives are widely used in aircraft industry. The upper temperature limit of  $121\text{--}177^{\circ}\text{C}$  ( $250\text{--}350^{\circ}\text{F}$ ) is usually dictated by the degree of toughening required and by the overall choice of resins and curing agents. In general, toughening of a resin results in a lower usable service temperature. Film materials are frequently supported by fibers that serve to improve handling of the films prior to cure, control adhesive flow during bonding, and assist in bond line thickness control. Fibers can be incorporated as short-fiber mats with random orientation or as woven cloth. Commonly encountered fibers are polyesters, polyamides (nylon), and glass. Adhesives containing woven cloth may have slightly degraded environmental properties because of wicking of water by the fiber. Random mat scrim cloth is not as efficient for controlling film thickness as woven cloth because the unrestricted fibers move during bonding.

Spun-bonded nonwoven scrims do not move and are, therefore, widely used.

## IV. CONCLUSION

Paste adhesives are used as an alternative to film adhesive. These are often used to secondary bond repair patches to damaged parts and also used in places where film adhesive is difficult to apply. Paste adhesives for structural bonding are made mostly from epoxy. One part and two part systems are available. The advantages of paste adhesives are that they can be stored at room temperature and have a long shelf life. The disadvantage is that the bond line thickness is hard to control, which affects the strength of the bond.

## V. REFERENCES

- [1]. Prof. Jones R.M., 1990, *Mechanics Of Composite Materials*, 2e, McGraw- Hill Book Company, New York.
- [2]. J.H.Park, J.H.Hwang, C.S.Lee, W.Hwang, 2001, "Stacking Sequence Design Of Composite Laminates For Maximum Strength Using Genetic Algorithms", *Journal Of Composite Structures*, Vol.52, Pp217- 231.
- [3]. Goldberg, D.E., 1989, "Genetic Algorithm In Search Optimization And Machine Learning", Addison-Wesley Publishing Company Inc., Reading Massachusetts.
- [4]. Johan.W.Et.Al .*Engineers Guide To Composite Materials*, American Society For Metals,1986
- [5]. T. Rangaswamy , Et.Al. " Optimal Sizing And Stacking Sequence Of Composite Drive Shafts."Issn 1392-1320
- [6]. *Materials Science* Vol.11, No.2,2005.
- [7]. Belingardi.G, Calderale.P.M. And Rosetto.M, 1990, "Design Of Composite Material Drive Shafts For Vehicular Applications", *Int. J. Of Vehicle Design*, Vol.11, No.6, Pp. 553-563.
- [8]. Jin Kook Kim. Dai Gillee, And Durk Hyun Cho, 2001, "Investigation Of Adhesively Bonded Joints For Composite Propeller Shafts", *Journal*

Of Composite Materials, Vol.35, No.11, Pp.999-1021.

- [9]. Azzi.V.D And Tsai.S.W, 1965, "Elastic Moduli Of Laminated Anisotropic Composites", Journal Of Exp. Mech, Vol.5, Pp 177-185.
- [10]. Azzi.V.D And Tsai.S.W, 1965, "Anisotropic Strength Of Composites", Journal Of Experimental .Mech. Vol.5, Pp.134-139.
- [11]. Pollard. A, 1989, "Polymer Matrix Composites In Driveline Applications", Journal Of Composite Structures, Vol.5, Pp 177-185