

CHAPTER-1

INTRODUCTION

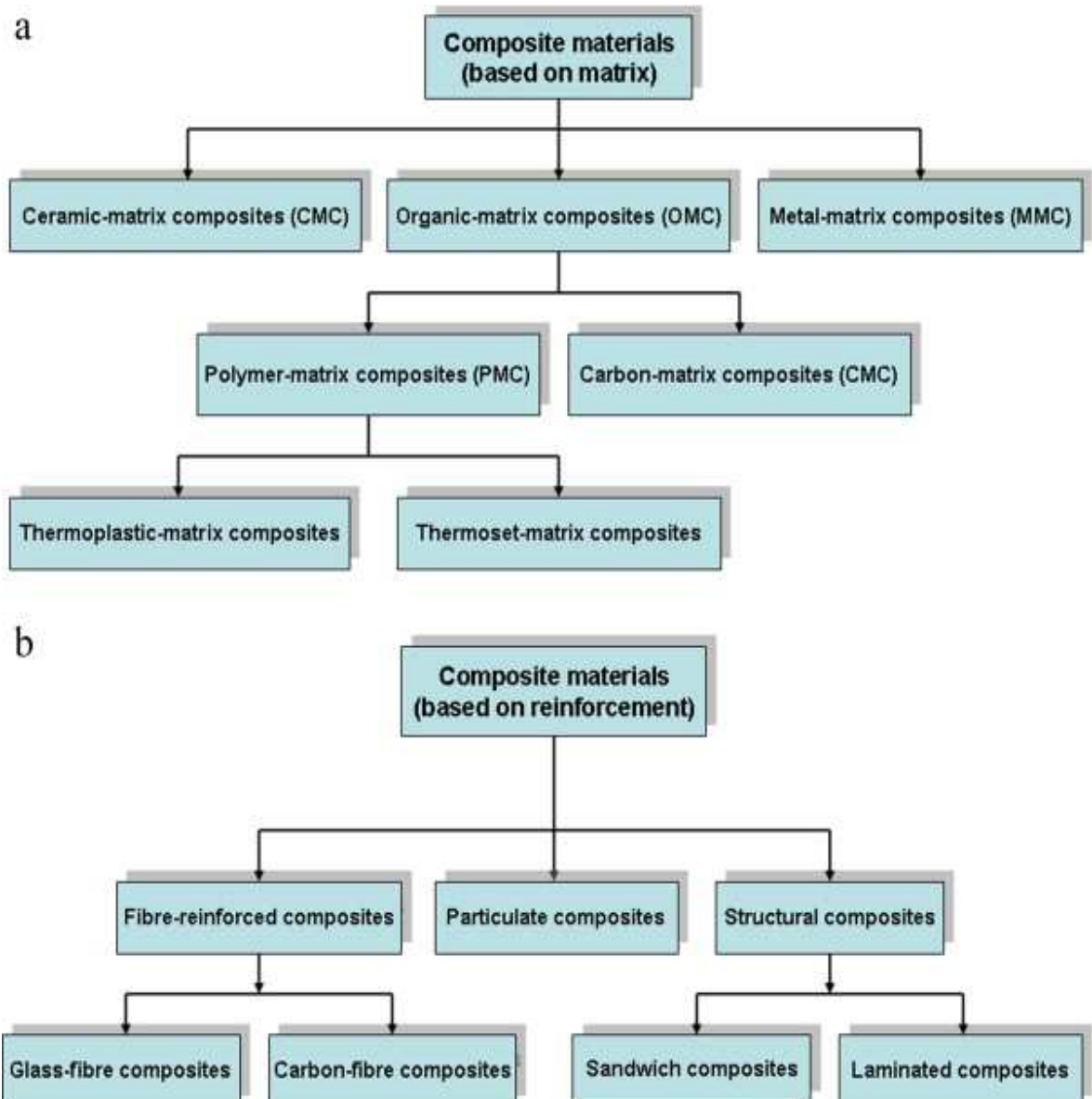
Weight is everything when it comes to heavier-than-air machines, and designers have striven continuously to improve lift to weight ratios since man first took to the air. Composite materials have played a major part in weight reduction, and today there are three main types in use: carbon fiber-, glass- and aramid- reinforced epoxy; there are others, such as boron-reinforced (itself a composite formed on a tungsten core).

Generally, a composite material is composed of reinforcement (fibers, particles, flakes, and/or fillers) embedded in a matrix (polymers, metals, or ceramics). The matrix holds the reinforcement to form the desired shape while the reinforcement improves the overall mechanical properties of the matrix. When designed properly, the new combined material exhibits better strength than would each individual material. Composites are versatile, used for both structural applications and components, in all aircraft and spacecraft, from hot air balloon gondolas and gliders, to passenger airliners, fighter planes and the Space Shuttle. Applications range from complete airplanes such as the Beech Starship, to wing assemblies, helicopter rotor blades, propellers, seats and instrument enclosures.

1.1 ADVANTAGES OF COMPOSITES IN AEROSPACE

- Weight reduction - savings in the range 20%-50% are often quoted.
- It is easy to assemble complex components using automated layup machinery and rotational molding processes.
- Mechanical properties can be tailored by 'lay-up' design, with tapering thicknesses of reinforcing cloth and cloth orientation.
- Thermal stability of composites means they don't expand/contract excessively with change in temperature (for example a 90°F runway to -67°F at 35,000 feet in a matter of minutes).
- High impact resistance - Kevlar (aramid) armor shields planes, too - for example, reducing accidental damage to the engine pylons which carry engine controls and fuel lines.
- High damage tolerance improves accident survivability.

1.2 CLASSIFICATION OF COMPOSITES:



1.3 TYPES OF FIBERS

1.3.1 Carbon fiber:

Sometimes known as graphite fiber -- is a strong, stiff, lightweight material that has the potential to replace steel and is popularly used in specialized, high-performance products like aircrafts, racecars and sporting equipment. Carbon fiber is produced by two different methods known as PAN or Pitch. Thousands of tiny strands of carbon are produced and combined to create a filament. Using textile techniques, these filaments are then woven or stitched together to create cloth like fabrics that are used in the composite structure. Standard grade carbon fibers have a good combination of strength with stiffness. With a specific modulus of 92, over 3 times that of metal (Steel and aluminum are both the same) carbon fiber / epoxy laminates are finding increasing application. Typically UTS 1.5 GPa Modulus (Ex) 130 GPa Density 1.6 g/cc.

1.3.2 Aramid fibers:

In the early 1970's, Du Pont Company introduced Kevlar aramid, an organic fiber with high specific tensile modulus and strength. This was the first organic fiber to be used as a reinforcement in advanced composites. Today this fiber is used in various structural parts including reinforced plastics, ballistics, tires, ropes, cables, asbestos replacement, coated fabrics, and protective apparel. Aramid fiber is manufactured by extruding a polymer solution through a spinneret. Major forms available from Du Pont are continuous filament yarns, roving's, chopped fiber, pulp, spun-laced sheet, wet-laid papers, thermoplastic impregnated tows, and thermoformable composite sheets. Important generic properties of aramid fibers are: low density, high tensile strength, high tensile stiffness, low compressive properties (nonlinear), and exceptional toughness characteristics. The density of aramid is 0.052 lb/in³ (1.44gm/cm³) . This is about 40% lower than glass and about 20% lower than commonly used carbon. Aramids do not melt and they decompose at about 900°F (500°C). Tensile strength of yarn, measured in twisted configuration, can be varied from 500 - 600 ksi (3.4 - 4.1 GPa) by choosing different types of aramids. Aramid fibers, being aromatic polyamide polymers, have high thermal stability and dielectric and chemical properties.

Excellent ballistic performance and general damage tolerance is derived from fiber toughness. Aramid is used, in fabric or composite form, to achieve ballistic protection for humans, armored tanks, military aircraft, and so on.

1.3.3 Glass fiber:

Glass in the forms used in commerce has been produced by many cultures since the early Etruscan civilization. Glass as a structural material was introduced early in the seventeenth century and became widely used during the twentieth century as the technology for flat pane was perfected. Glass fibrous usage for reinforcement was pioneered in replacement of metals and used for both commercial and military uses with the advent of formulation control and molten material which is die or bushing pulled into continuous filaments. These events lead to a wide range of aerospace and commercial high performance structural applications still in use today.

Due to the high quantity of commercial applications for glass products, there are many product forms available. For purposes of this publication glass forms will be limited to continuous filament product forms. These forms fall into four major categories. They are continuous roving's, yarn for fabrics or braiding, mats, and chopped strand. They are available with a variety of physical surface treatments and finishes. Most structural applications utilize fabric, roving, or roving's converted to unidirectional tapes. Perhaps the most versatile fiber type to produce glass product forms is "E" glass. "E" glass is identified as such for electrical applications. This type or grade of glass has eight or more standardized filament diameters available. These range from 1.4 to 5.1 mils (3.5 to 13 micrometers). This facilitates very thin product forms. The "S" glasses are identified as such to signify high strength. The S-2 type glasses are available with but one filament diameter. This does not limit the availability of basic structural fabric styles for S-2 glass however. Although there are more "E" roving products, as to yields, available, this has not noticeably restricted the use of S-2 type roving products or roving for unidirectional tape. S-2 type roving's are available in yields of 250, 750, and 1250 yards per lb (500, 1500, and 2500 m/kg). Although woven roving's may be considered a fabric product form it should be noted for its importance for military applications. Also, there are glass product forms which could be considered as

complimentary products for advanced structures. These would include milled fibers and chopped strand.

1.4 Resins

1.4.1 Overview

Resin is a generic term used to designate the polymer, polymer precursor material, and/or mixture or formulation thereof with various additives or chemically reactive components. The resin, its chemical composition and physical properties, fundamentally affect the processing, fabrication and ultimate properties of composite materials. Variations in the composition, physical state, or morphology of a resin and the presence of impurities or contaminants in a resin may affect handleability and processability, lamina/laminate properties, and composite material performance and long-term durability. This section describes resin materials used in polymer matrix composites and adhesives, and considers possible sources and consequences of variations in resin chemistry and composition, as well as the effects of impurities and contaminants, on resin processing characteristics and on resin and composite properties.

1.4.2 Epoxy

The term epoxy is a general description of a family of polymers which are based on molecules that contain epoxide groups. An epoxide group is an oxirane structure, a three-member ring with one oxygen and two carbon atoms. Epoxies are polymerizable thermosetting resins containing one or more epoxide groups curable by reaction with amines, acids, amides, alcohols, phenols, acid anhydrides, or mercaptans. The polymers are available in a variety of viscosities from liquid to solid.

Epoxies are used widely in resins for prepregs 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. The cost of the resin is also higher than the polyesters. 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° and 180°C).

The use temperatures of the cured structure will also vary with the cure temperature. Higher temperature cures generally yield greater temperature resistance. Cure pressures are generally considered as low pressure molding from vacuum to approximately 700 kPA

1.4.3 Polyester (thermosetting)

The term thermosetting polyester resin is a general term used for orthophthalic polyester resin or isophthalic polyester resin. Polyester resins are relatively inexpensive and fast processing resins used generally for low-cost applications. In combination with certain fillers, they can exhibit resistance to breakdown under electrical arc and tracking conditions. Isophthalic polyester resins exhibit higher thermal stability, dimensional stability, and creep resistance. In general, for a fiber-reinforced resin system, the advantage of polyester is its low cost and its ability to be processed quickly. Fiber-reinforced polyesters can be processed by many methods. Common processing methods include matched metal molding, wet lay-up, press (vacuum bag) molding, injection molding, filament winding, pultrusion, and autoclaving. Polyesters can be formulated to cure more rapidly than do phenolics during the thermoset molding process. While phenolic processing, for example, is dependent on a time/temperature relationship, polyester processing is primarily dependent on temperature. Depending on the formulation, polyesters can be processed from room temperature to 350°F (180°C). If the proper temperature is applied, a quick cure will occur. Without sufficient heat, the resin/catalyst system will remain plasticized. Compared to epoxies, polyesters process more easily and are much tougher, whereas phenolics are more difficult to process and brittle, but have higher service temperatures.

1.4.4 Phenolic

Phenol-formaldehyde resins and their direct precursors were first produced commercially in the early 1900's for use in the commercial market. Urea-formaldehyde and melamine-formaldehyde appeared in the 1920 - 1930's as a less expensive alternative for lower temperature use. Phenolics, in general, cure by a condensation route with the off-gassing of water. The resulting matrix is characterized by both chemical and thermal resistance as well as hardness, and low smoke and toxic degradation products. The phenolic polymers, often called either phenolic resole or novolacs resins are condensation polymers based upon either a reaction of excess formaldehyde with a base catalyst and phenol (resole), or a reaction of excess phenol with an acidic catalyst and formaldehyde (novolac). The basic difference between resoles and novellas consist of no methyl groups in the novellas and the resulting need for an extension agent of par formaldehyde, hexamethylenetetraamine, or additional formaldehyde as a curative. These resins have higher molecular weights and viscosities than either parent material. Consequently, they are optimal for processing parts of unusual conformations and complex curvature. The resins allow either press or autoclave cure and allow relatively high temperature free-standing postcures.

1.4.4.1 Resoles

The reaction of phenol and excess formaldehyde in the presence of base is characterized by lowmolecular- weight prepolymers that are soluble in base and contain a large degree of methylol groups (-CH₂OH). These prepolymers are processed to a workable viscosity (resites) and then cured to an intractable solid of high crosslink density. Water is lost as a volatile (as much as 10-12% of the resin by weight).

1.4.4.2 Novolacs

The second type of phenolic consists of excess phenol reacted in the presence of an acid catalyst with formaldehyde. These prepolymer resins are complex mixtures of low molecular weight materials slightly soluble in acids and exhibiting random methylene (-CH₂) at the ortho-, para-, and ortho parapositions on the aromatic ring. Unless a large excess of

phenol is present, the material will form an infusible resin. The excess phenol used to moderate the processing viscosity can be varied as the application requires. Both water and formaldehyde are volatile products.

1.4.5 Bismaleimide

Bismaleimides are a class of thermosetting resins only recently available commercially in prepreg tapes, fabrics, roving, and sheet molding compound (SMC). Bismaleimide resins, as the term implies, are the maleimide formed from the reaction of a diamine and maleic anhydride. Typically the diamine is aromatic, with methylenedianiline (MDA), the most common by far.

Bismaleimides form useful polymers by homopolymerization or by polymerization with diamines, epoxies, or unsaturated compounds, singular or in mixtures. A wide range of materials like allyl-, vinyl-, acrylate-, epoxy-, and polyester-, and phenolic-type reactive diluents and resins can be used to tailor the properties of the bismaleimide system. However, attention to the specific components is required for useful polymers.

The physical form of the bismaleimide resin depends on the requirement of the final application. The form can vary from a solid to a pourable liquid at room temperature. For aerospace prepregs, sticky resins are required resulting in proprietary specific formulations.

The advantages of BMI resins are best discussed in the relation to epoxy resins. Emerging data suggests that BMI's are versatile resins with many applications in the electronic and aerospace industries. Their primary advantage over epoxy resins is their high glass transition temperature, in the 500-600°F range (260-320°C). Glass transition temperatures for high temperature epoxies are generally less than 500°F (260°C). The second advantage of BMI resins is high elongation with the corresponding high service temperature capabilities. While the high temperature epoxies have approximately one percent elongation when cured with diaminodiphenylsulfone (DDS), BMI's can have two-three percent elongation. Thus, bismaleimide resins deliver higher temperature capability and higher toughness providing excellent performance at ambient and elevated temperatures.

1.4.6 Polyimides

The polyimide resin family comprises a diverse number of polymers all of which contain an aromatic heterocyclic ring structure. The bismaleimides discussed in Section 2.4.2.5 are a subset of this family. Other polyimides are synthesized from a variety of cyclic anhydrides or their diacid derivatives through reaction with a diamine. This reaction forms a polyamic acid which then undergoes condensation by the removal of water and/or alcohol.

Polyimide matrix composites 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 aerospace structures.

A polyimide may be either a thermoset resin or a thermoplastic. The thermoplastic varieties are discussed in Section 2.4.2.7.2. Thermosetting polyimides characteristically have cross linkable end-caps and/or a rigid polymer backbone. A few thermoplastic polyimides can become thermoset polymers if a sufficiently high postcure temperature is employed during part processing. Alternately, partially cured thermoset polyimides containing residual plasticizing solvents can exhibit thermoplastic behavior. Thus, it is difficult to state with certainty that a particular polyimide is indeed a thermoset or thermoplastic. Polyimides, therefore, represent a transition between these two polymer classifications.

Polyimide properties, such as toughness and thermal resistance, are influenced by the degree of crosslinking and chain extension. Molecular weight and crosslink density are determined by the specific end cap group and by the stoichiometry of the anhydride:amine mixture which produces the polyamic acid by stepwise chain growth, after which the polyamic acid is recycled by continued thermal cure to form the final polymer structure. The choice of solvent employed in the resin formulation has a significant impact on crosslinking and chain extension. Solvents such as N-methyl 2-pyrrolidone (NMP), promote chain extension by increasing resin flow, chain mobility and molecular weight prior to formation of a substantial crosslink network. From a practical standpoint, these solvents are beneficial to polymerization, but they are detrimental to part manufacture because of their tendency to cause ply delaminations.

Most polyimide resin monomers are powders. Some bismaleimides are an exception. As a result, solvents are also added to the resin to enable impregnation of unidirectional fiber

and woven fabrics. Commonly, a 50:50 by weight mixture is used for fabrics, and a 90:10 by weight high solids mixture is used to produce a film for unidirectional fiber and low areal weight fabric prepregs. Solvents are further used to control prepreg handling qualities, such as tack and drape. Most of the solvents are removed in a drying process during impregnation, but total prepreg volatiles contents typically range between 2 and 8% by weight. This includes all volatiles, including those produced by the condensation cure reactions.

Polyimides require high cure temperatures, usually in excess of 550°F (~90°C). Consequently, normal epoxy composite consumable materials are not usable, and steel tooling becomes a necessity. Polyimide bagging and release films, such as Kapton and 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.

1.4.7 Thermoplastic material:

1.4.7.1 Semi-crystalline

Semi-crystalline thermoplastics are so named because a percentage of their volume consists of a crystalline morphology. The remaining volume has a random molecular orientation termed amorphous, the name given to thermoplastics containing no crystalline structure. The total percentage of volume which can become crystalline depends on the polymer. Low density polyethylene, for example, can be as high as 70% crystalline. Semi-crystalline thermoplastics are characterized by the ability of their molecules to form three-dimensionally ordered arrays. This is in contrast to amorphous polymers that contain molecules which are unable to pack in an ordered crystalline structure. A partial list of semi-crystalline thermoplastics includes polyethylene, polypropylene, polyamides, polyphenylene sulfide, polyetheretherketone, (polyetherketoneketone) and polyarylketone.

Semi-crystalline thermoplastics can be converted into several physical forms, including films, powders and filaments. Combined with reinforcing fibers, they are available in injection molding compounds, compression-moldable random sheets, unidirectional tapes, towpregs, and woven prepregs. Fibers impregnated include carbon, nickel-coated carbon, aramid, glass, quartz, and others.

Semi-crystalline thermoplastics reinforced with short fibers have been used for over two decades in the injection molding industry. The inherent speeds of processing, ability to produce complicated, detailed parts, excellent thermal stability, and corrosion resistance have enabled them to become established in the automotive, electronic, and chemical processing industries.

The combination of long and continuous fibers with higher performance semi-crystalline thermoplastics is a recent development, but these composites have already shown several advantages over existing materials. The chemical stability of the materials provides for unlimited shelf life. Pot life problems and the need for cold storage are eliminated. The semi-crystalline materials usually possess better corrosion and solvent resistance than amorphous polymers, exceeding that of thermosets in some cases. This corrosion resistance is exploited in chemical processing industry equipment. Another benefit of the crystal structure is retention of properties above the glass transition temperature (T_g) of the material. These materials may be used in applications above their T_g depending on loading requirements. One example is down-hole oil field sucker rod guides.

The primary disadvantages of semi-crystalline thermoplastic composites are lack of a design data base, 0° compression properties that are lower than those of 350°F (180°C) epoxy systems, and creep resistance. The creep resistance of semi-crystalline thermoplastics is superior to that of amorphous thermoplastics. Creep resistance in the fiber direction of a laminate is not expected to be a problem.

Processing speed is the primary advantage of thermoplastic materials. Chemical curing of the material does not take place during processing. Therefore, reduced cycle times compared to thermoset composites are experienced. However, thermoplastic prepregs are typically boardy and do not exhibit the tack and drape of thermosets. Forms are available that consist of thermoplastic and reinforcing fibers interlaced together, known as commingled which are drape able. The present costs of high performance engineering thermoplastic materials are slightly higher than equivalent performance epoxies, and tooling costs may be higher. However, final part cost may be reduced, due to the decreased processing time. The ability to post form or reprocess molded parts also offers cost saving advantages.

1.4.7.2 Amorphous:

The majorities of thermoplastic polymers are composed of a random molecular orientation and are termed amorphous. The molecules are unable to align themselves in an ordered manner, since they are non-uniform or composed of units which have large side groups. In contrast, semi-crystalline thermoplastics have molecules that form ordered three-dimensional arrays. Some amorphous thermoplastics include polysulfone, polyamide-imide, polyphenylsulfone, polyphenylene sulfide sulfone, polyether sulfone, polystyrene, polyetherimide, and polyarylate.

Amorphous thermoplastics are available in several physical forms, including films, filaments, and powders. Combined with reinforcing fibers, they are also available in injection molding compounds, compressive moldable random sheets, unidirectional tapes, woven prepregs, etc. The fibers used are primarily carbon, aramid, and glass.

Amorphous thermoplastics are used in many applications; the specific use depends on the polymer of interest. Their applications are well established in the medical, communication, transportation, chemical processing, electronic, and aerospace industries. The majority of applications use the unfilled and short fiber form. Some uses for the unfilled polymers include cookware, power tools, business machines, corrosion resistant piping, medical instruments, and aircraft canopies. Uses for short-fiber-reinforced forms include printed circuit boards, transmission parts, under-the-hood automotive applications, electrical connections, and jet engine components.

The use of amorphous thermoplastics as matrix materials for continuous fiber reinforced composites is a recent development. The properties of composites have led to their consideration for primary and secondary aircraft structures, including interior components, flooring, fairings, wing skins, and fuselage sections.

The specific advantages of amorphous thermoplastics depend upon the polymer. Typically, the resins are noted for their processing ease and speed, high temperature capability, good mechanical properties, excellent toughness and impact strength, and chemical stability. The stability results in unlimited shelf life, eliminating the cold storage requirements of thermoset prepregs. Several amorphous thermoplastics also have good electrical properties, low flammability and smoke emission, long term thermal stability, and hydrolytic stability.

CHAPTER-II

FABRICATION TECHNIQUES

There are numerous methods for fabricating composite components. Some methods have been borrowed (injection molding, for example), but many were developed to meet specific design or manufacturing challenges. Selection of a method for a particular part, therefore, will depend on the materials, the part design and end-use or application.

Some of them are

- Filament Winding
- Pre-pegg
- Wet/Hand Lay-Up
- Spray Lay-Up
- Vacuum Bagging
- Pultrusion
- Resin Transfer moulding
- Resin Film Infusion

2.1 Filament winding:

This process is primarily used for hollow, generally circular or oval sectioned components, such as pipes and tanks. Fibre tows are passed through a resin bath before being wound onto a mandrel in a variety of orientations, controlled by the fibre feeding mechanism, and rate of rotation of the mandrel.

Advantages:

- This can be a very fast and therefore economic method of laying material down.
- Resin content can be controlled by metering the resin onto each fibre tow through nips or dies.
- Fibre cost is minimized since there is no secondary process to convert fibre into fabric prior to use.
- Structural properties of laminates can be very good since straight fibres can be laid in a complex pattern to match the applied loads.

Disadvantages:

- The process is limited to convex shaped components.
- Fibre cannot easily be laid exactly along the length of a component.
- Mandrel costs for large components can be high.
- The external surface of the component is unmolded, and therefore cosmetically unattractive.
- Low viscosity resins usually need to be used with their attendant lower mechanical and health and safety properties.

2.2 Pre-Pregg

Fabrics and fibres are pre-impregnated by the materials manufacturer, under heat and pressure or with solvent, with a pre-catalyzed resin. The catalyst is largely latent at ambient temperatures giving the materials several weeks, or sometimes months, of useful life when defrosted. However to prolong storage life the materials are stored frozen. The resin is usually a near-solid at ambient temperatures, and so the pre-impregnated materials (prepregs) have a light sticky feel to them, such as that of adhesive tape. Unidirectional materials take fibre direct from a creel, and are held together by the resin alone. The prepregs are laid up by hand or machine onto a mould surface, vacuum bagged and then heated to typically 120-180°C. This allows the resin to initially reflow and eventually to cure.

Advantages:

- Resin/catalyst levels and the resin content in the fibre are accurately set by the materials manufacturer. High fibre contents can be safely achieved.
- The materials have excellent health and safety characteristics and are clean to work with.
- Fibre cost is minimized in unidirectional tapes since there is no secondary process to convert fibre into fabric prior to use.
- Resin chemistry can be optimized for mechanical and thermal performance, with the high viscosity resins being impregnable due to the manufacturing process.
- The extended working times (of up to several months at room temperatures) means that structurally optimized, complex lay-ups can be readily achieved.
- Potential for automation and labour saving.

Disadvantages:

- Materials cost is higher for pre impregnated fabrics.
- Autoclaves are usually required to cure the component. These are expensive, slow to operate and limited in size.
- Tooling needs to be able to withstand the process temperatures involved.

Applications:

Aircraft structural components (e.g. wings and tail sections), F1 racing cars, sporting goods such as tennis racquets and skis

2.3 Wet/Hand Lay-Up:

Resins are impregnated by hand into fibres which are in the form of woven fabrics. This is usually accomplished by rollers or brushes, with an increasing use of roller type impregnators for forcing resin into the fabrics by means of rotating rollers.

Advantages:

- Widely used for many years.
- Simple principles to teach.
- Low cost tooling, if room-temperature cure resins are used.
- Wide choice of suppliers and material types.
- Higher fibre contents, and longer fibres than with spray lay-up

Disadvantages:

- Resin mixing, laminate resin contents, and laminate quality are very dependent on the skills of laminators. Low resin content laminates cannot usually be achieved without the incorporation of excessive quantities of voids.
- Health and safety considerations of resins. The lower molecular weights of hand lay-up resins generally mean that they have the potential to be more harmful than higher molecular weight products. The lower viscosity of the resins also means that they have an increased tendency to penetrate clothing etc.
- Limiting airborne styrene concentrations to legislated levels from polyesters and vinyl esters is becoming increasingly hard without expensive extraction systems.
- Resins need to be low in viscosity to be workable by hand. This generally compromises their mechanical/thermal properties due to the need for high diluents/styrene levels.

2.4 Spray Lay-Up:

Fibre is chopped in a hand-held gun and fed into a spray of catalyzed resin directed at the mould. The deposited materials are left to cure under standard atmospheric conditions.

Advantages:

- Widely used for many years.
- Low cost way of quickly depositing fibre and resin.
- Low cost tooling.

Disadvantages:

- Laminates tend to be very resin-rich and therefore excessively heavy.
- Only short fibres are incorporated which severely limits the mechanical properties of the laminate.
- Resins need to be low in viscosity to be sprayable. This generally compromises their mechanical/thermal properties.
- The high styrene contents of spray lay-up resins generally means that they have the potential to be more harmful and their lower viscosity means that they have an increased tendency to penetrate clothing etc.
- Limiting airborne styrene concentrations to legislated levels is becoming increasingly difficult.

2.5 Vacuum bagging:

This is basically an extension of the wet lay-up process described above where pressure is applied to the laminate once laid-up in order to improve its consolidation. This is achieved by sealing a plastic film over the wet laid-up laminate and onto the tool. The air under the bag is extracted by a vacuum pump and thus up to one atmosphere of pressure can be applied to the laminate to consolidate it .

Advantages:

- Higher fibre content laminates can usually be achieved than with standard wet lay-up techniques.
- Lower void contents are achieved than with wet lay-up.
- Better fibre wet-out due to pressure and resin flow throughout structural fibres, with excess into bagging materials.
- Health and safety: The vacuum bag reduces the amount of volatiles emitted during cure.

Disadvantages:

- The extra process adds cost both in labour and in disposable bagging materials
- A higher level of skill is required by the operators
- Mixing and control of resin content still largely determined by operator skill

Applications:

Large one-off cruising boats, racecar components and core-bonding in production boats

2.6 Pultrusion:

Fibres are pulled from a creel through a resin bath and then on through a heated die. The die completes the impregnation of the fibre, controls the resin content and cures the material into its final shape as it passes through the die. This cured profile is then automatically cut to length. Fabrics may also be introduced into the die to provide fibre direction other than at 0° . Although Pultrusion is a continuous process, producing a profile of constant cross-section, a variant known as 'Pull forming' allows for some variation to be introduced into the cross-section. The process pulls the materials through the die for impregnation, and then clamps them in a mould for curing. This makes the process non-continuous, but accommodating of small changes in cross-section.

Advantages:

- This can be a very fast, and therefore economic, way of impregnating and curing materials.
- Resin content can be accurately controlled.
- Fibre cost is minimized since the majority is taken from a creel.
- Structural properties of laminates can be very good since the profiles have very straight fibres and high fibre volume fractions can be obtained.
- Resin impregnation area can be enclosed thus limiting volatile emissions

Disadvantages:

- Limited to constant or near constant cross-section components
- Heated die costs can be high.

2.7 Resin Transfer Molding (RTM):

Fabrics are laid up as a dry stack of materials. These fabrics are sometimes pre-pressed to the mould shape, and held together by a binder. Then these 'preforms' are more easily laid into the mould tool. A second mould tool is then clamped over the first, and resin is injected into the cavity. Vacuum can also be applied to the mould cavity to assist resin in being drawn into the fabrics. This is known as Vacuum Assisted Resin Injection (VARI). Once all the fabric is wet out, the resin inlets are closed, and the laminate is allowed to cure. Both injection and cure can take place at either ambient or elevated temperature.

Advantages:

- High fibre volume laminates can be obtained with very low void contents.
- Good health and safety, and environmental control due to enclosure of resin.
- Possible labor reductions.
- Both sides of the component have a molded surface.

Disadvantages:

- Matched tooling is expensive and heavy in order to withstand pressures.
- Generally limited to smaller components.
- Un impregnated areas can occur resulting in very expensive scrap parts.

Applications:

Small complex aircraft and automotive components.

2.8 Resin Film Infusion:

Dry fabrics are laid up interleaved with layers of semi-solid resin film supplied on a release paper. The lay-up is vacuum bagged to remove air through the dry fabrics, and then heated to allow the resin to first melt and flow into the air-free fabrics, and then after a certain time, to cure.

Advantages:

- With low void contents, high fibre volumes can be accurately achieved.
- Good health and safety and a clean lay-up, like prepregs.
- High resin mechanical properties due to solid state of initial polymer material and elevated temperature cure.
- Potentially lower cost than prepregs, with most of the advantages.
- Less likelihood of dry areas than SCRIMP process due to resin travelling through fabric thickness only.

Disadvantages:

- An oven and vacuum bagging system is required to cure the component as for prepregs, although the autoclave systems used by the aerospace industry are not always required.
- Tooling needs to be able to withstand the process temperatures of the resin film
- Core materials need to be able to withstand the process temperatures and pressures.

Applications:

Aircraft radomes and submarine sonar domes.

CHAPTER-III

SELECTION OF MATERIALS

3.1 E-Glass Fabric

E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fibre forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as fibreglass.

The use of E-Glass as the reinforcement material in polymer matrix composites is extremely common. Optimal strength properties are gained when straight, continuous fibers are aligned parallel in a single direction. To promote strength in other directions, laminate structures can be constructed, with continuous fibers aligned in other directions. Such structures are used in storage tanks and the like.

2.1.1 Technical specifications:

1. Nomenclature	:	13 MILL E-GLASS FABRIC
2. Thickness, mm	:	0.36
3. Width, inch	:	40"
3. Weave	:	4 Harness Satin
4. Construction		
Warp, Threads/inch:		48
Weft, Threads/inch:		36
5. Weight per Sq.mtr	:	455.400 gms
6. Breaking Strength per 50 mm	:	
Warp	:	383.000 Kgs
Weft	:	258.000 Kgs

3.1.2 ACCEPTANCE TEST PROCEDURE

Breaking Strength:

The breaking strength of the fabric shall be inspected as per ASTM D1682.
3 specimens of Warp and 3 specimens of weft shall be tested.

- The acceptance value shall be Warp 191 Kg/inch and Weft 129 Kg/inch.

- Cut the samples of fabric, that is
25mm width --- 48 threads for warp sample and 36 threads for weft

3.2 Resin and Hardener

Resin and hardener used in this project are Lapox L-12 (Resin) and K-6 (Hardener)

Lapox L-12 is a liquid, unmodified epoxy resin of medium viscosity which can be used with various hardeners for making glassfibre reinforced composites. The choice of hardener depends on the processing method to be used and on the properties required of the cured composite.

Hardener K6 is a low viscosity room temperature curing liquid hardener. it is commonly employed for hand layup applications. Being rather reactive , it gives a short pot life and rapid cure at normal ambient temperatures.

3.2.1 Technical Specifications:

Lapox L-12

Epoxy equivalent	182-192 gm/eq
Epoxy value	5.2-5.5 eq/kg

Hardener K-6

Visual appearance	Pale yellow liquid
Refractive index at 25°C	1.4940-1.5000

PROPERTIES OF CURED RESIN WITHOUT REINFORCEMENT

Tensile strength	50-60	N/mm ²
Compressive strength	110-120	N/mm ²
Flexural strength	130-150	N/mm ²
Impact strength	17-20	KJ/mm ²
Modulus of elasticity	4400-4600	N/mm ²
Thermal conductivity	0.211	kcal/mh°C
Thermal expansion	64-68	10 ⁻⁶ /°C

CHAPTER-IV

CALIBRATION OF THERMOCOUPLE AND TEMPERATURE INDICATOR

Introduction:

The thermocouple is the most common type of temperature sensor, primarily because it is inexpensive and easy to use. In fact, it is used in many places familiar to you: in the home, it is used to control the temperature of the furnace, water heater, and the kitchen oven; in the automobile, it is used to monitor coolant and oil temperature, and even to control the air conditioner. It is not the most accurate technique available to measure temperature – typical thermocouples are accurate to around $\pm 0.5^{\circ}\text{C}$ – but for many applications this accuracy is acceptable.

Thomas Johann Seebeck discovered that a circuit comprised of dissimilar metals produces a voltage (and current) when the two dissimilar junctions are exposed to different temperatures. This phenomenon, called the Seebeck Effect. The voltage produced is proportional to the temperature difference between the junctions. The voltage produced is small, on the order of millivolts, so it is not very suitable for producing power. But the device can easily be calibrated to measure temperature.

Equipment:

1. Thermocouple kit
2. Mercury Bulb Thermometer
3. Beakers
4. Heat Source

Procedure:

- Make a water bath by filling the beaker with water.
- Place the J-type (Iron-Constantan) thermocouple bead and Mercury Bulb Thermometer in the water bath as shown in the diagram.
- Begin heating the water, setting the heat source to 50% power. At increments of approximately 10°C, Note the thermocouple temperature reading and the corresponding temperature indicated by the thermometer.
- At about 80°C, increase the hot plate setting to high. Continue taking data for about a minute after the water begins boiling. Record the temperature of the water at full boil.
- Plot the graph (Calibration Chart) between Temperature indicated by thermometer and Indicated by gauge.

Temperature indicated by thermometer(°C)	Temperature Indicated by gauge (°C)
30	
40	
50	
60	
70	
80	
90	

CHAPTER-V

EXPERIMENTAL METHOD

Fabrication of E-Glass Epoxy Laminates Composites

A single layer of a laminated composite material is generally referred to as a ply or laminate. It usually contains a single layer of reinforcement, unidirectional or multidirectional. A single lamina is generally too thin to be directly used in any engineering application. Several laminae are bonded together to form a structure termed as laminate. Properties and orientation of the laminae in a laminate are chosen to meet the laminate design requirements. Properties of a laminate may be predicted by knowing the properties of its constituent laminae.

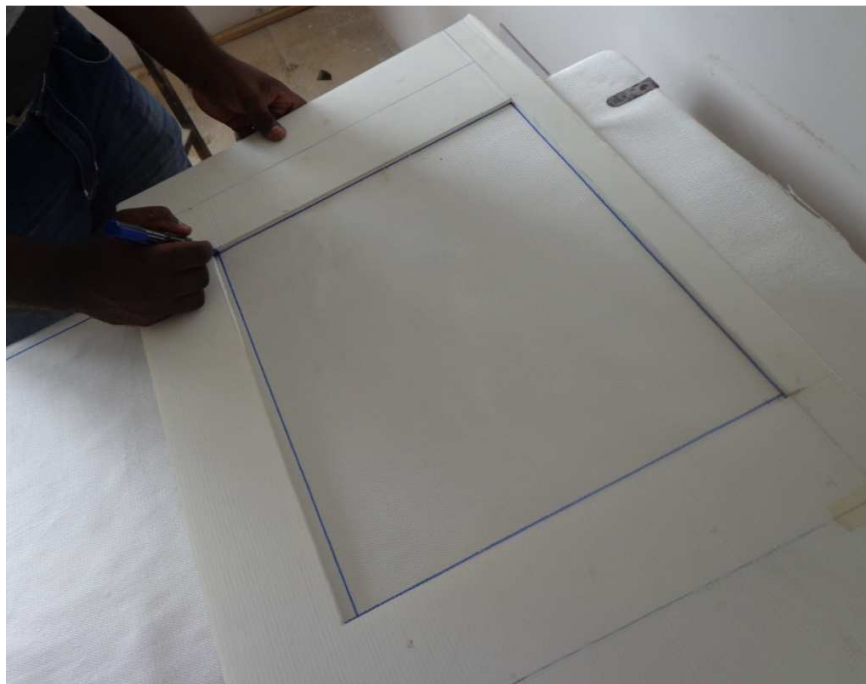
In this experimental work the following types of laminates were made with different orientations:

- **0°/0° - -** (all plies are in 0° direction)
- **0°/90° -** (0/90/0/90/0/90/0/90/0/90/0/90)
- **±45° -** (+45/-45/+45/-45/+45/-45/+45/-45/+45/-45/+45/-45)
- **0°/90°/±45°** (+45/0/90/-45/+45/0/0/+45/-45/90/0/+45)
- **0°/0°(3mm)** (for making tabs)

- **Step 1:** The fabric is laid on work bench which is covered with polythene sheet.



- Marking is taken by using 0° , 90° and 45° templates with mould dimensions 390mmx340mm respectively.



- **Step 2:** Resin is weighed as per specifications of fabric that is 1050gms for 12 plies, pigmented (5%) for colored surface typically white is chosen and hardener is added in the ratio of (10% i.e. 105gms). Epoxy is stirred well.



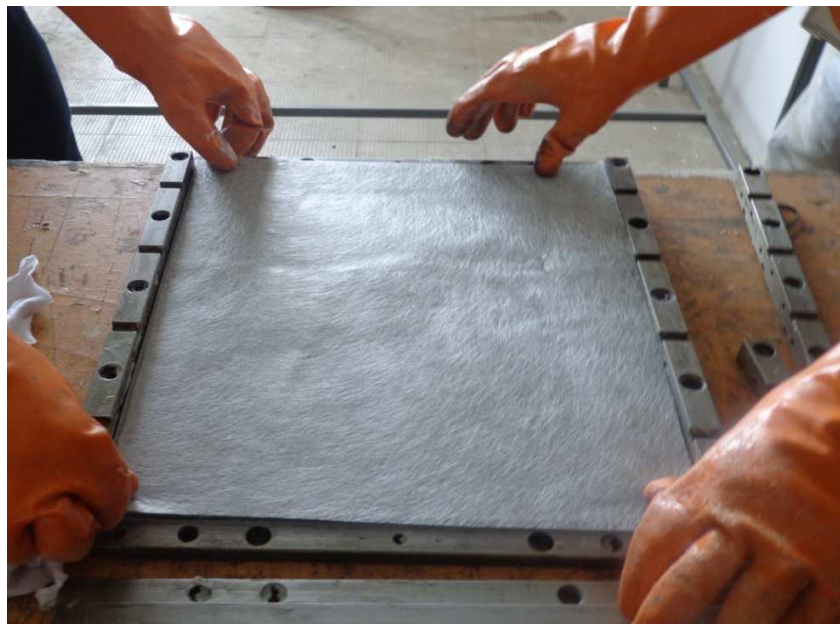
- **Step 3:** Bonding agent (epoxy resin) is applied to create bonding between layers. This is usually accomplished by rollers or brushes, with an increasing use of roller type impregnators for forcing resin into the fabrics by means of rotating rollers.

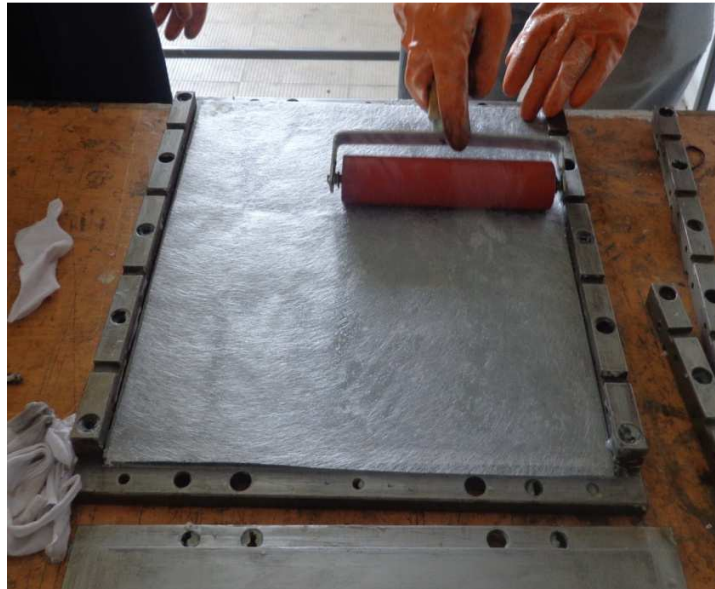


- **Step 4:** The surface of the mould is cleaned with 0-grade Emery paper, the clearance holes are cleaned with jewellery files, also cleaned with acetone and a release agent (waxpol) is applied. If the surface is not clean, then the release agent will not function properly.



- **Step 5:** An optional sacrificial layer (Surface mat) is laid up on the mould surface. This layer is usually a fiberglass fabric made with the same resin system as the composite laminate. The sacrificial layer protects the laminate from surface abrasion and surface irregularities during manufacturing.



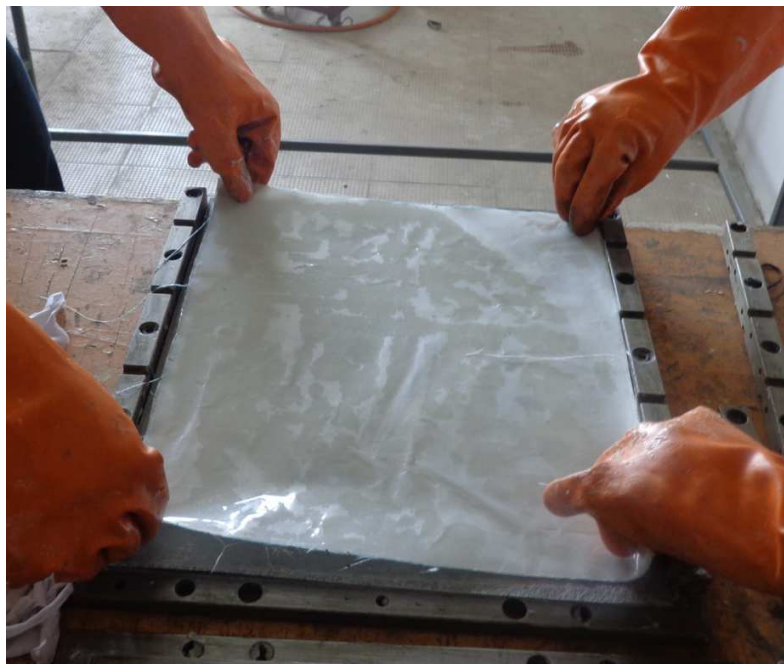


➤ **Step 6:** Impregnated Plies are cut to the required size.





➤ **Step 7:** The first pre-peg ply is oriented and placed upon the mold.



A roller or other small hand tool is used to compact the plies and remove entrapped air that could later lead to voids or layer separations.



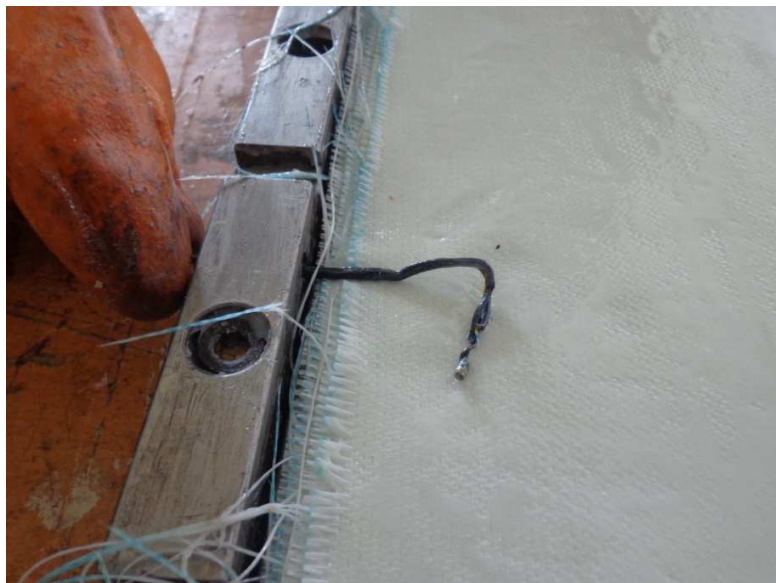
The polythene sheet is peeled from the ply.



It is important that the pre impregnated material have sufficient tack so that it sticks slightly to the peel ply and to the adjacent plies.



- **Step 8:** Thermocouple bead is placed on middle ply just about 3mm from the spacer clearance hole to get the exact temperature reading of the laminate.



Subsequent plies are placed one upon another. These plies are stacked layer by layer of about 12 layers to attain the thickness of 5mm as per the ASTM Standard Specimen.

- **Step 9:** Another surface mat is placed on the top of laminate to protect the laminate surface.





Step 10: Then the mould is closed with punch



➤ tightened with specified torque.



Torque is applied on the tool (Mould), causing the excess resin to flow of the clearance holes. The resin flow is critical, since it allows the removal of entrapped air and volatiles from the prepreg and thus reduces the void content in the cured laminate.



Curing

The mould is now kept in the oven for curing,



The process of polymerization is called "curing", and can be controlled through temperature and choice of resin and hardener compounds; the process can take minutes to hours. Some formulations benefit from heating during the cure period, whereas others simply require time, and ambient temperatures.



The first stage in this cure cycle consists of increasing the temperature up to 100 °C and dwelling at this temperature for nearly 60 minutes when the minimum resin viscosity is reached. During this period of temperature dwell, 30KN/m Torque is applied on the tool (Mould), causing the excess resin to flow of the clearance holes



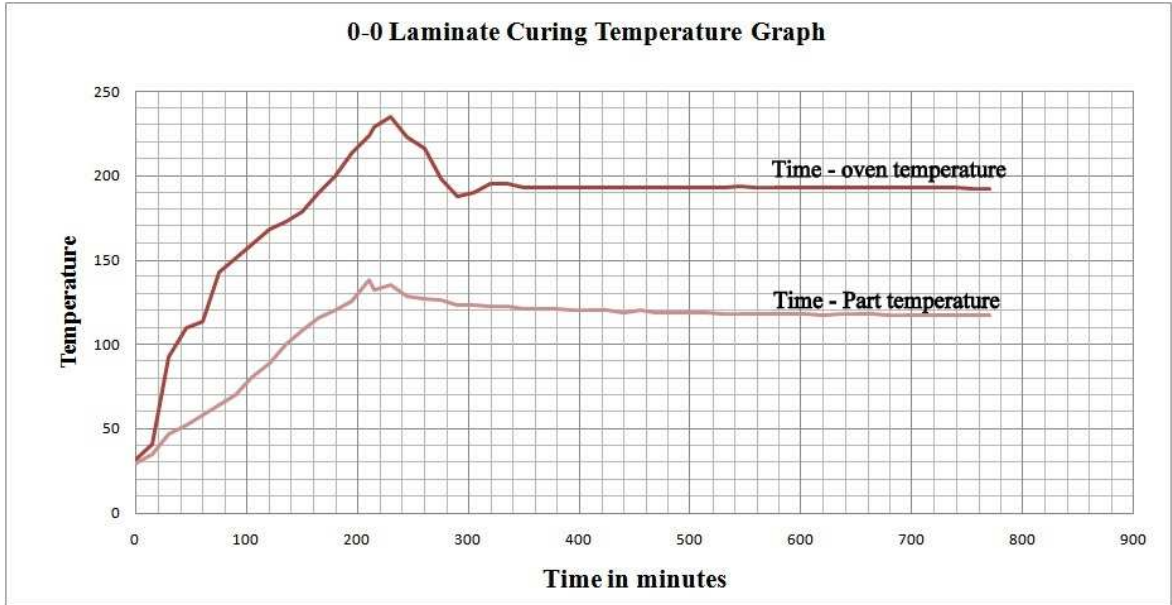
At the end of the temperature dwell, the oven temperature is increased to the actual curing temperature for the resin that is 200°C. After setting the oven temperature to 200°C the part temperature slightly increases to 160°C, The laminate temperature is maintained for 4 hours or more, until a pre-determined level of cure has occurred. At the end of the cure cycle, the temperature is slowly reduced.

One of the first concepts in evaluating data is to collect them in a rigorous manner. Once the data have been gathered, the data should almost always be plotted in some fashion. Graph is plotted between time and part temperature/oven temperature.

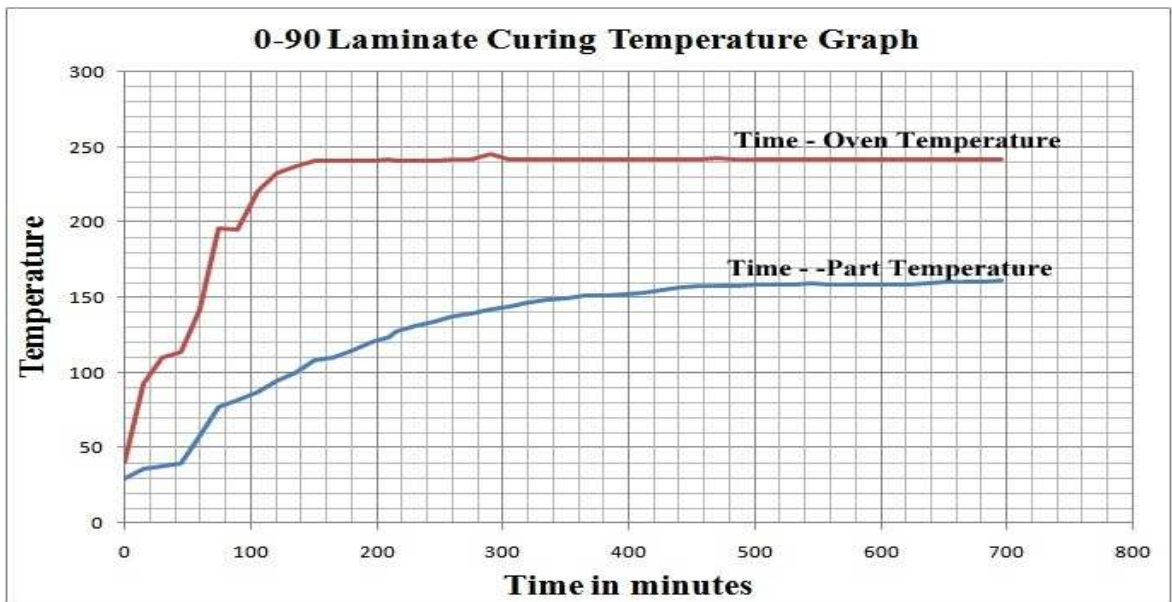
The format of data collected for each mould during curing.

TIME	ELAPSED TIME FROM STARTING (min)	TEMP SETTING IN THERMOSET(°C)	ACTUAL TEMP OF PART(°C)	OVEN TEMP	CORRECTED PART TEMP
9:15	0	200	26	26	25
9:30	15	200	32	170	31
9:45	30	200	41	189	40
10:00	45	200	47	195	46
10:15	60	200	54	192	53
10:30	75	200	61	193	60
10:45	90	200	67	193	66
11:00	105	200	73	193	71
11:15	120	200	78	193	76
11:30	135	200	77	148	75
11:45	150	200	85	192	83
12:00	165	200	88	195	86
12:15	180	200	93	193	91
12:30	195	200	97	194	95
12:45	210	200	100	193	97
13:00	215	200	104	196	101
13:15	230	200	107	192	104

The following are the graphs of each laminate:



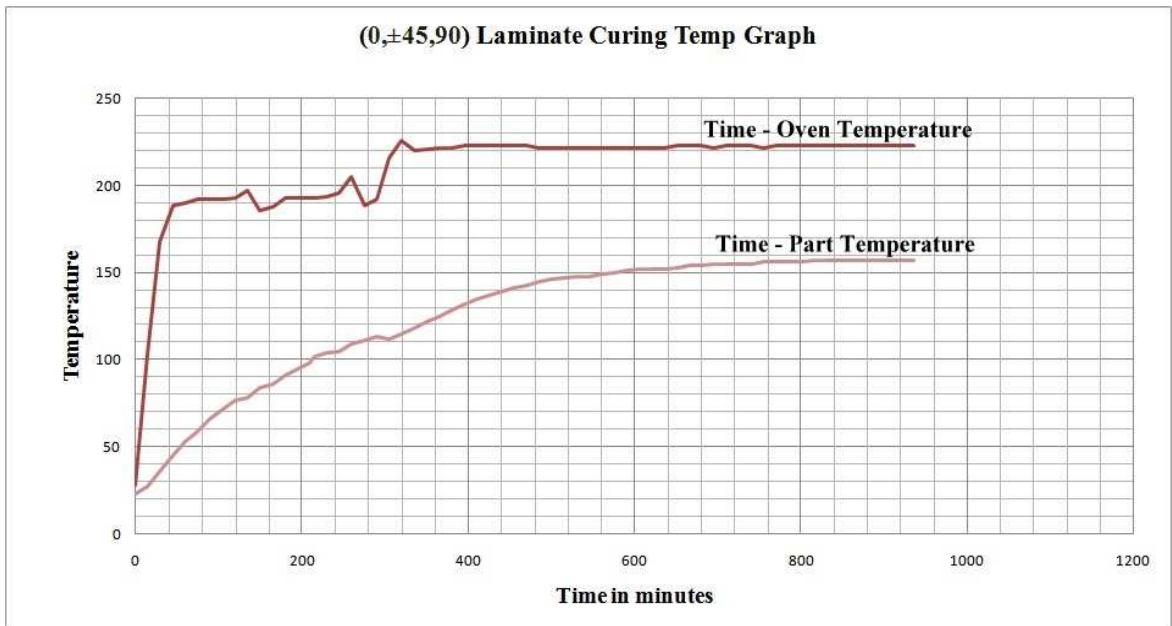
The total curing is done in 13 hrs, The part took 3 hrs to reach 120°C. The part temperature is maintained for 10 hrs.



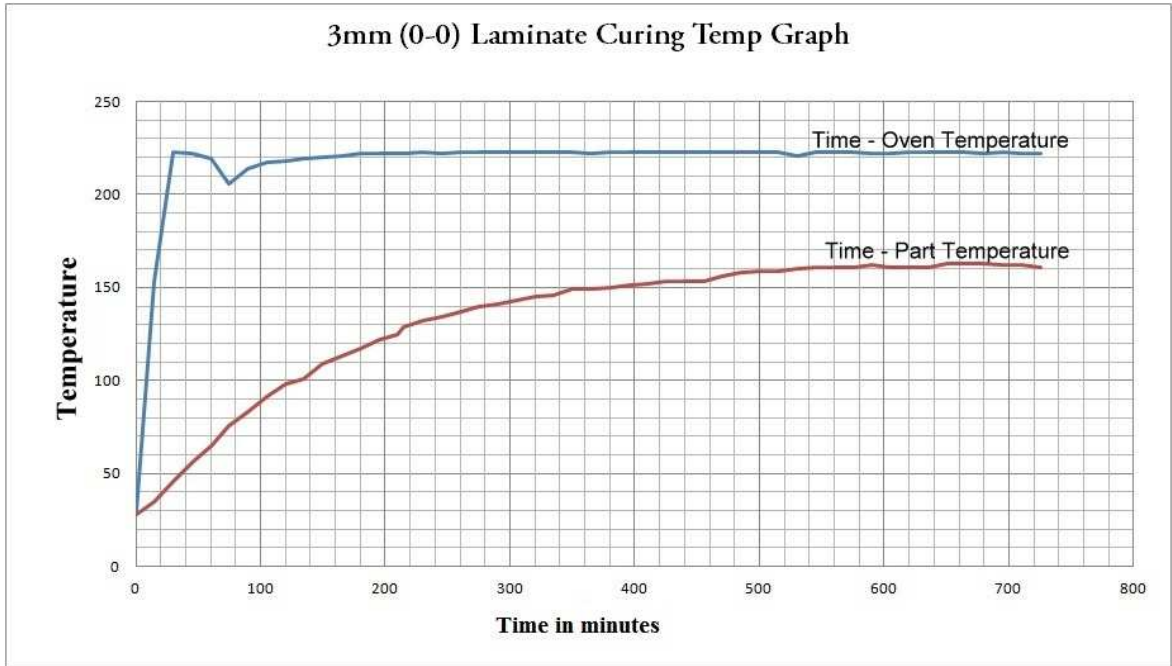
The total curing is done in 11½ hrs, The part took 6 hrs to reach 160°C. The part temperature is maintained for 5½ hrs.



The total curing is done in 12 hrs, The part took 7½ hrs to reach 160°C. The part temperature is maintained for 4½ hrs.



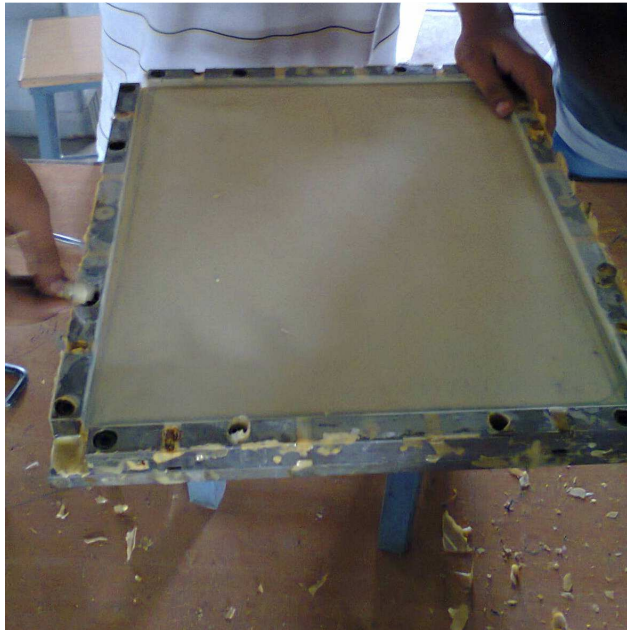
The total curing is done in 15½ hrs, The part took 10 hrs to reach 160°C. The part temperature is maintained for 5½ hrs.



The total curing is done in 12 hrs, The part took 7½ hrs to reach 160°C. The part temperature is maintained for 4½ hrs.

When the part is sufficiently cured, the mold is opened and the part is removed







CHAPTER-V

PREPARATION OF TABBED SPECIMENS

. Finished molding must usually be trimmed with a handsaw to size outside edges.



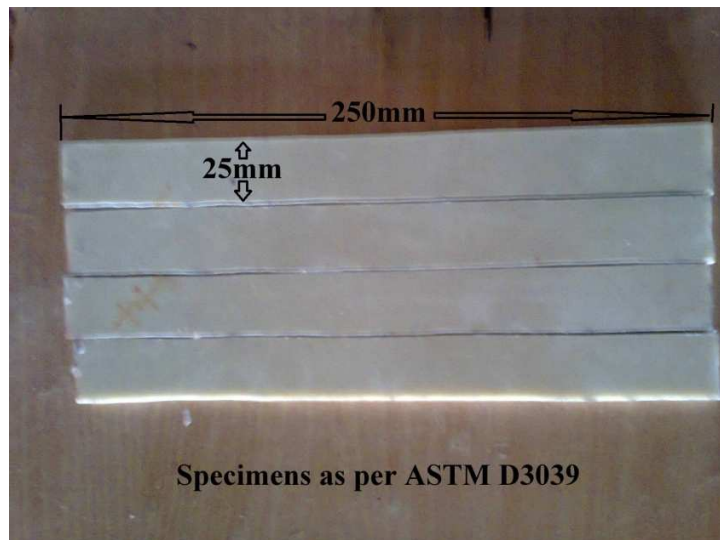
Trimming the edges of Cured Laminate

Cutting Specimens:

- Clamp the laminate appropriately so that it does not shift during cutting.
- Clamp the specimen with a rubber pad (or) wooden block to absorb vibration from the operation.
- Begin the cut with a lower load to set the blade.
- Use largest appropriate blade flanges to prevent the blade from becoming distorted.

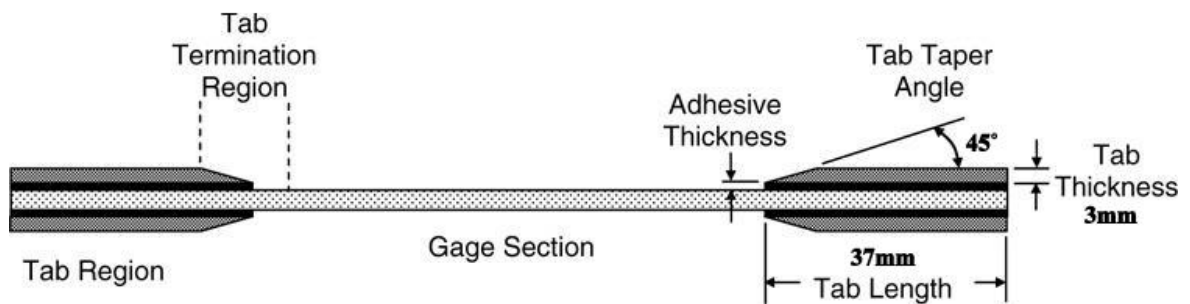


The laminate fabricated is cut as per ASTM-D3039 (length 250mm and width 25mm) using Handsaw.



TABBING

The purpose of tabbing a composite specimen is to introduce load into the test specimen without producing premature failure in an undesired failure mode. Thus, a successful tab configuration design is one that produces a valid failure mode within the central gage section of the specimen. Thus, a main focus when designing a tab configuration is to minimize stress concentrations within the tab region of the specimen. Other considerations include the ability of the tab material and adhesive to transmit the required load into the composite specimen during testing and their ability to withstand the environment used to fabricate and test the specimens.



Tabbed specimen

2.1 Tabbing material selection:

The tabbing material must be capable of transmitting adequate load into the composite specimen to produce the desired specimen failure prior to a shear or compressive failure of the tab material itself. Another desirable feature is the selection of relatively low cost materials that may be machined using the same techniques to be used to machine the composite material.

A glass fabric/epoxy laminate (3mm) is an excellent choice for tabbing material. Main focus when designing a tab configuration is to minimize stress concentrations within the tab region of the specimen.

Geometry design:

- Tab thickness : 3mm
- Tab length : 37mm/1½inch
- Tab taper angle : 45°

There are several methods that may be used to produce a taper angle on a tabbing strip. One method is to place the tabbing strip on a belt sander at the desired angle and sand away the edge of the tabbing material. An angle guide may be used to hold the tabbing strip in the proper orientation when sanding.



Taper produced on Tabbing strip

Selection of Adhesive:

Adhesive transmits the required load into the composite specimen during testing. Adhesive selection is no less important than tabbing material selection. The adhesive must be able to transmit the required load into the test specimen through shear and must withstand the compressive force applied by the grips. Other desirable features include workability and readily available at a reasonable cost.

Attaching Tabs to the Specimens:

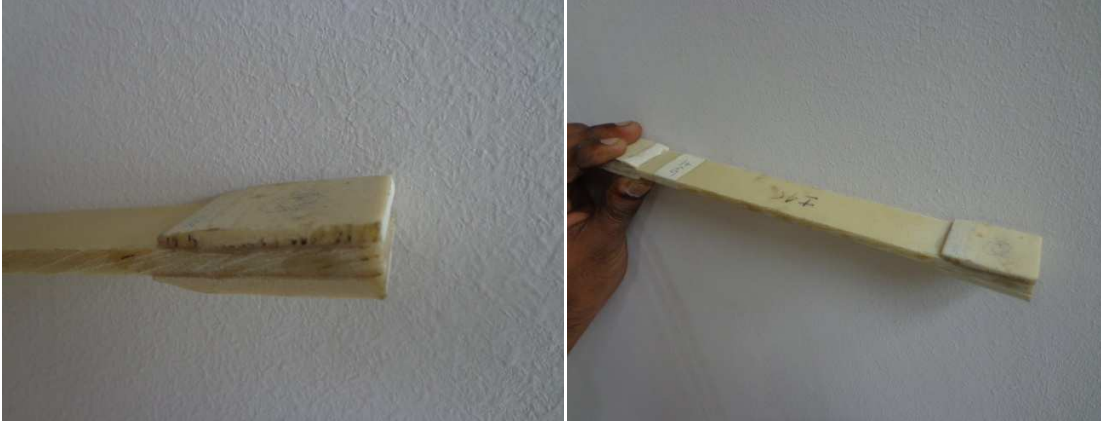
Sanding may be performed by 100 grade emery paper. Sand tabs and in the tab regions of the specimen. Apply a thin, uniform coat of adhesive to the tabbed regions of the subpanel and the bonding surface of the tabbing strips. The amount of adhesive needed will be dependent on the desired bond line thickness. Applying excessive quantities of adhesive will cause additional adhesive to spew from the edges of the tabbed region, requiring additional cleanup.

Once the adhesive-coated tabbing strips have been applied to the adhesive-coated specimens and taped to the gage section spacer, place the assembly onto a flat, level surface. The surface should be covered by a nonporous release film in the event that excess adhesive is released. Two small C-clamps can be attached to the tabs on either side (or) Place weights on top of the upper tabbing strips, taking precautions to keep them away from the edges where excess adhesive is being squeezed out.



Weights placed on tabbed specimens

Once the adhesive is fully cured, remove the weights from the tabbing strips and separate the tabbed specimen. No gaps or voids should be present in the adhesive layer along this tab edge. If any excess adhesive exists along the reference edge of the panel, carefully remove the adhesive using a knife or sandpaper.



CHAPTER-VI

ARCHIMEDES PRINCIPLE

Density of Composite (ASTM-D-792)

Density of composite is determined by Archimedes principle, any object, completely or partially immersed in a fluid is buoyed by a force equal to the weight of the fluid displaced by the object.

Theory:

Whenever a solid body is immersed in a fluid, it displaces a volume of fluid equal to its own volume. Since the displaced fluid was in equilibrium with the surrounding fluid before being displaced, meaning the buoyant force on the displaced fluid was equal to its weight, an equal buoyant force will be exerted on the specimen. In other words, for any solid body the buoyant force acting on it is equal to the weight of the fluid displaced.

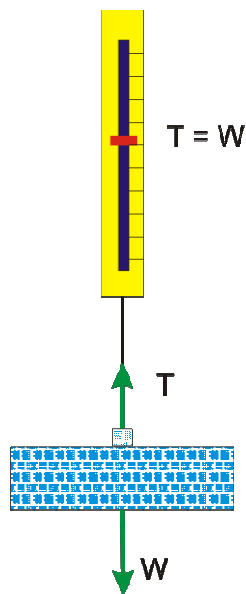


Figure 2: Measuring the weight of the specimen in air.

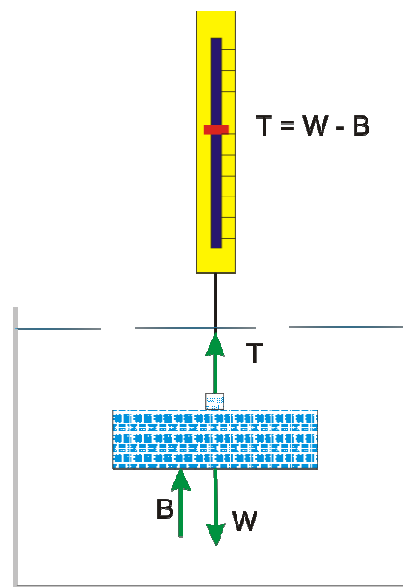


Figure 3: Measuring the weight of the specimen in water.

The density of specimen ρ , is defined as the ratio of an composite sample's mass to its volume. Specific gravity is the ratio of the density of a sample to the density of some other substance that has been chosen to act as a standard. Water, at room temperature, is generally chosen as this standard.

1. The weight of the sample W , which can be expressed in terms of the sample's density as,

$$W = m_b g = \rho_b V_b g$$

Where m_b is the mass of the sample, V_b is volume of the sample, ρ_c is the density of the sample and g is the acceleration due to gravity.

2. The buoyant force B : This can be expressed as,

$$B = W_{\text{fluid displaced}} = \rho_{\text{fluid}} V_{\text{fluid}} g = \rho_{\text{fluid}} V_b g$$

Where $W_{\text{fluid displaced}}$ is the weight of the fluid displaced, ρ_{fluid} is the density of the fluid, V_{fluid} is the volume of the fluid displaced, V_b is the volume of the specimen. Notice that the last equality comes from the fact that a submerged solid object will displace a volume of fluid equal to its own volume.

$$\text{Density of specimen} = \frac{\text{Density of fluid} \times \text{weight of specimen}}{\text{weight of fluid displaced}}$$

CHAPTER-VII

RESIN BURNOFF TEST (ASTM D-2584)

The weight fractions are obtained experimentally using "Resin Burnoff Test" utilizing muffle furnace and precision weighing balances. Based on this, Compute volume fractions of the reinforcement and thereby predict the load to failure.

This method is designed to determine the resin content percent of prepreg which is reinforced with inorganic fabric, by removal of the resin from the reinforcement using a burn-off test.

Apparatus:

- **Precision Balance:** Precision balance capable of weighing to the nearest milligram [0.001 gram].
- **Muffle Furnace:** Muffle furnace capable of maintaining 600°C.
- **Crucible:** Crucible of sufficient size and type to hold the specimen when placed in a muffle furnace.
- **Cutting Apparatus:** Hand saw or other equipment capable of cutting specimens to the specified size.

Procedure:

- Samples with size ½inch x ½inch cut from laminate and weighed.
- The test is done in the Muffle furnace.
- After temperature reaches to 600°C, Place the crucible containing the specimen in the muffle furnace for 60 minutes, minimum.
- The resin gets evaporated at this temperature and fabric plies are remained in the crucible.
- The weight of the fabric is measured in Precision balance.
- The difference between total weight of the test piece and fabric plies will give the resin content in the laminate.

w_c = weight of composite.

w_f = weight of fabric , w_m = weight of resin/matrix.

$$\mathbf{W_f} = \text{weight fraction of fabric} = \frac{\text{weight of fabric}}{\text{weight of composite}}$$

$$\mathbf{W_m} = \text{weight fraction of matrix} = \frac{\text{weight of matrix}}{\text{weight of composite}}$$

- The test done with 4 samples.

S.NO	w_c (gms)	w_f	w_m	$\mathbf{W_f}$	$\mathbf{W_m}$
1	1.611	0.967	0.644	0.6002483	0.399752
2	1.605	0.966	0.639	0.6018692	0.398131
3	1.506	0.906	0.6	0.6015936	0.398406
4	1.447	0.868	0.579	0.5998618	0.400138

Testing

The mechanical tests were carried out in an Universal testing machine. The Universal testing machine is a highly accurate instrument. It comprises of a standing frame designed for testing in either tension or compression and a microprocessor based console. The frame has a maximum load capacity of 100kN. A moving crosshead can be operated on the frame through two vertical ball screws in a drive system with positional electronic control servo mechanism.

ASTM D3039 tensile testing is used to measure the force required to break a polymer composite specimen and the extent to which the specimen stretches or elongates to that breaking point. Tensile tests produce a stress-strain diagram, which is used to determine tensile modulus. The data is often used to specify a material, to design parts to withstand application force and as a quality control check of materials. Since the physical properties of many materials can vary depending on ambient temperature, it is sometimes appropriate to test materials at temperatures that simulate the intended end use environment.

Test procedure:

- Specimens are placed in the grips of a Universal Test Machine at a specified grip separation and pulled until failure. For ASTM D3039 the test speed can be determined by the material specification or time to failure (1 to 10 minutes). A typical test speed for standard test specimens is 2 mm/min (0.05 in/min). An extensometer or strain gauge is used to determine elongation and tensile modulus. Depending upon the reinforcement and type, testing in more than one orientation may be necessary.
- State-of-the-art equipment including Align-pro for reduced bending.

