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ABSTRACT

Advanced composites such as fibre, reinforced polymer matrix composites are being used for mechanical applications because of their high specific strength, specific modulus and low density. A structural composite laminate were prepared using high strength PAN carbon fabric and epoxy resin system by hand layup and match die moulding. The laminates were characterized for physical, mechanical and thermal properties and their application in structural backup of divergent liner has been evaluated. Effects of consolidation on mechanical properties of composites were also evaluated.

A **Composite Material** (also called a composition material or shortened to composite) is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components. The individual components remain separate and distinct within the finished structure. The new material may be preferred for many reasons: common examples include materials which are stronger, lighter, or less expensive when compared to traditional materials.

Fiber reinforced polymer is extensively used in many fields of engineering such as aerospace engineering and mechanical engineering. These materials due to their light weight, High specific strength and high specific modulus.

LITERATURE SURVEY

LAMINATE

Lamination is the technique of manufacturing a material in multiple layers, so that the composite material achieves improved strength, stability, sound insulation, appearance or other properties from the use of differing materials. A laminate is usually permanently assembled by heat, pressure, welding, or adhesives.

In general the composite materials are made of the materials like fibers, s-glass, e-glass, etc. the simple figures of composite laminates are shown in Fig

Fig:E-Glass Laminate

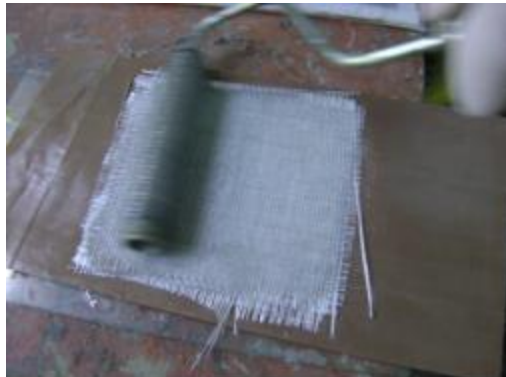


Fig:Pan Carbon Laminate



In materials science, Composite fiber laminates are assemblies of layers of fibrous composite materials which can be joined to provide required engineering properties, including in-plane stiffness, bending stiffness, strength, and coefficient of thermal expansion. Layers of different materials may be used, resulting in a hybrid laminate.

The individual layers generally are orthotropic (that is, with principal properties in orthogonal directions) or transversely isotropic (with isotropic properties in the transverse plane) with the laminate then exhibiting anisotropic (with variable direction of principal properties), orthotropic, or quasi-isotropic properties. Quasi-isotropic laminates exhibit isotropic (that is, independent of direction) in plane response but are not restricted to isotropic out-of-plane (bending) response. Depending upon the stacking sequence of the individual layers, the laminate may exhibit coupling between in plane and out-of-plane response. An example of bending, stretching, coupling is the presence of curvature developing as a result of in-plane loading.

FIBRES

FIBERS are load carrying members due to High Tensile Strength & Modulus. Classification of **FIBERS** based on materials / compositions / precursors.

In a continuous fiber-reinforced composite, the fibers provide virtually all of the strength and stiffness. Even in particle reinforced composites, significant improvements are obtained. For example, the addition of 20% SiC to 6061 aluminum provides an increase in strength of over 50% and an increase in stiffness of over 40%. As mentioned earlier, typical reinforcing materials (graphite, glass, SiC, alumina) may also provide thermal and electrical conductivity, controlled thermal expansion, and wear resistance in addition to structural properties, table 2.1 shows classification of fibers.

TABLE CLASSIFICATION OF FIBRES

S.NO	Classifications of fibers	Types of fiber based on composition
1	Glass fibers	E-glass,S-glass,D-glass,R-glass,C-glass,H silica
2	Carbon fibers	Based on precursor type

		✧ Rayon ,carbon, pitch Based on strength/modulus ✧ High strength, standard modulus, intermediate modulus and ultra high modulus.
3	Aramid fibers	DuPont's Kevlar 29,kevlar 49,kevlar 149

Initial scientific and engineering understanding of fiber-reinforced organic-matrix composites was based on studies of glass-fiber reinforced composites. Both continuous and discontinuous Glass Fiber reinforced composites have found extensive application, ranging from nonstructural, low-performance uses, such as panels in aircraft and appliances, to such high performance applications as rocket motor cases and pressure vessels. The reasons for the widespread use of glass fibers in composites, both in the past and in the present, include competitive price, availability, good handle ability, ease of processing, high strength, and

Other acceptable properties. Furthermore, the advent of highly efficient silane coupling agents, which are very compatible with either polyester or epoxy matrices, provided a strong and much-needed boost in property translation and in environmental durability.

APPLICATIONS OF DIFFERENT FIBERS:

✧ Rayon carbon fabric : Ablative composites

✧ E-glass fabric: Commercial application

✧ Pan carbon fabric :Aerospace structural composites

- ✧ High silica fabric: Thermal insulation composites

- ✧ Kevlar fabric: structural composites & ballistic applications

- ✧ D-glass fabric: Dielectric application

GLASS FIBRE

The glass fiber most commonly used is known as E-glass, a glass fiber having a useful balance of mechanical, chemical, and electrical properties at very moderate cost. Typical strength and stiffness levels for the individual filaments are about 3450 Mpa (500 ksi) tensile strength and 75.8 Gpa (11 X 10⁶ psi) Young's modulus. Higher performance, higher-cost S-2 glass fibers have properties of 4830 Mpa (700 ksi) tensile strength and a modulus of 96.5 Gpa (14 x 10⁶ psi). For specialized applications, such as ablatives, thermal barriers, antenna windows, and radomes, high-silica and quartz fibers are also used.

Glass fibers fall into two categories, low-cost general-purpose fibers and premium special-purpose fibers. Over 90% of all glass fibers are general-purpose products. These fibers are known by the designation E-glass and are subject to ASTM specifications. The remaining glass fibers are premium special-purpose products. Many, like E-glass, have letter designations implying Special properties. Some have trade names, but not all are subject to ASTM specifications, fig 2.1 shows the glass fiber.

Specifically:

LETTER DESIGNATION PROPERTY OR CHARACTERISTIC:

E- Electrical: Low electrical conductivity

S- Strength: High strength

C- Chemical: High chemical durability

M- Modulus: High stiffness

A- Alkali: High alkali or soda lime glass

D- Dielectric: Low dielectric constant

CARBON FIBRE

Carbon fiber is defined as a fiber containing at least 92 wt % carbon, while the fiber containing at least 99 wt % carbon is usually called a graphite fiber. Carbon fibers generally have excellent tensile properties, low densities, high thermal and chemical stabilities in the absence of oxidizing agents, good thermal and electrical conductivities, and excellent creep resistance. They have been extensively used in composites in the form of woven textiles, prepregs, continuous fibers/roving's, and chopped fibers. The composite parts can be produced through filament winding, tape winding, pultrusion, compression molding, vacuum bagging, liquid molding, and injection molding, Fig 2.2 shows the carbon fibers.



Carbon fibers are available from a number of domestic and foreign manufacturers in a wide range of forms having an even wider range of mechanical properties. The earliest commercially available carbon fibers were produced by thermal decomposition of rayon precursor materials. The process involved highly controlled steps of heat treatment and tension to form the appropriately ordered carbon structure. Rayon has been largely supplanted as a precursor by Polyacrylonitrile (PAN). Polyacrylonitrile precursors produce much more economical fibers because the carbon yield is higher and because PAN-based fibers do not intrinsically require a final high-temperature “graphitization” step. Carbon fibers are also manufactured from pitch precursor for specialty applications. Pitch fiber properties typically include high modulus and thermal conductivity, as might be required on satellite structures. Modulus values in commercially available fibers range up to 825 GPa (120 x 10⁶ psi). Aramid Fibers. Aramid is a generic term for a class of aromatic polyamide fibers introduced

Commercially during the early 1960s. These high performance fibers are all variations of polyparaphenyleneterephthalamide.

A broad range of properties are available. Kevlar 149 (DuPont), for example, has a tensile modulus of 180 GPa (26 X 10⁶ psi) and tensile strength of 3450 MPa (500 ksi). The more commonly used Kevlar 49 (DuPont) has a tensile modulus of 131 GPa (19 X 10⁶ psi) and a tensile strength of 3620 MPa (525 ksi).

Table 2.2 Estimated Global Carbon Fiber consumption

	1999 (tons)	2004(tons)	2006(tons)	2008(tons)	2010(tons)
Aerospace	4,000	5,600	6,500	7,500	9,800
Industrial	8,100	11,400	12,800	15,600	17,500
Sporting goods	4,500	4,900	5,900	6,700	6,900
Total	16,600	21,900	25,200	29,800	34,200

ARAMID FIBRE

Aramid fiber is unusual in that it is technically a thermoplastic polymer (like nylon), but rather than melting when heated, it, decomposes before reaching its projected melting temperature. With polymerization, it forms rigid, rod like molecules that cannot be drawn from a melt, as textile fiber molecules can, but must instead be spun from a liquid crystalline solution in sulfuric acid. The polymerization and manufacturing processes for Aramid fibers are complex and exacting and involve many aggressive chemical species.

The high strength of Aramid fiber, combined with a fiber modulus considerably higher than 8glass, gave it early application in filament wound rocket motor cases, gas pressure vessels, and lightly loaded secondary structures on commercial aircraft and helicopters. The fiber shows linear tensile stress strain behavior to failure, but unlike inorganic fibers, is surprisingly damage tolerant. However, it also displays far lower strength in compression than carbon and other inorganic fibers and relatively poor adhesion to matrix resins. Moisture uptake may also need to be considered. Nevertheless, because of properties such as its high specific strength, low density, and toughness, significant markets exist. Other Organic Fibers.

Another common category of fibers are ultrahigh-molecular weight polyethylene fibers, such as Spectra from AlliedSignal Inc. These fibers have high chemical. Impact

and moisture resistance. As well as low density, good vibration damping, and low dielectric constant. Major applications include ballistic armor, radomes, boats, and other recreational products.

PROPERTIES MEASUREMENT FOR FIBRES

Here table shows the parameters and the standards to measure the fabric

Table properties measurement for fiber

Forms of fiber	parameters required for characterization	Standards
Monofilaments	❖ Diameter, tensile strength and modulus	ASTM D 3379
Roving	❖ Number of filaments ❖ Tex and density ❖ Impregnated tow tensile test for strength and modulus ❖ Un-impregnated tow tensile test for strength ❖ Sizing content	ASTM D 578 ASTM D 3317 ASTM D 4018 ASTM D 2343 ASTM D 3171
Yarn	❖ Tex, twist and density ❖ Impregnated tow tensile test for strength and modulus ❖ Dry tow tensile test for strength	ASTM D 3317 ASTM D 4018 ASTM D 2343

Woven roving Fabrics a)unidirectional b)bi-directional	<ul style="list-style-type: none"> ❖ Type of roving used in both warp and weft direction ❖ GSM, thickness, weave style ❖ Fabric count(no. of ends/inch) in both warp and weft ❖ Fabric breaking strength(kg/inch) in both warp and weft ❖ Sizing content(compatibility with resin) ❖ Carbon content(for PAN carbon fabrics) 	As per ASTM standards
fabrics	<ul style="list-style-type: none"> ❖ Type of yarn used in both warp and weft direction ❖ Doubling yarn if used any ❖ GSM, thickness, weave style ❖ Fabric count(no. of ends/inch)in both warp and weft ❖ Fabric breaking strength (kg/inch) in both warp and weft ❖ Sizing content (compatibility with resin) ❖ Carbon content (for rayon carbon fabrics) ❖ Silica content (high silica content) 	As per ASTM standards
Chopped stran mat	<ul style="list-style-type: none"> ❖ GSM,compatibity 	BS 3496

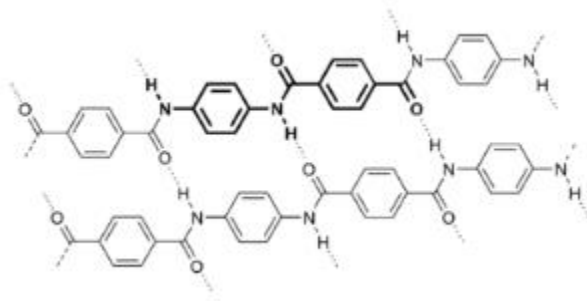
TESTING METHODS**Table shows the testing methods and its ASTM D STANDARDS**

FIBER form	Test	Standard	Sailent features of test	Remarks
Monofilament	Tensile test (Tensile strength Modulus)	ASTM D 3379	<ul style="list-style-type: none"> • Single filament diameter 5 or 7 microns (for carbon fibers) • Paper tab material for mounting filament • Gauge length:25mm • Specimen length : 3*gauge length • Cross head speed: 0.4mm/min 	Scattering is very high
Roving / Yarn	Impregnated Tow tensile Test (tensile strength & Modulus)	ASTM D 4018	<ul style="list-style-type: none"> • Applicable to strands/yarns/roving's of only carbon/graphite fiber • Impregnation with resin and consolidation 	Consistent values
			<ul style="list-style-type: none"> • Specimen gauge length: 250mm • Cross head : 12.7mm/min • Testing of specimen with /without tabs • Tensile modulus possible with 	

			extensometer	
	Impregnated/tensile test(tensile strength & Modulus)	ASTM D 2343	<ul style="list-style-type: none"> ➤ Applicable to strands/yarns/roving's of only glass FIBRE where strands are coated resin for compatible sizing. ➤ Impregnation with resin and consolidation. ➤ Specimen gauge length :250mm ➤ Tensile strength mainly drawn from this test. Modulus is possible with extensometer but not general used 	
	Dry roving tensile test	ASTM D 2256	<ul style="list-style-type: none"> ➤ Generally textile yarn test method without impregnation. Values in N/tex 	
Fabrics	Breaking strength	ASTM D 5035	<ul style="list-style-type: none"> ➤ Strip method, end of specimen is coated with rubber based adhesive for gripping during tensile test of fabric. ➤ Specimen length:175mm, 	

			<p>gauge length:75mm</p> <ul style="list-style-type: none"> ➤ Cross head speed :12.7mm/minute ➤ Given tensile strength per unit width ➤ Expressed as tensile breaking load per unit inch width(kg/inch) in both warp and weft direction of fabric 	
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Aramid fiber



RESIN

The Primary functions of the resin in composite materials are

- Act as a glue to hold the fibers together.
- To transfer stress between the reinforcing fibers.
- Protect the fibers from mechanical and environmental damage.

Resins are divided into two major groups.

1) Thermosetting Resins: Epoxy, Phenolic, Vinyl Ester, Bismaleimide, Unsaturated Polyester, PMR 15, Cynate ester resin.

2) Thermoplastic Resins: Polyethylene (PE) , PVC , PP , Polycarbonates , Nylons , PET , Polyether ether ketone (PEEK) , Polyphenylene Sulphide , Polyether Sulphone (PES) .

The purpose of the matrix is to bind the reinforcements together by virtue of its cohesive and adhesive characteristics, to transfer load to and between reinforcements, and to protect the reinforcements from environments and handling. The matrix also provides a solid form to the composite, which aids handling during manufacture and is typically required in a finished part. This is particularly necessary in discontinuously reinforced composites, because the

Reinforcements are not of sufficient length to provide a handle able form.

Because the reinforcements are typically stronger and stiffer, the matrix is often the “weak link” in the composite, from a structural perspective. As a continuous phase, the matrix therefore controls the transverse properties, interlaminar strength, and elevated temperature strength of the composite. However, the matrix allows the strength of the reinforcements to be used to their full potential by providing effective load transfer from external forces to the reinforcement. The matrix holds reinforcing fibers in the proper

orientation and position so that they can carry the intended loads and distributes the loads more or less evenly among the reinforcements. Further, the matrix provides a vital inelastic response so that stress concentrations are reduced dramatically and internal stresses are redistributed from broken reinforcements. In organic matrices, this inelastic response is often obtained by micro cracking; in metals, plastic deformation yields the needed compliance. Debonding, often properly considered as an interfacial phenomenon, is an important mechanism that adds to load redistribution and blunting of stress concentrations. A broad overview of important matrices is provided subsequently. Organic matrices for commercial applications include polyester and Vinyl ester resins; epoxy resins are used for some “hi gh-end” applications. Polyester and vinyl ester resins are the most widely used of all matrix materials.

They are used mainly in commercial, industrial, and transportation applications, including chemically resistant piping and reactors, truck cabs and bodies, appliances, bathtubs and showers, and automobile hoods, decks, and doors. The very large number of resin formulations, curing agents, fillers, and other components provides a tremendous range of possible properties.

The development of highly effective silane coupling agents for glass fibers allowed the fabrication of glass fiber reinforced polyester and vinyl ester composites that have excellent mechanical properties and acceptable environmental durability. These enhanced characteristics have been the major factors in the widespread use of these composites today.

The problems of attaining adequate adhesion to carbon and Aramid fibers have discouraged the development of applications for polyester or vinyl ester composites that use these fibers. Although there are applications of high-performance fiber glass composites in military and aerospace structures, the relatively poor properties of advanced composites of polyester and vinyl ester resins when used with other fibers, combined with the comparatively large cure shrinkage of these resins, have generally restricted such composites to lower performance applications. When property

requirements justify the additional costs, epoxies and other resins, as discussed subsequently, are used in commercial applications, including high-performance sporting goods (such as tennis rackets and fishing rods), piping for chemical processing plants, and printed circuit boards.

Organic matrices for aerospace applications include epoxy, Bismaleimide, and polyimide resins. Various other thermo set and thermoplastic resins are in development or use for specific applications. Epoxy resins are presently used far more than all other matrices in advanced composite materials for structural aerospace applications. Although epoxies are sensitive to moisture in both their cured and uncured states, they are generally superior to polyesters in resisting

Moisture and other environmental influences and offer lower cure shrinkage and better mechanical properties. Even though the elongation-to-failure of most cured epoxies is relatively low, for many applications epoxies provide an almost unbeatable combination of handling characteristics, processing flexibility, composite mechanical properties, and acceptable cost. Modified “toughened” epoxy resin formulations (typically via the addition of thermoplastic or rubber additives) have improved elongation capabilities.

Moisture absorption decreases the glass transition temperature (T_g) of an epoxy resin. Because a significant loss of epoxy properties occurs at the T_g , the T_g in most cases describes the upper-use temperature limit of the composite. To avoid subjecting the resins to temperatures equal to or higher than this so-called wet T_g (the wet T_g is the T_g measured after the polymer matrix has been exposed to a specified humid environment and allowed to absorb moisture until it reaches equilibrium), epoxy resins are presently limited to a maximum service temperature of about 120 °C (250 °F) for highly loaded, long-term applications and even lower temperatures (80 to 105 °C, or 180 to 220 °F) for toughened epoxy resins. Although this limit is conservative for some applications, its imposition has generally avoided serious thermal-performance difficulties. Considerable effort continues to be expended to develop epoxy resins that will perform satisfactorily at higher temperatures when wet.

However, progress in increasing the 120 °C (250 °F) limit has been slow. 2.3.1 Bismaleimide Resins

Bismaleimide resins (BMI) possess many of the same desirable features as do epoxies, such as fair handle ability, relative ease of processing, and excellent composite properties. They are superior to epoxies in maximum hot/wet use temperature, extending the safe in-service temperature to 177 to 230 °C (350 to 450 °F).

They are available from a number of suppliers. Unfortunately, BMIs also tend to display the same deficiencies (or worse) as do epoxies: they have an even lower elongation-to-failure and are quite brittle. Damage tolerance is generally comparable to commercial aerospace epoxy resins. Progress has been made to formulate BMIs with improved toughness properties.

POLYIMIDE RESINS

Polyimide resins are available with a maximum hot/wet in-service temperature of 232 °C (450 °F) and above (up to 370 °C, or 700 °F, for single use short periods). Unlike the previously mentioned resins, these cure by a condensation reaction that releases volatiles during cure. This poses a problem, because the released volatiles produce voids in the resulting composite. Substantial effort has been made to reduce this problem, and there are currently several polyimide resins in which the final cure occurs by an addition reaction that does not release volatiles. These resins will produce good-quality, low void-content composite parts. Unfortunately, like BMIs, polyimides are quite brittle.

The attempt to produce improved thermosetting resins is ongoing, with major efforts focusing on hot/wet performance and/or impact resistance of epoxies, BMIs, and polyimide's. Other resins are constantly in development, and some are in commercial use for specialized applications.

PHENOLIC RESIN

PHENOLICS are thermosetting resins produced by the reaction of phenol or substituted phenol with an aldehyde, usually formaldehyde, in the presence of a catalyst. Phenolic resin composites offer superior fire resistance, excellent high-temperature performance, long-term durability, and resistance to hydrocarbon and chlorinated solvents. This article describes the chemistry of phenolic resins, reviews their characteristics and properties for various composites manufacturing processes, and discusses some representative applications.

Phenolic resins, for example, have been used for years in applications requiring very high heat resistance and excellent char and ablative performance. These resins also have good dielectric properties, combined with dimensional and thermal stability. Unfortunately, they also cure by a condensation reaction, giving off water as a byproduct and producing a void laminate. However, they also produce low smoke and less toxic by-products upon combustion and are therefore often used in such applications as aircraft interior panels where combustion requirements justify the lower properties. Cyanate esters are also used as matrix materials. Their low-moisture absorption characteristics and superior electrical properties allow them to see applications in satellite structures, radomes, antennas, and electronic components.

EPOXY RESIN

The first production of epoxy resins occurred simultaneously in Europe and in the United States in the late 1930s and early 1940s. Credit is most often attributed to Pierre Castan of Switzerland and S.O. Greenlee of the United States who investigated the reaction of bisphenol-A with epichlorohydrin. The families of epoxy resins that they commercialized were first used as casting compounds and coatings. The same resins are now commodity materials that provide the basis for most epoxy formulations.

Epoxy resins are a class of thermo set materials used extensively in structural and specialty composite applications because they offer a unique combination of properties that are unattainable with other thermo set resins. Available in a wide variety of physical forms from low-viscosity liquid to high-melting solids, they are amenable to a wide range of

Processes and applications. Epoxies offer high strength, low shrinkage, and excellent adhesion-to various substrates, effective electrical insulation, chemical and solvent resistance, low cost, and low toxicity. They are easily cured without evolution of volatiles or lay-products by a broad range of chemical specie. Epoxy resins are also chemically compatible with most substrates and tend to wet surfaces easily, making them especially well suited to composites applications.

Epoxy resins are routinely used as an adhesive, coatings, encapsulates, casting materials, potting compounds, and binders. Some of their most interesting applications are found in the aerospace and recreational industries where resins and fibers are combined to produce complex composite structures. Epoxy technologies satisfy a variety of nonmetallic composite designs in commercial and military aerospace applications, including flooring panels, ducting, vertical and horizontal stabilizers, wings, and even the fuselage. This same chemistry, developed for aerospace applications, is now being used to produce lightweight bicycle frames, golf clubs, snowboards, racing cars, and musical instruments.

TYPES OF PHENOLIC & EPOXY RESINS

S.NO	Resin system	Types
1.	Phenolic resin <ul style="list-style-type: none"> ➤ High char yield ➤ Abrasive resin ➤ Volatile by product(water-vapour)release during curing ➤ Voids formed during curing ➤ Poor mechanical properties ➤ Ablative composite 	Resole (single component) <ul style="list-style-type: none"> ➤ P/F & NaOH catalyst ➤ Curing by self polymerization at elevated temperature without catalyst ➤ Curing at RT with catalyst PTSA ➤ Using in fabrication ablative nozzle liners for missiles/rockets
		Novalic (two components) <ul style="list-style-type: none"> ➤ P/F>1 & Acidic catalyst ➤ Using moulding component
2.	Epoxy resin system <ul style="list-style-type: none"> ➤ Two component system resin and hardener ➤ High mechanical properties ➤ No byproduct is released during curing ➤ Resin has adhesive nature 	a. Difunctional epoxy: epoxy LY 556 <ul style="list-style-type: none"> ➤ RT curing hardener: HY 951 ➤ High temperature curing Hardeners: HT 972(solid) HY 5200(liquid)

	➤ Structural composite	<p>HT 976(solid)</p> <p>b. Multifunctional epoxy resins: epoxy novolac,</p> <p>TGDDM:MY 720, MY 721, MY 722</p>
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HARDENER

Hardener is a substance mixed with paint or other protective covering to make the finish harder or more durable. It is a curing agent for epoxies or fiberglass.

An agent which does not enter into the reaction is known as a catalytic hardener or catalyst. A reactive curing agent or hardener is generally used in much greater amounts than a catalyst, and actually enters into the reaction.

Hardener is usually classed as a corrosive, and as an irritant when in contact with the skin or by inhalation

TYPES OF HARDENER

AMINES

Polyfunctional primary amines form an important class of epoxy hardeners. Primary amines undergo an addition reaction with the epoxide group to form a hydroxyl group and a secondary amine. The secondary amine can further react with an epoxide to form a tertiary amine and an additional hydroxyl group. For aliphatic amines both primary and secondary amino hydrogen's have approximately the same reactivity, while for aromatic amines, the reactivity of the secondary amine is typically 2 to 5 times less than the reactivity of a primary amino hydrogen. Use of a difunctional or polyfunctional amine along with a difunctional epoxy resin forms a three-dimensional cross-linked network. Aliphatic, cycloaliphatic and aromatic amines are all employed as epoxy hardeners. Amine type will alter both the processing properties (viscosity, reactivity) and the final properties (mechanical, temperature and chemical resistance) of the cured copolymer network. Thus amine structure is normally selected according to the application. Reactivity is broadly in the order aliphatic amines > cycloaliphatic amines > aromatic amines. Temperature resistance generally increases in the same order, since aromatic amines form much more rigid structures than aliphatic amines. Whilst aromatic amines were once widely used as epoxy resin hardeners due to the excellent end

properties they imparted, health concerns with handling these materials means that they have now largely been replaced by safer aliphatic or cycloaliphatic alternatives.

PHENOLS

Polyphenols, such as bisphenol A or novolacs can react with epoxy resins at elevated temperatures (130-180 °C), normally in the presence of a catalyst. The resulting material has ether linkages and displays higher chemical and oxidation resistance than typically obtained by curing with amines or anhydrides. Since many novolacs are solids,

This class of hardeners is often employed for powder coatings

HOMOPOLYMERISATION

Epoxy resin may be reacted with itself in the presence of an anionic catalyst (a Lewis base such as tertiary amines or imidazoles) or a cationic catalyst (a Lewis acid such as a boron trifluoride complex) to form a cured network. This process is known as catalytic homopolymerisation. The resulting network contains only ether bridges, and exhibits high thermal and chemical resistance, but is brittle and often requires elevated temperature to effect curing, so finds niche applications industrially. Epoxy homopolymerisation is often used when there is requirement for UVcuring, since cationic UV catalysts may be employed (e. g. for UVcoatings).

ANHYDRIDES

Epoxy resins may be cured with cyclic anhydrides at elevated temperatures. Reaction occurs only after opening of the anhydride ring, e.g. by secondary hydroxyl groups in the epoxy resin. A possible side reaction may also occur between the epoxide and hydroxyl groups, but this may be suppressed by addition of tertiary amines. The low viscosity and high latency of anhydride hardeners makes them suitable for processing

systems which require addition of mineral fillers prior to curing, e.g. for high voltage electrical insulators.

THIOLS

Also known as mercaptans, thiols with the (S-H) functional group, contain electron poor hydrogen which reacts very readily with the epoxide group, even at ambient or sub ambient temperatures. Whilst the resulting network does not typically display high temperature or chemical resistance, the high reactivity of the thiol group makes it useful for applications where heated curing is not possible, or very fast cure is required e. g. for domestic DIY adhesives and chemical rock bolt anchors. Thiols have a characteristic odour, which can be detected in many two-component household adhesives.

CHAPTER 1

COMPOSITE MATERIALS

1.1 INTRODUCTION:

Composite materials (also called composition materials or shorten to composites) are materials made from two or more constituent materials with significantly different physical or chemical properties, that when combined, produce a material with characteristics different from the individual components.

Composite materials= fibres+ resins

COMPOSITE MATERIALS TYPES:

- Composite building materials such as cements, concrete
- Reinforced plastics such as fibre-reinforced polymer
- Metal Composites
- Ceramic composites(composite ceramic and metal matrices)

RESINS:

Resins are materials with a property of interest that is similar to natural plant resins: they are viscous liquids that are capable of hardening permanently. Polyester resin tends to have yellowish tint, and is suitable for most backyard projects. Its weaknesses are that it is UV sensitive and can tend to degrade overtime, and thus generally is also coated to help preserve.

Vinyl ester resin tends to have a purplish to bluish to greenish tint. This resin has lower viscosity than polyester resin, and is more transparent.

Epoxy resin is almost totally transparent when cures. In the aerospace industry, epoxy is used as a structural matrix material or as structural glue.

FIBRES:

Reinforcement usually adds rigidity and greatly impedes crack propagation. Thin fibres can have very high strength, and provided they are mechanically well attached to the matrix they can greatly improve the composite's overall properties.

Fibre-reinforced composite materials can be divided into main categories normally referred to as short fibre-reinforced materials and continuous fibre-reinforced materials.

1.3 PLASTICS

A **plastic** material is any of a wide range of synthetic or semi-synthetic organic solids that are mouldable plastics are typically organic polymers of high molecular mass, but they often contain other substances. They are usually synthetic, most commonly derived from petrochemicals but many are partially natural.

1.4 VARIOUS INDUSTRIAL APPLICATIONS OF COMPOSITE MATERIALS:

ENGINEERING APPLICATIONS: Composite materials have been used in aerospace, automobile and marine applications (see figs 1-3).

Recently, composite materials have been increasingly considered in civil engineering structures. The later applications includes seismic retrofit of bridge columns (fig 4), replacements of deteriorated bridge decks (fig 5) and new bridge structures (fig 6)

Fig 1



Fig 2



Fig 3



Fig 4



Fig 5



Fig 6



1.5 ADVANTAGES AND DISADVANTAGES

ADVANTAGES OF COMPOSITE MATERIALS:

- Low density leads to high specific strength and modulus. Very strong and stiff structures can be designed with substantial weight savings.
- Fibre orientation with the direction of principle stress increasing structural efficiency.
- Excellent corrosion resistance.
- Very low coefficient of thermal expansion.
- Improved vibration damping properties.
- Good fatigue resistance.
- Ease of manufacturing of complex shapes.

DISADVANTAGES OF COMPOSITE MATERIALS:

- Cost of materials.
- Long development time.
- Difficulty manufacturing.
- Fasteners.
- Low ductility.
- Temperature limits.

1.6 MECHANICAL PROPERTIES:

- Tensile strength and modulus.
- Flexural strength and modulus.
- Deflection temperature.

MECHANICAL PROPERTIES DEPENDS UPON:

- Mechanical properties of fibre.
- How much load the matrix can transmit to the fibre.

(Depends upon the interfacial bond between the fibre and matrix)

CRITICAL FIBRE LENGTH DEPENDS UPON:

- Fibre diameter and fibre tensile strength.
- Fibre/Matrix bond strength.

CHAPTER 2

FIBRES

2.1 INTRODUCTION:

Reinforcement usually adds rigidity and greatly impedes crack propagation. Thin fibres can have very high strength, and provided they are mechanically well attached to the matrix they can greatly improve the composites overall properties.

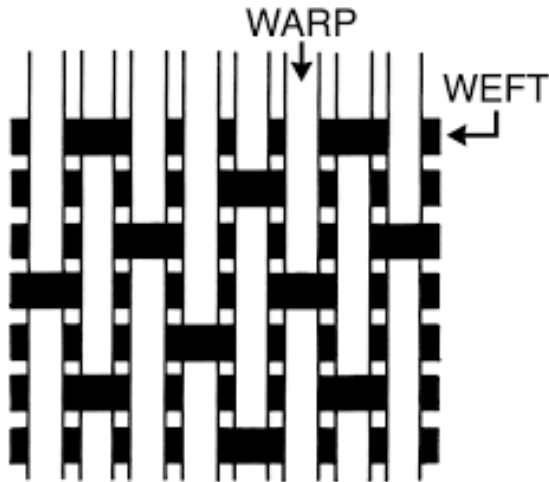
Fibre-reinforced composite materials can be divided into two main categories normally referred to as short fibre-reinforced materials and continuous fibre-reinforced materials. Continuous reinforced materials will often constitute a layered or laminated structure. The woven and continuous fibre styles are typically available in a variety of forms, being pre-impregnated with the given matrix (resin), dry, uni-directional tapes of various widths, plain weave, and hardness satins, braided and stitched.

The short and long fibres are typically employed in compression moulding and sheet moulding operations. These come in forms of flakes, chips and random made (Which can also be made from a continuous fibre laid in lab in random fashion until the desired thickness of the ply/laminate is achieved).

Common fibres used for reinforcement include glass fibres, Carbon fibres, Cellulose (Wood/paper fibre and straw) and high strength polymers for example **Aramid**.

2.2 DIFFERENT STYLES OF FIBRES:

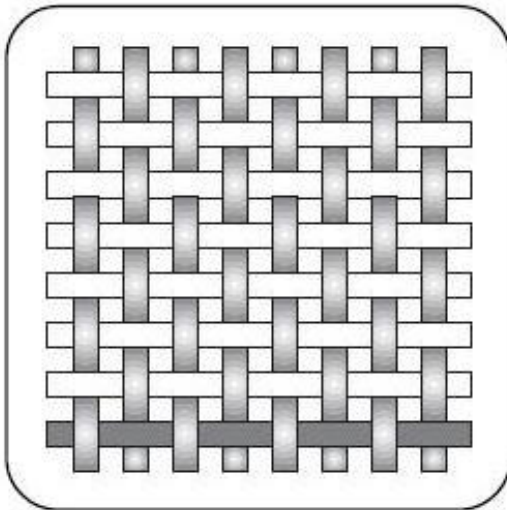
The fabrics consist of at least two threads which are woven together: The warp and the weft.



The weave style can be carried according to crimp and drapeability. Low crimp gives better mechanical performance because straighter fibres carry greater loads.

A drapeable fabric is easier to lay up over complex forms.

Plain weave: Low drapeability/high crimp.



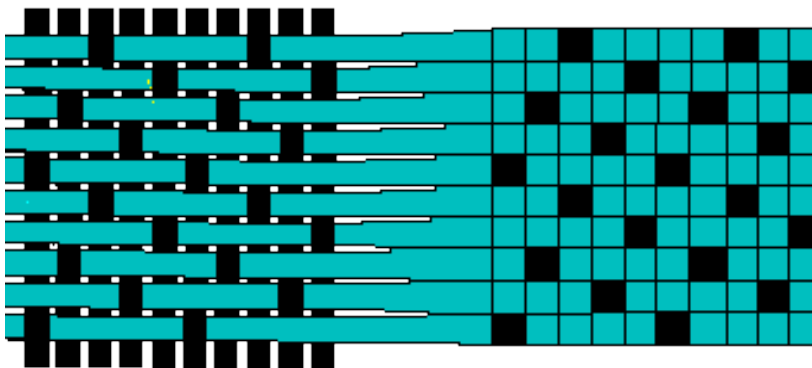
PAN FABRIC



Satin weave: High drapeability/low crimp



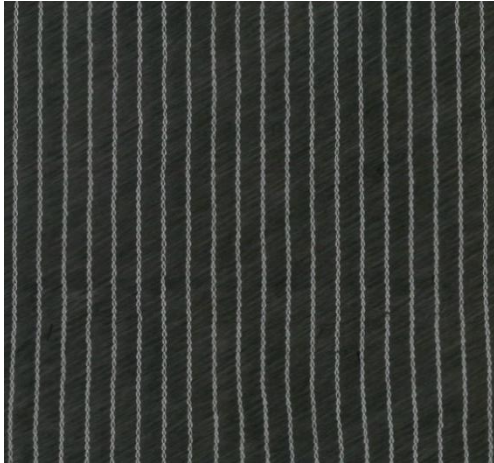
TWILL WEAVES: AVERAGE DRAPEABILITY/AVERAGE CRIMP



NON CRIMP FABRICS:

Uni directional layers assembled and stitched

Average drapeability/no crimp



2.3 PAN (POLY-ACRYLO-NITRILE) CARBON FABRIC:

GRAPHITE FIBERS

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

PAN-based carbon cloth or fibre is produced at about 1320°C, while graphite fibres and cloth are graphitized at 1950 to 3000°C.

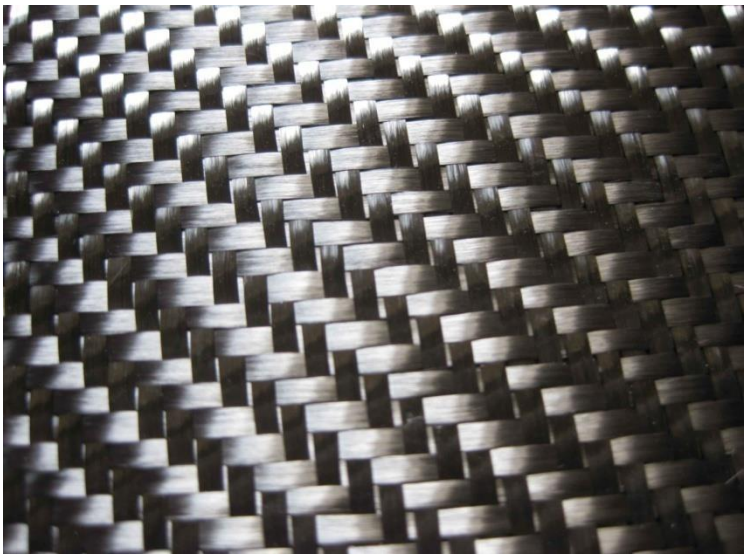
The properties of graphite remain unchanged even at high temperatures, but its willingness to react readily with most metals at the fabrication stage or during use at very high temperatures is often a stumbling block, as seen in aluminium matrices when carbides are produced at the interface. These carbides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

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

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

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

PAN fabric



2.5 ROVING

A roving is a single grouping of filament or fibre ends, such as 20-end or 60-end glass roving. All filaments are in the same direction and they are not twisted. Carbon roving's are usually identified as 3K, 6K or 12K roving's, K meaning 1000 filaments. Most applications for roving products utilize mandrels for filament winding and then resin cure to final configuration.



2.5APPLICATIONS OF FABRICS:

- Sports goods
- Mechanical industries
- Large advanced structures
- Pressure vessels
- Drive shafts
- Tubes
- Wind mill blades etc.

CHAPTER 3

RESINS

3.1 INTRODUCTION:

Resins are materials with a property of interest that is similar to natural plant resins: they are viscous liquids that are similar of hardening permanent.

TYPES OF RESINS:

- Epoxy resin (Excellent mechanical performance)
- Phenolic resin (excellent)
- Bismaleimide

3.2 EPOXY RESIN

Epoxy resin are a class of thermo set materials used extensively in structural and especially composite application because they offer a unique combination of properties that are unattainable with other thermo set resin.

Epoxies offer high strength, low shrinkage and excellent adhesion to various resistances, low cost and low toxicity.

They are easily cured without the evolution of volatiles or by product by a broad range of chemical specie.

Epoxy resin are routinely used as adhesives, coatings, encapsulates, casting material, potting composite and binders.

When selecting a thermo set resin , consideration is usually given to tensile strength, module and strain , compression strength and modulus , notch sensitivity , impact resistance , heat deflection temperature or gross translation temperature , flammability , durability in service , material availability , ease of processing , and price.

RESIN AND HARDENER:



3.3 APPLICATION OF RESINS:

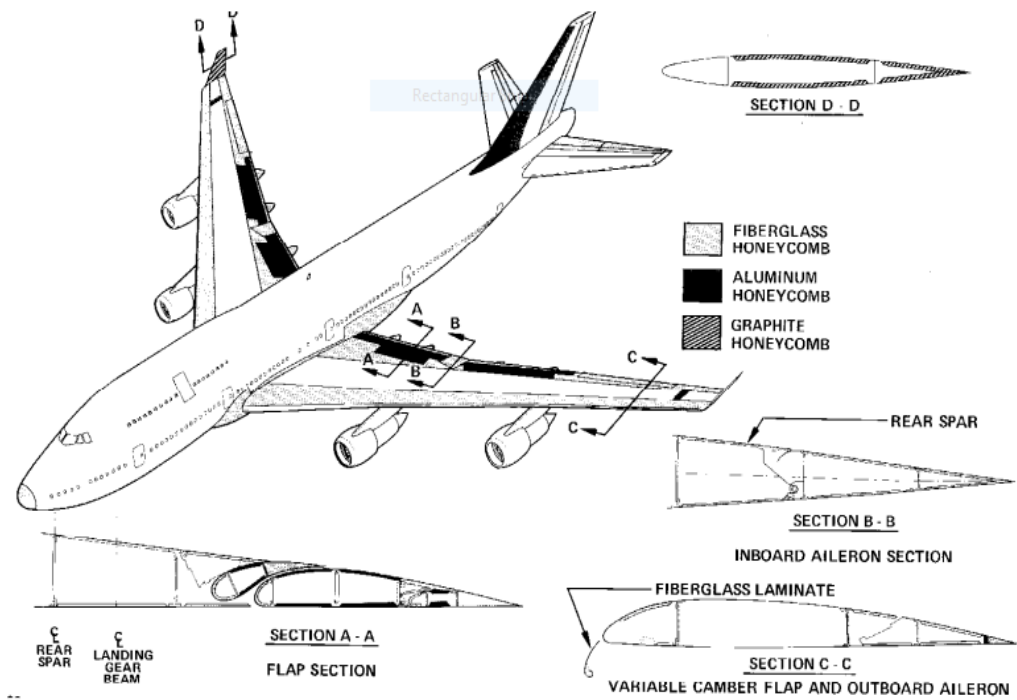
- Easy moulding
- Better mechanical strength
- Chemical resistance
- Electrical insulation properties
- laminating techniques to make glass fibres, reinforced articles

CHAPTER 4

4.1 IMPORTANCE OF COMPOSITES IN AEROSPACE INDUSTRY:

- The use of composites in the aerospace industry has increased dramatically since the 1970s.
- Traditional material for aircraft construction includes aluminium, steel and platinum.
- The primary benefits that composite components can offer are reduced weight and assembly simplification.
- Although commercial carries have increasingly been concerned with fuel economy, the potential for reduced production and maintenance costs has proven to be a major factor in the push toward composite. Composites are also being used increasingly as replacement for metal part on order planes.

EXTERIOR COMPOSITE PARTS



AGNI 5 MISSILE



4.2 SPACE APPLICATION:

The successful application of composites in missiles has led to the development of primary structures for space vehicles.

In fact, space application lend themselves in many ways to the utilisation of new material.

For satellites, for example, the timescales from concept to manufacture can be as little as two years and due to the short product runs normally involved, the materials element in the final cost is often relatively low.

Also, in many applications no other material is suitable for technical reasons.

Glass fibre composite (also commonly referred to as GRP) is used in application where thermal insulation is important, for example in local basketry. The material is also used in some antenna reflectors.

Carbon fibre composite (also commonly referred to as CFRP), however, is most often associated with space applications. The potential for very high stiffness and excellent thermal stability over a wide temperature range make CFRPs ideal. Examples of their application include: fairings, manipulator arms, antennae reflectors, solar array panels and optical platforms and benches.

They have also recently been used for primary structure application. In the past the needs for a combination of stiffness and strength and for thermal and electrical conductivity have favoured metals.

However, the constant pressure for weight reduction means that now some satellites have been built with a predominantly composite structure sub system.



CHAPTER 5

FABRICATION TECHNIQUES

5.1 INTRODUCTION:

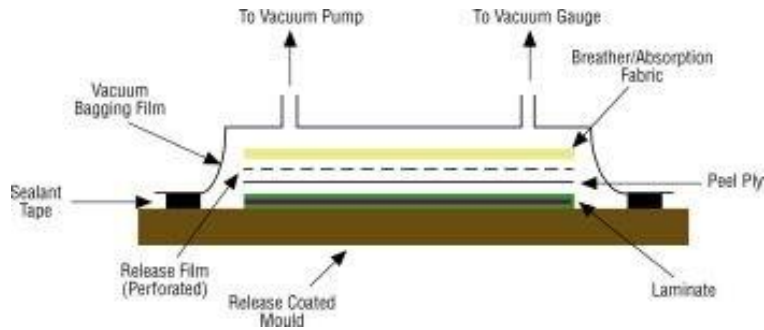
Fabrication usually involves wetting or mixing or saturating the reinforcement with the matrix, arrest then causing the matrix to bind together (with heat or a chemical reaction) into a rigid structure. The operation is usually done in an open or closed forming mould, but the order and ways of introducing the ingredients varies considerably.

- Mould overview
- Pressure bag moulding
- Vacuum bag moulding
- Autoclave moulding
- Resin transfer moulding

Other types of fabrication include press moulding, transfer moulding, pultrusion moulding, filament winding, casting, centrifugal casting, continuous casting and slip forming. There are also forming capability including CNC filament winding, vacuum infusion, wet lay-up, compression moulding, and thermoplastic moulding, to name a few. The use of curing ovens and paint booths is also needed for some project.

5.2 VACUUM BAG MOULDING:

After hands layup or spray up, vacuum is applied using a bag. It helps to remove air void and compact the layup. Only male and female half of the mould is used. Wet layup and prepeg layup are possible.



5.3 PRESSURE BAG MOULDING:

After hand layup, pressure is applied on the la up using a flexible pressure bag which helps to compact the product. Vacuum can be applied prior to pressing. Bath wet layup and prepeg layup are possible.

5.4AUTOCLAVE MOULDING

After lay up the product is cured in autoclave. Vacuum, pressure and temperature are applied. One male or female half of mould made of FRP or metal is used.



5.5COMPRESSION MOULDING COLD PRESSING

Layup of fibre and resin is done by hand lay up on the two halves of the mould. Mould is closed and pressed gives good finish on both sides. Thickness is controlled and air entrapment is possible at the joint line.

5.6COMPRESSION MOULDING HOT PRESSING:

The charge is placed in the cavity of a heated mould. Mould is closed and pressed until the product is cured. Faster production precise control of thickness and good finish on both surfaces.

5.6 THE PREPREG

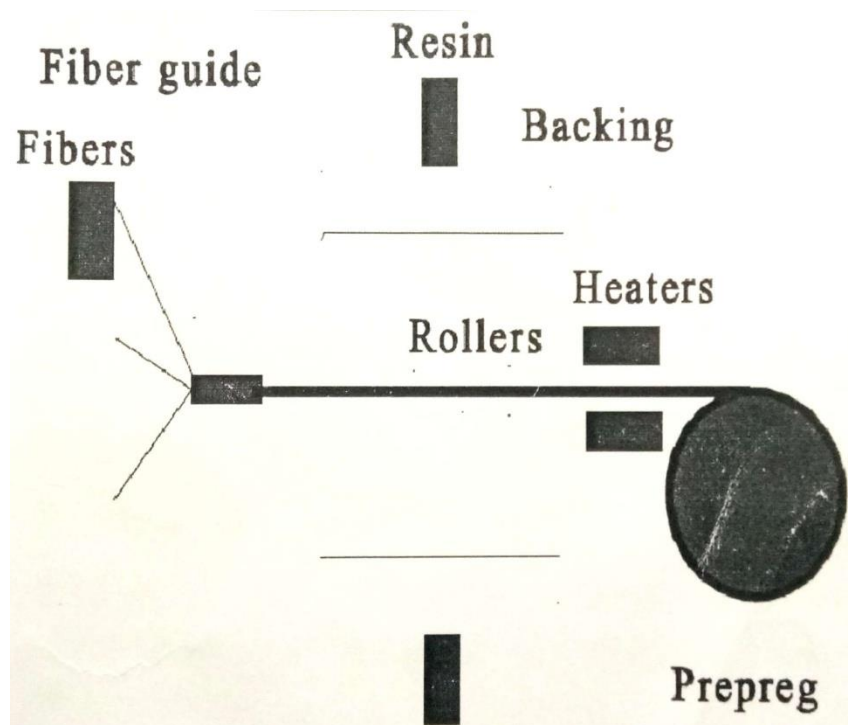
What are prepregs? They are rolls of uncured composite material in which the fibres have been “preimpregnated.”

This process of combination fibres with resin is done by prepreggers who specialized in supplying these materials.

They use equipment designed to precisely introduction the proper amount of resin onto the fibre, works the resin into the fibres, and then package the material so that the user (you) can easily layup the prepreg into the desired shape and the desired thickness.

You then curve the layup (more details will be given) and the part is done.

The process for making for making prepreg is quite simple in concept and is depicted.



The fibres are drawn from continuous fibres spools or reels and directed into a fibre guide that flattens and aligns the fibres onto a belt, thus forming a web or sheet of fibres.

The fibre must be controlled at a precise thickness and each of the fibre bundles must be oriented so that each touches the neighbouring bundle without overlap and without a gap between them.

Alternately, instead of using fibre tows from reels to form the fibre sheet, the sheet could be formed by simply using woven fabric.

5.7 THE PREPEG PLANT



Pre-preg is a term for “pre-impregnated” composite fibres where a material, such as epoxy is already present. These usually take the form of a weave or are uni-directional.

They already contain an amount of the matrix material used to bond them together and to other components during manufacture.

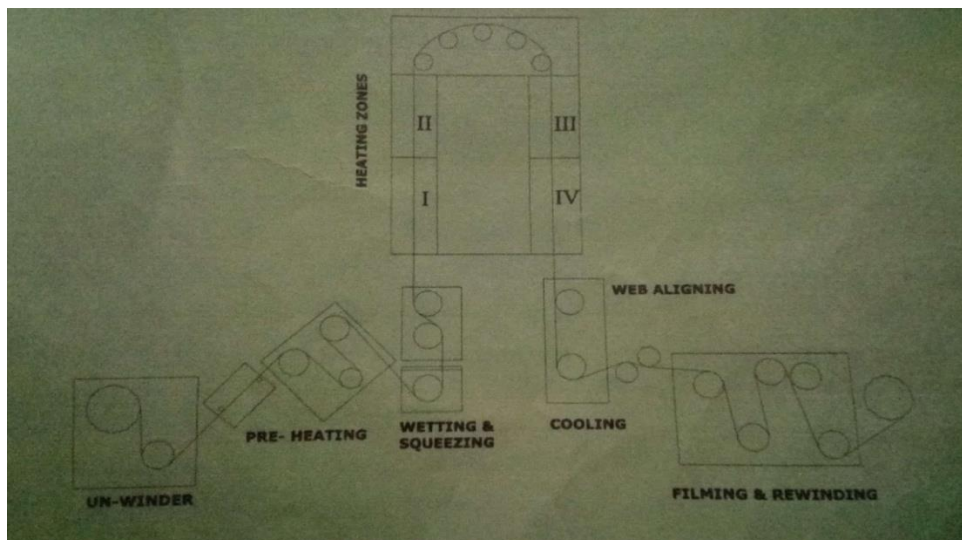
The resin is only partially cured to allow easy handling, this is called B-stage material and requires cold storage to prevent complete polymerization is most commonly done by heat.

Hence, composite structures built of pre-pregs will mostly require an oven or **autoclave** to finish the complete polymerization.

Pre-preg allows one to impregnate the fibre on a flat workable surface, or rather in a cooled area for an extended period of time to cure later.

Unfortunately the process can also be time consuming in comparison to the hot injection process and the added value for pre-preg preparation is at the stage of the material supplier.

PROCESSING OF PREPREG:



SCOPE OF THE PROJECT WORK

The main aim of “**characterization of mechanical properties of PAN carbon fabric/epoxy epofine resin laminates**” is to

- Fabrication of PAN carbon fabric/epoxy resin laminates by hand layup procedure.
- Specimen cutting as per ASTM D standards for tensile test, flexural test, shear test.
- Evaluation of tensile properties of PAN carbon fabric/epoxy resin by testing it on UTM machine.
- Studying failure modes of specimen during different mechanical characteristics tests.
- Generation of experimental characteristics of PAN carbon fabric/epoxy epofine resin composite.
- Obtaining the material strength values by different tests.

CHAPTER 6

PREPARATION OF THE LAMINATES

PAN fabric (thickness 0.35mm) and oven curing. Epoxy resin LY556 and hardener HY972. For curing 4 hours in oven at 100 degree centigrade.

Laminate size is 250mm*250mm*2mm

I. (a) CALCULATION OF NUMBER OF LAYERS TO GET THICKNESS OF THE TOTAL LAMINATE:

- Laminate size 250mm*250mm*2mm
- Give the fabric thickness = 0.35mm(measured using vernier)
- Approximately resin thickness on the layer=0.10mm
- The thickness of one wet layer= $0.35+0.10=0.45$ mm
- Required laminate thickness= 2mm

(b) CALCULATION OF FABRIC AND RESIN:

- In hand layup process, for making laminate
 - Ratio of fabric and resin =3:2
 - Total weight of dry fabric for laminate =450gms
 - Weight of required quantity of resin hardener=300gms
 - Ratio of resin=219gms
 - Weight of hardener=81gms

II. BILL OF RAW MATERIAL:

(a) Direct materials:

- High strength PAN carbon fabric
- Epoxy resin
- Hardener

(b) Indirect materials:

- Laminate layup plate
- Emery paper
- Acetone

- Wax polish
- Scale
- Marking pencil
- Pair of scissors
- Weighing balance
- Cotton waste
- Plastic mugs
- Stirring rods
- Nylon hair brush
- Surgical blades with handle
- Surgical gloves
- Chisel

III. COLLECTING OF MATERIALS FROM THE STOVE:

- PAN fabric
- Epoxy resin LY556(grade)
- Hardener HY972(grade)
- Acetone

IV. MOULD PREPARATION:

- Mould metal plate can be cleaned by emerging with fine emery paper in order to remove rust and foreign particles sticking to the mould plate.
- Cleaning the mould plate de greasing with acetone with the help of cotton waste.
- Apply two coats of wax polish gently with cotton cloth preferably
- In both directions and allow it to dry to release the laminate easily from the metal mould plate.
- Now mould is ready for layup.

MOULD 1



MOULD 2



Acetone



Wax coating



V. RESIN AND HARDENER PREPARATION:

- The resin should be stored at room temperature (24.4) and the specific gravity of the measured by using Archimedes principle and is found to be 1.17.



- Viscosity of the resin should be measured using Brookfield viscometer and is found to be 7238 centipoises but it should be around 1000 centipoises (the error is occurred due to air voids which eliminates during heating).
- Required quantity of resin is measured in a beaker and kept on a mantle and should be heated up to 90 degree centigrade.



- The resin should be stirred continuously and now the flame should be lowered and required quantity of hardener should be measured and poured into the resin beaker and should be stirred continuously until the solution becomes homogeneous by slowly increasing the temperature.



- The temperature at which the solution becomes homogeneous is noted and is found to be 95 degrees.
- Then the resin mixture beaker is kept in water beaker for getting cool.



VI. LAY UP PROCESS:

- Take the resin and hardener in required ratio and mix them thoroughly with the stirring rod.
- Dimensions are to be marked on the pan fabric.

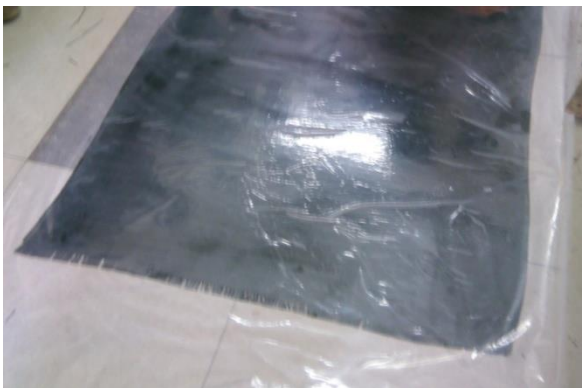


- Apply thin resin coating on PAN fabric and cover its both sides with plastic wrapper.

RESIN COATING 1



PREPEG 1



- Cut the prepegs into required dimensions and give numbering.
- Now lay up the prepegs until the required thickness is achieved which is up to 6 layers on the die part of the mould and is covered with the punch and c clamps are attached to the mould and allowed to rest for sometimes and extra resin will squeezed out.
- The mould is kept into the oven which cures for 4hours at 100 degrees centigrade.

VII. EXTRACTION OF THE LAMINATE AND TRIMMING OF THE LAMINATE:

- After complete curing laminate is extracted from the metal plate using chisel and trim laminate sides using cutting machine.

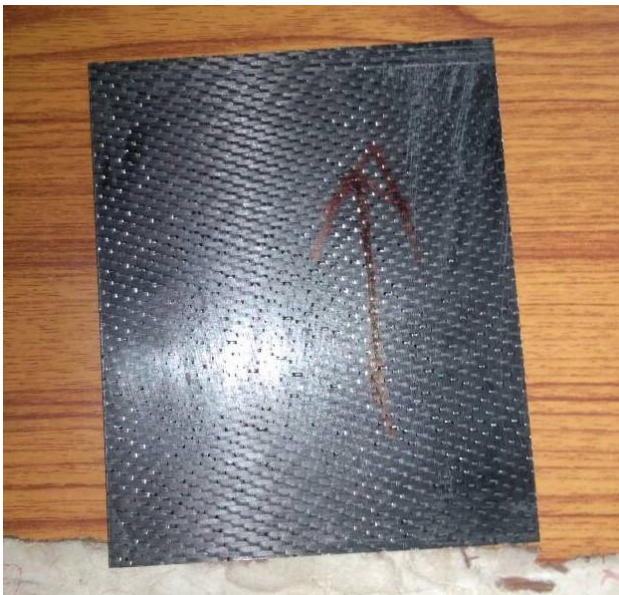
Before trimming Tensile specimen



Before trimming ILSS specimen



After trimming



VIII. INSPECTED BY VISUAL INSPECTION:

- For air voids in the laminate white patches resin rich areas and resin less areas.

IX. DIMENSIONS OF LAMINATE:

- Laminate is measured for its dimensions using venire callipers.

CHAPTER 7

INFORMATION ABOUT TESTING

7.1 UNIVERSAL TESTING MEACHINE:

A **universal testing machine**, also known as a **universal testing, materials testing testing machine or material test frame**, is used to test the tensile stress and compressive strength of material. It is named after the fact that it can perform many standard tensile and compressive tests on materials, compressive, and structures.



COMPONENTS:

LOAD FRAME - usually consisting of two strong supports for the machine. Some small machine has a single support.

LOAD CELL- A forced transducer or other means of measuring the load is required. Periodic calibration is usually called for.

CROSS HEAD- A movable cross head is controlled to move up or down. Usually this is at a constant speed: sometimes called a constant rate of extension (CRE) machine. Some machine can program the crosshead speed or conduct cyclical testing, testing at constant force, testing at constant deformation, ECT. Electromechanical, servo-hydraulic, linear drive and resonance drive are used.

MEANS OF MEASURING EXTENSION OR DEFORMATION - Many test required a measure of the response of the test specimen to the movement of the cross head. Extensometer is sometimes used.

OUTPUT DEVICE- A means of providing the test result is required. Some older machine has dial or digital display and charts recorded. Many newer machines have a computer interface for analysis and printing.

CONDITIONING - Many tests require controlled conditioning (temperature, humidity, pressure, ECT.). The machine can be in a controlled room or a special environment chamber can be placed around the test specimen for the test.

Test fixtures, specimen holding jaws, and relative sample making equipment are called for many test methods.

USAGE OF UTM:

The specimen is placed in the machine between the grips and an extensometer if required can automatically record the change in gauge length during the test. If extensometer is not fitted, the machine itself can record the displacement between its cross heads on which the specimen is held. However, this method not only records the change in length of the specimen but also all other extending / elastic components of the testing machine and its drive systems including any slipping of the specimen in the grips.

Once the machine is started it begins to apply load on specimen. Throughout the tests the control system and its associated software record the load and extension or compression of the specimen.

Machine range from very small table top system to once with over 53 MN (12million lbf) capacity.

7.1.1 THE TENSILE TEST:



The ability of a material to withstand force tending to pull it apart is “Tensile strength ”, also may be definite as the maximum tensile stress sustained by the material being tested to it breaking point.

In the tensile test, the specimen was subjected was subjected to a continuously increasing uniaxial tensile force while simultaneous observation were made on the elongation of specimen. The tensile strength is the maximum tensile stress of the material and can be found by applying equation,

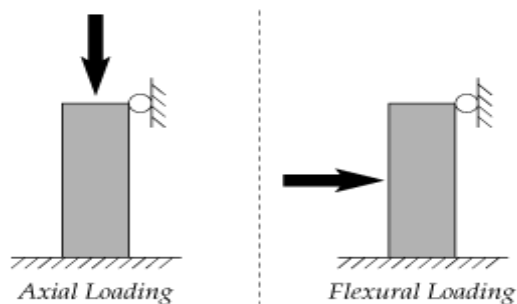
$$\text{Stress} = F / A$$

- Where, f= Applied force (N)

- $A = \text{cross section area (mm}^2\text{)}$
- It is also necessary to note the percentage elongation of the specimen. This shows the relative ductility of the material. The percentage elongation, %EL, is the percentage of plastic strain at fracture point. The percentage elongation can be found by applying the formula as shown below,
- $\%EL = (LF - LO) * 100 / LF$
- Where , $L_f = \text{final length,}$
- $L_o = \text{initial length}$
- Tensile tests are most widely used for defining both the of production lots of polymeric material, their design potential and their engineering behavior. Tensile stress-strain measurements are generally made under tension by stretching the specimen a uniform rate and simultaneously. Measuring the force on the specimen. In stretching such specimen at a uniform tensile stress exists within the gauge section and the distance between the clamps measures the elongation.

7.1.2 FLEXURAL TEST:

The flexural test measure the force required to bend a beam under three point loading condition. The data is often used to select material for parts that will support loads without flexing. Flexed modulus is used as an indication of a material's stiffness when flexed. Since the physical properties of many materials can vary depending on ambient temperature, it is sometime appropriate to test material at temperature, it is sometime appropriate to test material at temperature that simulation the intended user environment



Most commonly the specimen lies on a support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. The parameters for this are the support span and the load is applied to the center by the loading nose producing three points bending at a specified rate. The parameters for this test are the support span, the speed of the loading, and the maximum deflection for the test. These parameters are based on the test specimen thickness and defined differently by ASTM and IOS. For ASYM D790, the test is stopped when the specimen reaches 5%. For IOS 178, this is continued as far as possible and the stress at 3.5% (conventional deflection) is reported.

Flexible strength is calculated from the maximum bending moments by assuming a strength line stress -strain relation to failure. For a beam of rectangular cross section, it is given by the following expression,

- $F.S = 3PL/2bd^2$
- Where, f.s = flexural strength
- P = maximum load
- L = distance between two fixed points
- B = width of the specimen
- D = thickness of the specimen

The most two popular flexural tests are the

- i) Three point bending test
- ii) Four point bending test

THREE POINT FLEXURAL TEST

The **three point bending flexural test** provides values for the modulus of elasticity in bending, flexural stress E_f , flexural strain σ_f and the flexural stress-strain response of the material. The main advantage of a three-point flexural test is the ease of the specimen preparation and testing. However, this method has also some disadvantages: the results of the testing method are sensitive to specimen and loading geometry and strain rate.



Testing method

The [test method](#) for conducting the test usually involves a specified [test fixture](#) on a [universal testing machine](#). Details of the test preparation, conditioning, and conduct affect the test results. The sample is placed on two supporting pins a set distance apart and a third loading pin is lowered from above at a constant rate until sample failure.

Calculation of the flexural stress σ_f

$$\sigma_f = \frac{3FL}{2bd^2} \text{ for a rectangular cross section}$$

$$\sigma_f = \frac{FL}{\pi R^3} \text{ for a circular cross section [1]}$$

Calculation of the flexural strain ϵ_f

$$\epsilon_f = \frac{6Dd}{L^2}$$

Calculation of [flexural modulus](#) [2] E_f

$$E_f = \frac{L^3 m}{4bd^3}$$

in these formulas the following parameters are used:

- σ_f = Stress in outer fibers at midpoint, (MPa)
 - ϵ_f = Strain in the outer surface, (mm/mm)
 - E_f = flexural Modulus of elasticity, (MPa)
 - F = load at a given point on the load deflection curve, (N)
 - L = Support span, (mm)
 - b = Width of test beam, (mm)
 - d = Depth or thickness of tested beam, (mm)
 - D = maximum deflection of the center of the beam, (mm)
 - m = The gradient (i.e., slope) of the initial straight-line portion of the load deflection curve, (P/D), (N/mm)
-
- R = The radius of the beam, (mm)

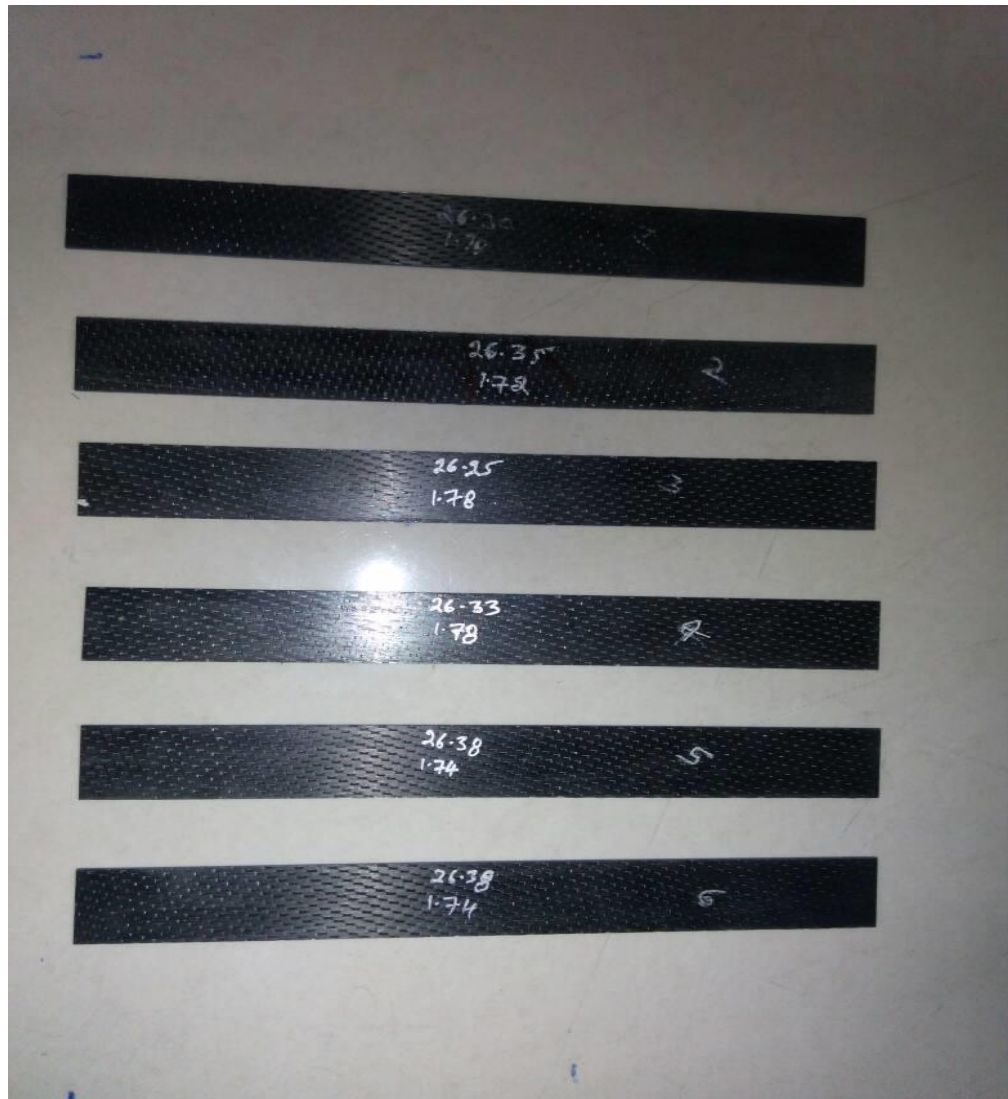
CHAPTER 8

RESULTS AND DISCUSSION

8.1 TENSILE STRENGTH TESTING

STANDARD: ASTM D 638

SPECIMEN FOR TENSILE TESTING:



Tabular column:

Specimen number	Dimensions (mm*mm) b*d	Maximum Displacement Mm	Maximum Load(kN)	Tensile Strength (Mpa)	Tensile Modulus (Gpa)	Remarks Failed in
1	26.30*1.78	5.049	23.963	511.9	109	SAB
2	26.35*1.72	5.819	27.321	602.8	99	SAT
3	26.25*1.78	5.612	25.775	551.6	105	SGM
4	26.33*1.78	5.876	27.084	577.9	102	SGM
5	26.38*1.74	5.416	26.201	570.8	78	SGM
6	26.38*1.74	5.832	26.169	576.1	68	SGM

Average value of tensile strength=565.1833Mpa

Average value of tensile modulus=93.5Gpa

UTM DURING TENSILE TESTING:



FAILURE DURING TENSILE TESTING:



REPORT:

Failure occurred within the gauge length

- Vacuum is applied during filtration
- Samples after filtering are kept into the oven to evaporate the extra moisture content.

8.2 FLEXURAL TESTING

STANDARD: ASTM D 790

Flexural test by three point bending test

Support span to depth ratio: 40 to maximum bending than shear

Cross head speed: 10mm/min

Span length=20*depth

$FS = 3P_{max} * L / (2bd)$

SPECIMENS FOR FLEXURAL TESTING:



Table

Specimen number	Dimensions (mm*mm) b*d	Maximum Displacement Mm	Maximum Load(kN)	Flexural Strength (Mpa)	Flexural Modulus (Gpa)	Remarks
1	10.66*1.79	0.437	0.315	387.6	12	Compressive failure
2	10.58*1.73	0.836	0.546	724.1	13	Compressive failure

3	10.33*1.73	0.674	0.434	589.6	13	Compressive failure
4	10.26*1.80	0.793	0.493	623.4	12	Compressive failure
5	10.37*1.80	0.716	0.361	451.1	14	Compressive failure
6	10.21*1.85	0.743	0.416	499.7	14	Compressive failure

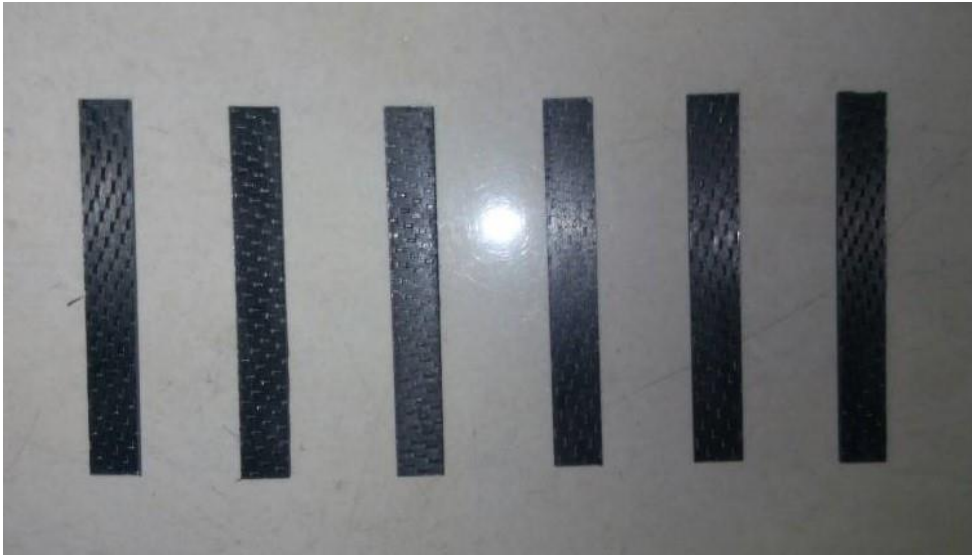
Average value of flexural strength= 545.91Mpa

Average flexural modulus=13Gpa

UTM DURING FLEXURAL TESTING:



SPECIMEN AFTER FLEXURAL TESTING:



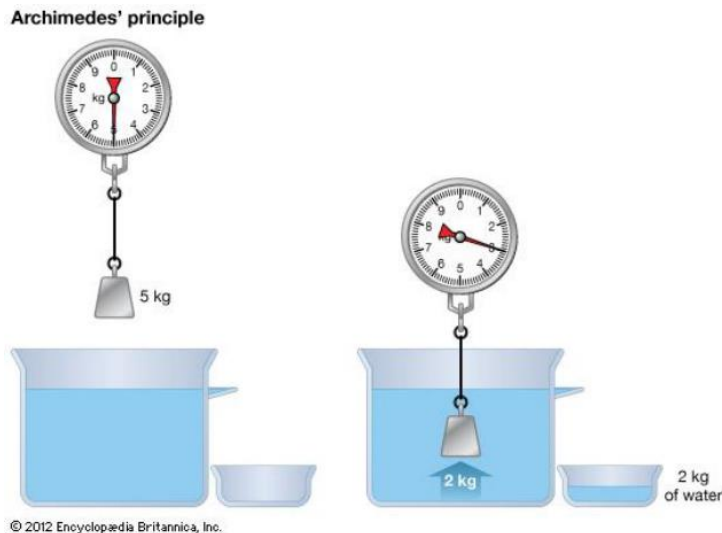
REPORT:

Failure occurred within the gauge length and is compressive failure.

8.3 DENSITY CALCULATION 6 LAYER LAMINATE

PRINCIPLE INVOLVED: ARCHEMEDES PRINCIPLE

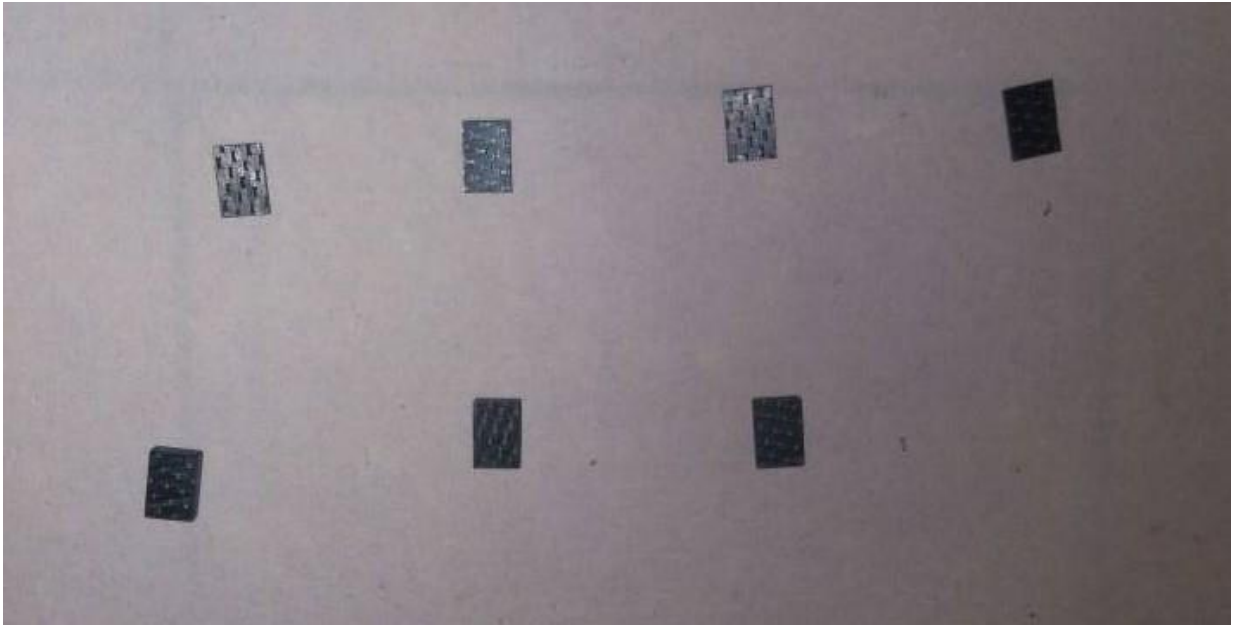
Archimedes' principle, physical law of buoyancy, discovered by the ancient Greek mathematician and inventor **Archimedes**, stating that any body completely or partially submerged in a fluid (gas or liquid) at rest is acted upon by an upward, or buoyant, force the magnitude of which is equal to the weight of the fluid ...



FORMULA USED

DENSITY= (weight of sample in air/ weight of sample in air –weight of sample in liquid)*density of liquid

SPECIMEN FOR DENSITY CALCULATIONS:



TABULAR COLUMN:

Specimen number	Thickness	Weight of sample in air	Weight of sample in water	Density
1	2.54	0.4323	0.1557	1.56
2	2.4	0.4431	0.1580	1.55
3	2.42	0.4405	0.1574	1.55
4	2.32	0.4368	0.1570	1.56

8.4 PERCENTAGE OF RESIN, FABRIC AND VOID CALCULATIONS

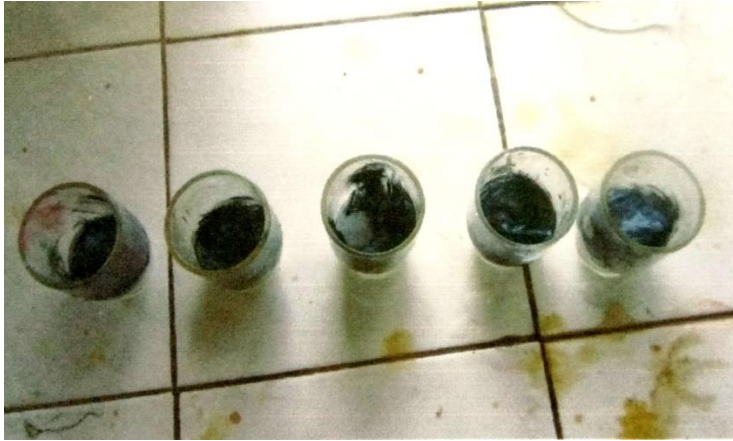
Procedure:

- 3 small (13.1mm*13.1mm) specimens are each separately in 5 beakers which consist of 30 ml of conc.HNO₃ and are kept on a heat plate whose temperature does not exceed 90 degree centigrade.



- After 1 hour we have to filter the fibre by diluting and filtering it continuously by acetone and water alternatively in sintered crucible which is kept on a borosil flask.





TABULAR COLUMN:

Sample number	Empty Crucible Weight (gms)	Weight With fabric (gms)	Density	%F	%R
1	51.5630	51.8909	1.56	75.850	24.14
2	62.0056	62.3402	1.55	75.513	24.48
3	59.9296	60.2634	1.55	75.77	22.22

Average value of %F=75.711%

Average value of %R=24.289%

8.5 VOLUME OF FABRIC AND RESIN

Volume fraction of fabric V_f :

$$\begin{aligned} V_f &= \% \text{ of fabric} * \text{density of carbon} / \text{density of fiber} \\ &= 75.711 * 1.45 / 1.8 = 60.98\% \end{aligned}$$

Volume fraction of resin V_m :

$$\begin{aligned} V_m &= \% \text{ of fabric} * \text{density of carbon} / \text{density of resin} \\ &= 24.289 * 1.45 / 1.812 = 19.463 \% \end{aligned}$$

Volume fraction of void V_e :

$$V_e = 1 - V_f + V_m = 1 - 0.6098 + 0.19463 = 5.8\%$$

OBSERVATION:

Therefore there is 5.8 % of space (voids) inside the laminate.

8.5 INTER LAMINAR SHEAR STRENGTH TESTING

STANDARD: ASTM D 2344

ILSS TEST BY 3 POINT BENDING TEST

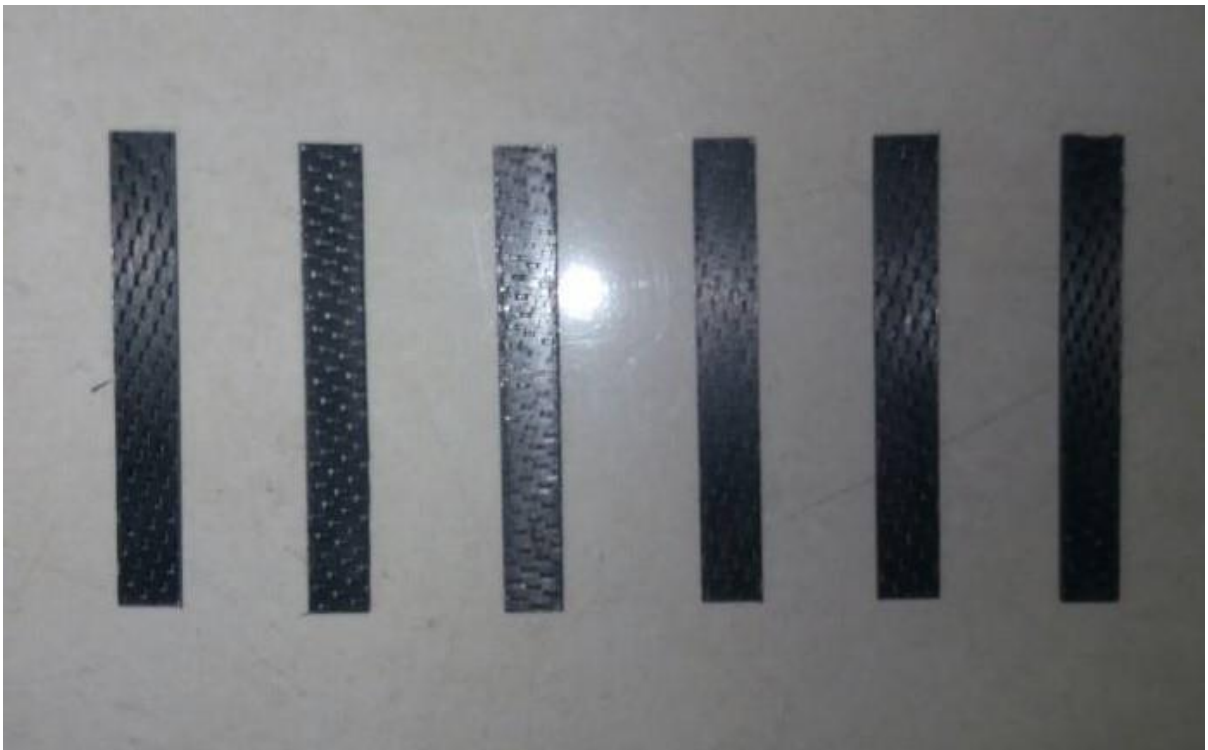
Support span to depth ratio: 4*to maximum pure shear rather than bending

Cross head speed: 1mm/min

Span length=4* depth of specimen

$ILSS = 3P_{max} * L / (4bd)$

SPECIMENS FOR ILSS TESTING:



For doing **ILSS** we need to fabricate the laminate of 14 layers **PAN** fabric impregnation with Epoxy resin and whose thickness will be around 5mm.

TABULAR COLUMN:

Specimen number	Dimensions b*d (mm*mm)	Displacement Mm	Maximum load Pmax(kN)	ILSS (Mpa)
1	10.50*4.98	0.348	2.234	32.04
2	10.53*4.97	0.379	2.412	34.56
3	10.44*4.77	0.378	2.312	34.82
4	10.43*4.90	0.335	2.314	33.95
5	10.50*5.03	0.384	2.458	34.90
6	10.48*4.94	0.321	2.188	31.69
7	10.50*4.98	0.339	2.360	33.84
8	10.55*4.95	0.319	2.346	33.69
9	10.50*4.93	0.399	2.442	35.38
10	10.34*4.88	0.320	2.202	32.72

Average value of inter laminar shear strength = 33.75

UTM during ILSS:



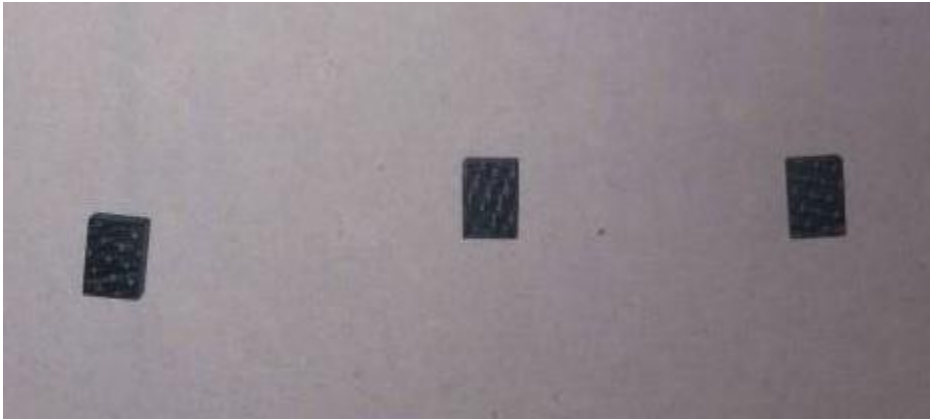
8.6 DENSITY CALCULATIONS OF 14 LAYER LAMINATE SPECIMENS:

PRINCIPLE INVOLVED: ARCHEMEDES PRINCIPLE

FORMULA USED

DENSITY= (weight of sample in air/ weight of sample in air -weight of sample in liquid)*density of liquid

SPECIMEN FOR DENSITY CALCULATIONS:



TABULAR COLUMN:

Specimen number	Weight of sample in air	Weight of sample in water	Density
1	1.1476	0.3760	1.48
2	1.1440	0.3745	1.48
3	1.1474	0.3724	1.48
4	1.1442	0.3756	1.48

Average value of density = 1.48

8.7 DEGREE OF CURE AND GLASS TRANSITION TEMPERATURE:

The degree of cure and glass transition temperature (T_g) of a composite is measured using the **Differential scanning calorimeter (DSC)**



Differential scanning calorimeter is a thermo-analytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature throughout the experiment. Generally, the temperature program for DSC analysis is designed such that the sample holder temperature increases linearly as a function of time. The reference sample should have a well-defined heat capacity over the range of temperatures to be scanned.

The glass transition temperature is the temperature at which the amorphous material changes from a hard, relatively brittle state to a molten, rubber like state.

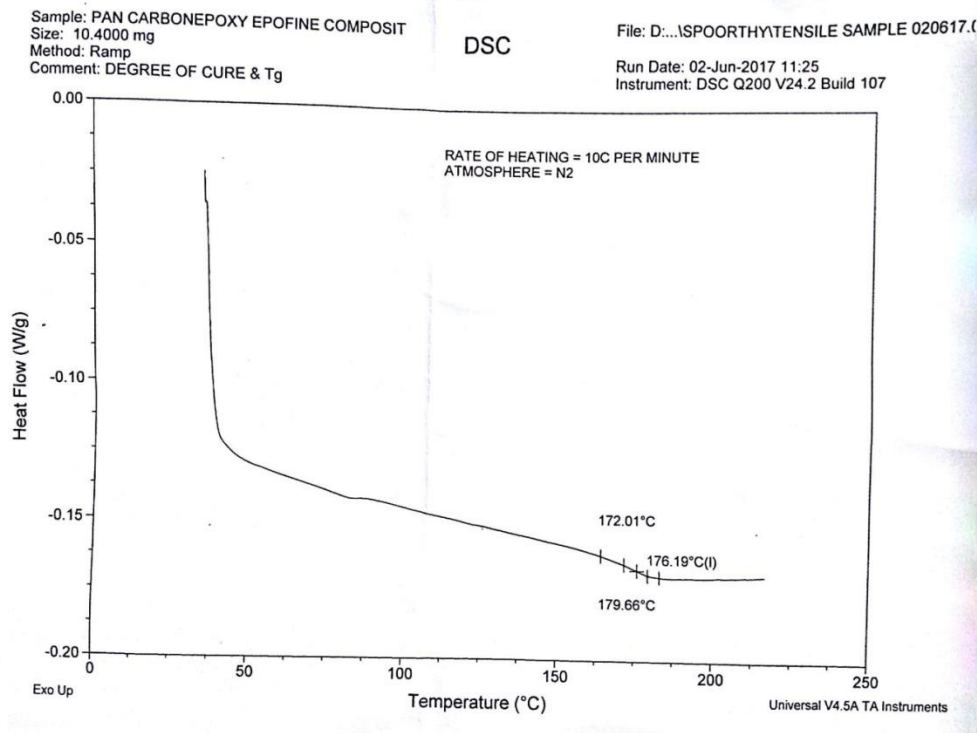
The composites after the use of DSC were seen as completely cured as there were no exothermic peaks, which would have signified release of heat due to incomplete curing and further curing occurring inside the DSC.

The glass transition temperature of composites (PAN carbon epoxy and Rayon carbon phenolic composite) was also obtained. A sudden drift is seen in the graph.

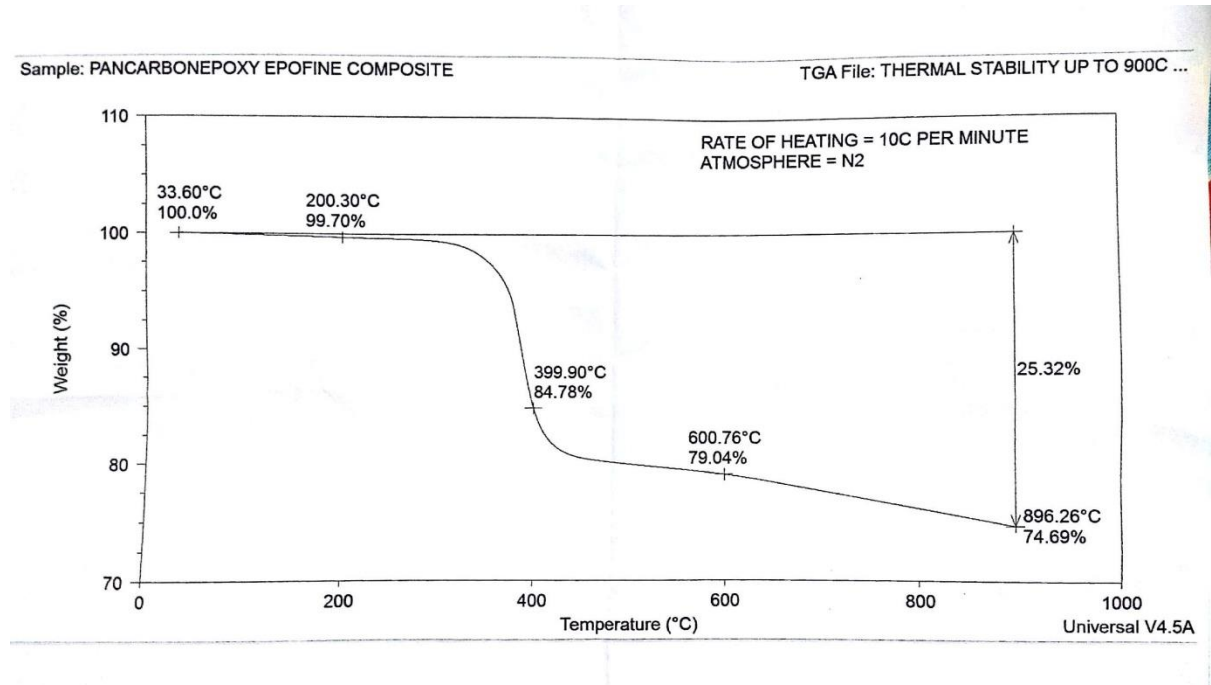
TGA DEVICE



DSC results:



TGA RESULTS:



WEIGHT LOSS W.R.T TIME AND TEMPERATURE

SPHN
File: THERMAL STABILITY UP TO 900C N2 ATMOSPHER... Run Date: 02-Jun-2017 11:05
Program: Universal V4.5A Run Number: 1

TA Instruments Thermal Analysis -- TGA

Sample: PANCARBONEPOXY EPOFINE COMPOSITE
Size: 9.6910 mg

Method: Ramp

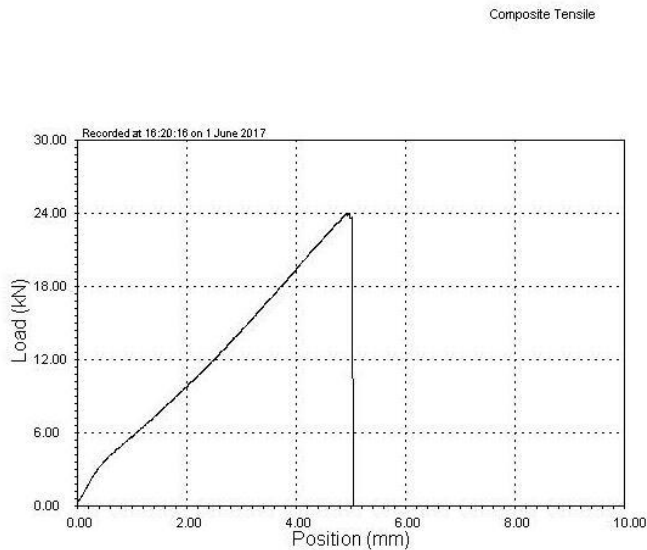
Time min	Temperature °C	Weight %
1.98	50.00	99.99
7.04	100.00	99.90
12.04	150.00	99.80
17.03	200.00	99.70
22.04	250.00	99.61
27.04	300.00	99.39
32.04	350.00	97.76
37.04	400.00	84.75
42.03	450.00	80.44
47.03	500.00	79.90
52.03	550.00	79.50
57.02	600.00	79.04
62.02	650.00	78.39
67.02	700.00	77.63
72.01	750.00	76.90
77.01	800.00	76.16
82.01	850.00	75.40
	900.00	

CHAPTER 9**PHYSICAL & MECHANICAL PROPERTIES OF PAN CARBON
FABRIC/EPOXY COMPRESSED LAMINATE**

Sp.no	Property name	No of specimen	Results obtained
1	Tensile strength	6	565.18Mpa
2	Tensile modulus	6	93.5Gpa
3	Flexural strength	6	545.91Mpa
4	Flexural modulus	6	13Gpa
5	ILSS (inter laminar shear strength)	10	33.75Mpa
6	Density	4	1.56gm/cc
7	Fibre by weight	4	450gms
8	Resin by weight	4	300gms
9	Volume fraction of fabric	3	60.98%
10	Volume fraction of resin	3	19.43%

CHAPTER 10

RESULTS:

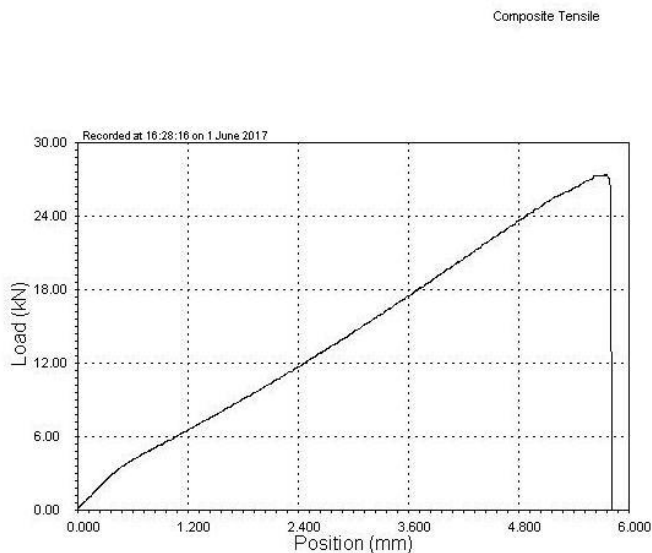
Pan 1

Specimen Identifier: IR 010617-1
 Project : B Tech Sphoorthy
 Material : PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot NO:
 Component No:
 SUPPLIER:
 PURPOSE: DATA GENERATION
 Resin Batch No:

Geometry: Flat
 Width: 26.300 mm
 Thickness: 1.780 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 46.813999 sq mm

Analysis Results

Extension at Maximum Load	-0.094 %
Maximum Load	23.963 kN
Load	
Maximum Stress	511.9 MPa
Modulus of Elasticity	109305.5 MPa
Modulus	

Pan 2

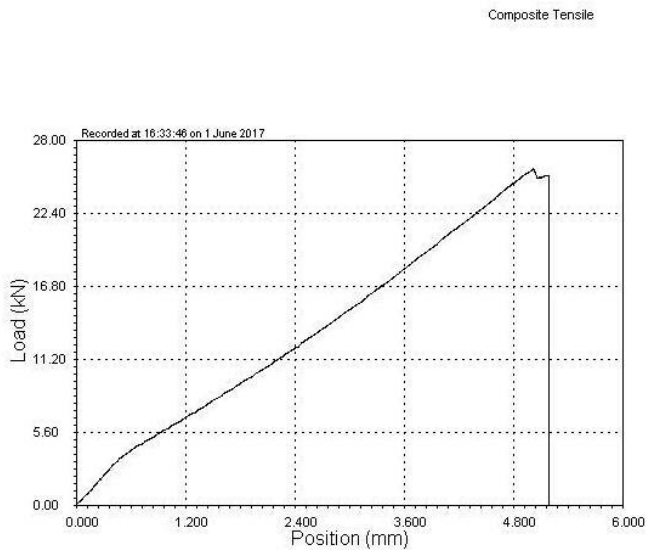
Specimen Identifier: IR 010617-3
 Project : B Tech Sphoorthy
 Material : PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot NO:
 Component No:
 SUPPLIER:
 PURPOSE: DATA GENERATION
 Resin Batch No:

Geometry: Flat
 Width: 26.350 mm
 Thickness: 1.720 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 45.321999 sq mm

Analysis Results

Extension at Maximum Load	0.027 %
Maximum Load	27.321 kN
Load	
Maximum Stress	602.8 MPa
Modulus of Elasticity	99379.4 MPa
Modulus	

Pan 3



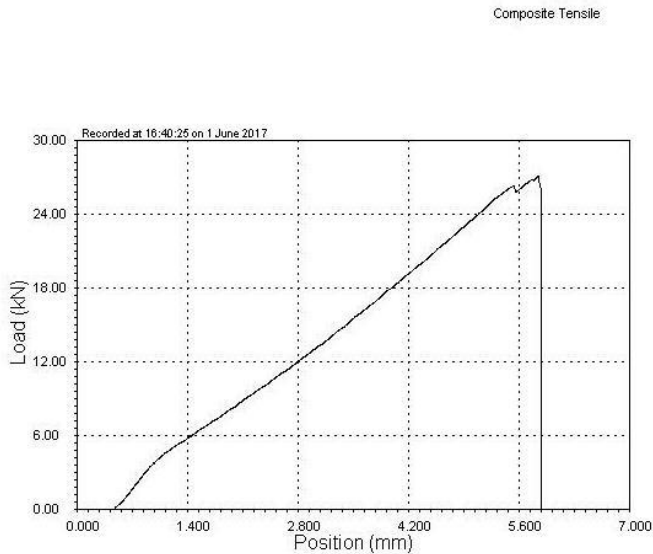
Specimen Identifier: IR 010617-4
 Project: B Tech Sphoorthy
 Material: PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot NO:
 Component No:
 SUPPLIER:
 PURPOSE: DATA GENERATION
 Resin Batch No:

Geometry: Flat
 Width: 26.250 mm
 Thickness: 1.780 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 46.724998 sq mm

Analysis Results

Extension at Maximum Load	-0.116 %
Maximum Load	25.775 kN
Load	
Maximum Stress	551.6 MPa
Maximum Stress	
Modulus of Elasticity	105085.1 MPa
Modulus	

Pan 4



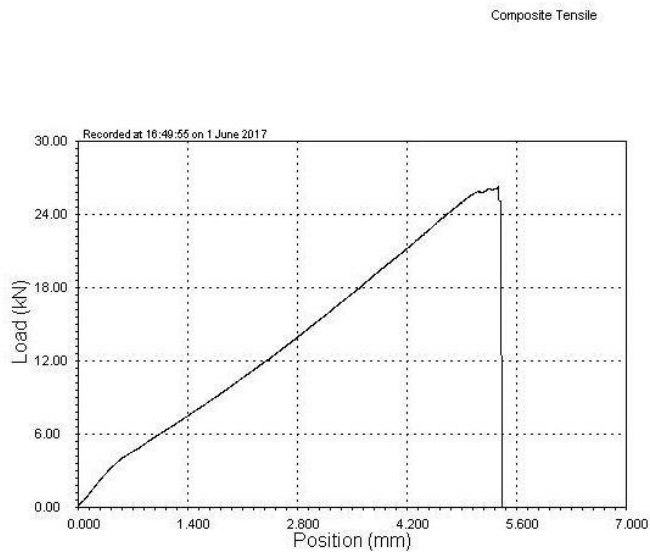
Specimen Identifier: IR 010617-5
 Project: B Tech Sphoorthy
 Material: PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot NO:
 Component No:
 SUPPLIER:
 PURPOSE: DATA GENERATION
 Resin Batch No:

Geometry: Flat
 Width: 26.330 mm
 Thickness: 1.780 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 46.867397 sq mm

Analysis Results

Extension at Maximum Load	0.10 %
Extension at Maximum Load	
Maximum Load	27.084 kN
Load	
Maximum Stress	577.9 MPa
Maximum Stress	
Modulus of Elasticity	102478.4 MPa
Modulus	

Pan 5



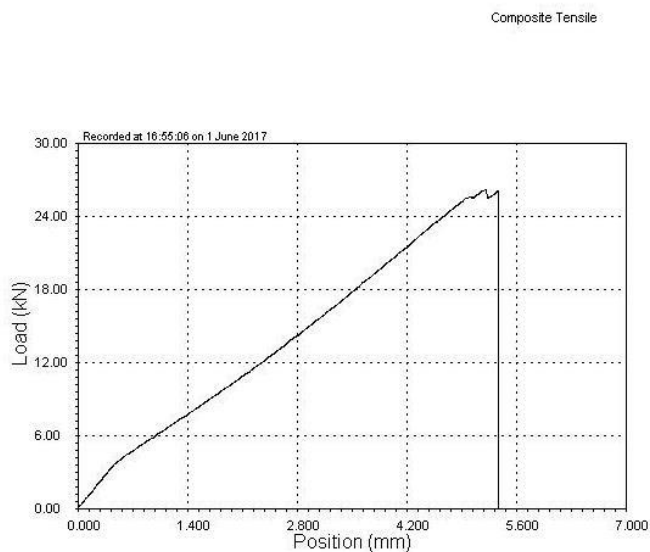
Specimen Identifier: IR 010617-6
 Project: B Tech Sphoorthy
 Material: PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot No:
 Component No:
 SUPPLIER:
 PURPOSE:
 Resin Batch No: DATA GENERATION

Geometry: Flat
 Width: 26.380 mm
 Thickness: 1.740 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 45.901199 sq mm

Analysis Results

Extension at Maximum Load
 Extension at Maximum Load -0.07 %
 Maximum Load
 Load 26.201 kN
 Maximum Stress
 Maximum Stress 570.8 MPa
 Modulus of Elasticity
 Modulus 78371.9 MPa

Pan 6



Specimen Identifier: IR 010617-7
 Project: B Tech Sphoorthy
 Material: PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot No:
 Component No:
 SUPPLIER:
 PURPOSE:
 Resin Batch No: DATA GENERATION

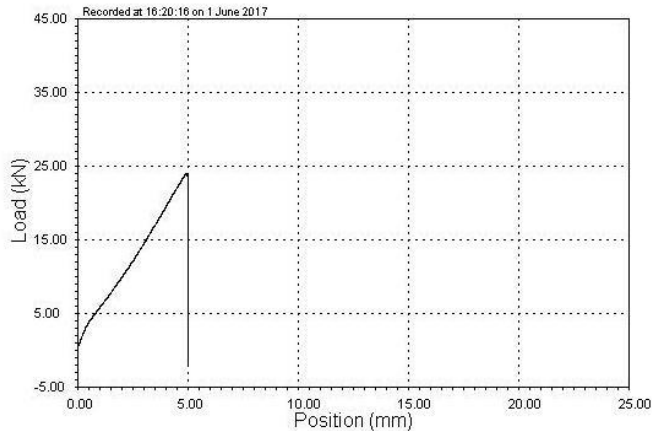
Geometry: Flat
 Width: 26.380 mm
 Thickness: 1.740 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 45.901199 sq mm

Analysis Results

Extension at Maximum Load
 Extension at Maximum Load -0.43 %
 Maximum Load
 Load 26.169 kN
 Maximum Stress
 Maximum Stress 570.1 MPa
 Modulus of Elasticity
 Modulus 68353.1 MPa

Pan

Composite Tensile



Specimen Identifier: IR 010617-1
 Project: B Tech Sphoorthy
 Material: PAN Carbon fabric/Epoxy ej
 COMPONENT ID:
 Requisition by: Ms G. Ramarao, Sc E
 Fibre Lot NO:
 Component No:
 SUPPLIER:
 PURPOSE:
 Resin Batch No: DATA GENERATION

Geometry: Flat
 Width: 26.300 mm
 Thickness: 1.780 mm
 Axial Strain Gauge Length: 25.000 mm
 Area: 46.813999 sq mm

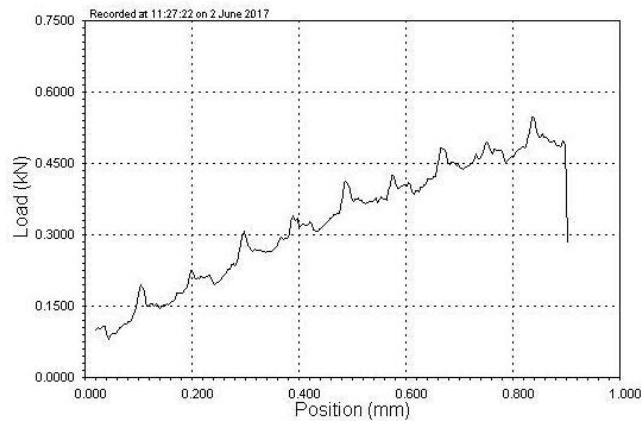
Analysis Results

Extension at Maximum Load	-0.094 %
Maximum Load	23.963 kN
Maximum Stress	511.9 MPa
Modulus of Elasticity	109305.5 MPa
Modulus	

Flexural

FLEXURAL TEST

ASL, HYDERABAD



Specimen Identifier: IR 020617-5
 Material: PAN Carbon fabric/Epoxy ej
 Requisition: Mr .G.Rama Rao Sc E
 PROJECT: B Tech SPHN
 Purpose of Test: Data Generation
 Supplier: M/S. CPDC

Geometry: Beam Center
 Width: 10.580 mm
 Depth: 1.730 mm
 Span Length: 28.000 mm
 Area: 0.753926 sq mm

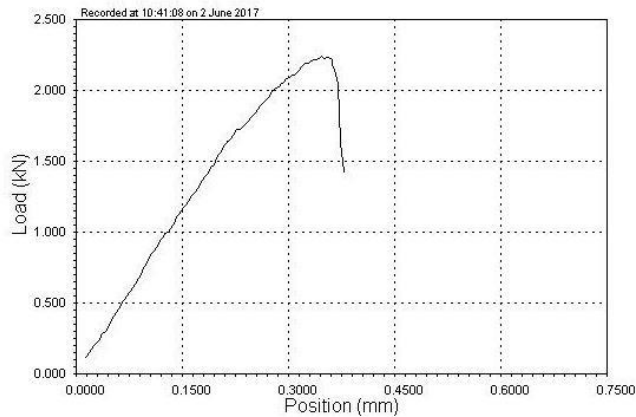
Analysis Results

Extension at Maximum Load	0.836 mm
Maximum Load	0.546 kN
Maximum Stress	724.1 MPa
Modulus of Elasticity	135927.0 MPa
Modulus	

ILSS 1

ILSS- ASTM D 2344

ASL, HYDERABAD



Specimen Identifier: IR 020617-1
 Material: PAN CARBON EPOXY EPC
 Batch No:
 Supplier: CPDC, ASL
 Requisition by: Mr G Rama Rao Sc E
 PROJECT: B Tech SPHN
 Purpose of test:

Geometry:
 Width: 10.500 mm
 Depth: 4.980 mm
 Span Length: 20.000 mm
 Area: 8.680140 sq mm

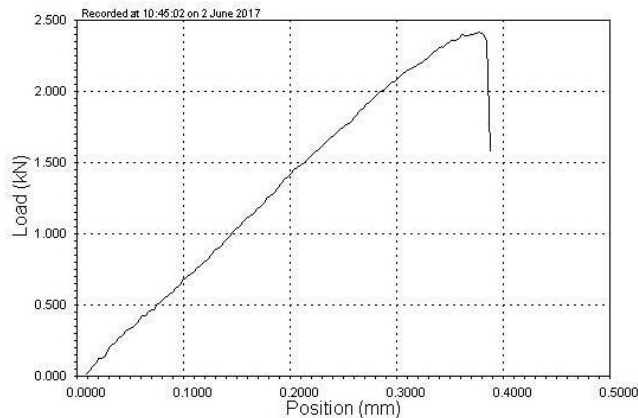
Analysis Results

Extension at Maximum Load	0.348 mm
Maximum Load	2.234 kN
Maximum Stress	257.4 MPa
Modulus of Elasticity	14360.0 MPa
Modulus	

ILSS 2

ILSS- ASTM D 2344

ASL, HYDERABAD



Specimen Identifier: IR 020617-2
 Material: PAN CARBON EPOXY EPC
 Batch No:
 Supplier: CPDC, ASL
 Requisition by: Mr G Rama Rao Sc E
 PROJECT: B Tech SPHN
 Purpose of test:

Geometry:
 Width: 10.530 mm
 Depth: 4.970 mm
 Span Length: 20.000 mm
 Area: 8.670015 sq mm

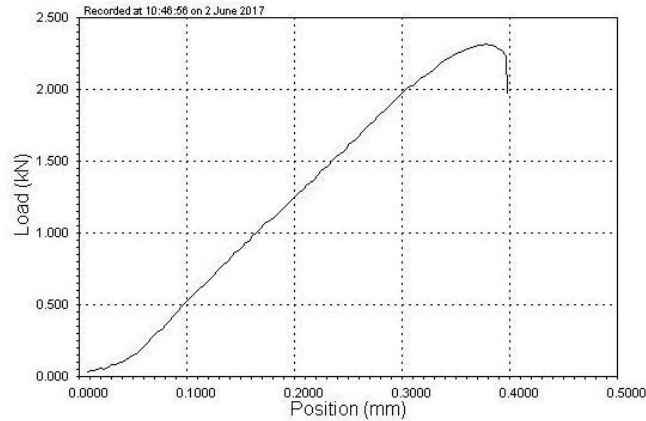
Analysis Results

Extension at Maximum Load	0.379 mm
Maximum Load	2.412 kN
Maximum Stress	278.2 MPa
Modulus of Elasticity	12557.9 MPa
Modulus	

ILSS 3

ILSS- ASTM D 2344

ASL, HYDERABAD



Specimen Identifier: IR 020617-3
 Material: PAN CARBON EPOXY EPC
 Batch No:
 Supplier: CPDC, ASL
 Requisition by: Mr G Rama Rao Sc E
 PROJECT: B Tech SPHN
 Purpose of test:

Geometry: Beam Center
 Width: 10.440 mm
 Depth: 4.770 mm
 Span Length: 20.000 mm
 Area: 7.918008 sq mm

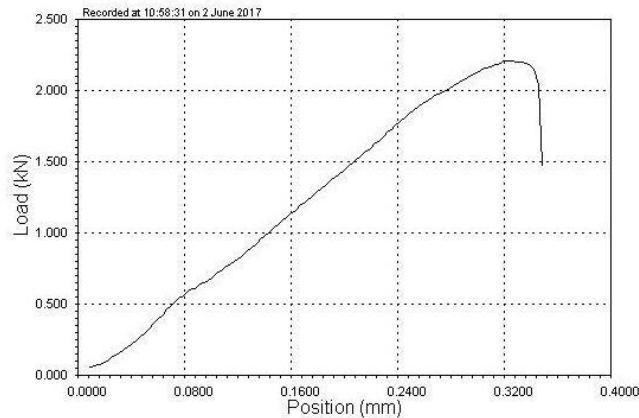
Analysis Results

Extension at Maximum Load	0.378 mm
Maximum Load	2.312 kN
Maximum Stress	291.9 MPa
Modulus of Elasticity	13899.9 MPa

ILSS 4

ILSS- ASTM D 2344

ASL, HYDERABAD



Specimen Identifier: IR 020617-10
 Material: PAN CARBON EPOXY EPC
 Batch No:
 Supplier: CPDC, ASL
 Requisition by: Mr G Rama Rao Sc E
 PROJECT: B Tech SPHN
 Purpose of test:

Geometry: Beam Center
 Width: 10.340 mm
 Depth: 4.880 mm
 Span Length: 20.000 mm
 Area: 8.208031 sq mm

Analysis Results

Extension at Maximum Load	0.320 mm
Maximum Load	2.202 kN
Maximum Stress	268.3 MPa
Modulus of Elasticity	15783.5 MPa

CHAPTER 11

CONCLUSION

Composites provide a better strength to load ratio for a given structure, hence, providing the required structural integrity to it. With the advancement of technology, composites seem to be replacing everything. These materials find a large use in buildings, bridges and structures such as boat hulls swimming pool panels, race car bodies, shower stalls, bath tubs and storage tanks, imitation granite and cultured marble sinks and countertops. The most advanced examples perform routinely on space craft's in demanding environments, the only disadvantage being its non-biodegradable property.

With so much usage and the world becoming a “composite world”, this is indeed the future.

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- ✓ nptel.ac.in/courses/Webcourse-contents/IIScOBANG/Compositesworld.com/resources/htp://www.ehow.com/about_5868282_tn-es-composites-materials.html
- ✓ [www.netcom.osites.com/ide/resin-t\[OBS/7](http://www.netcom.osites.com/ide/resin-t[OBS/7)
- ✓ www.netcom.osites.com/ide/resin-stems/6

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- ✓ Agarwal And Lawrence J. Broutman.
- ✓ Mechanics Of Composite Materials, Second Ed., By Autark.Kaw. Engineering Mechanics Of Composite Materials By Isaac And M Dani,
- ✓ Mechanics Of Composite Materials, By R.M.Jones.
- ✓ Analysis Of Laminated Composite Structures, By L.R.Caicote.