Lecture 6 to 10

Module I

Classification

Composite materials can be classified based on the form of their constituents, number of layers, orientation of fibers, length of fibers etc. The tree diagram shown below shows a list of composite materials under respective classification.

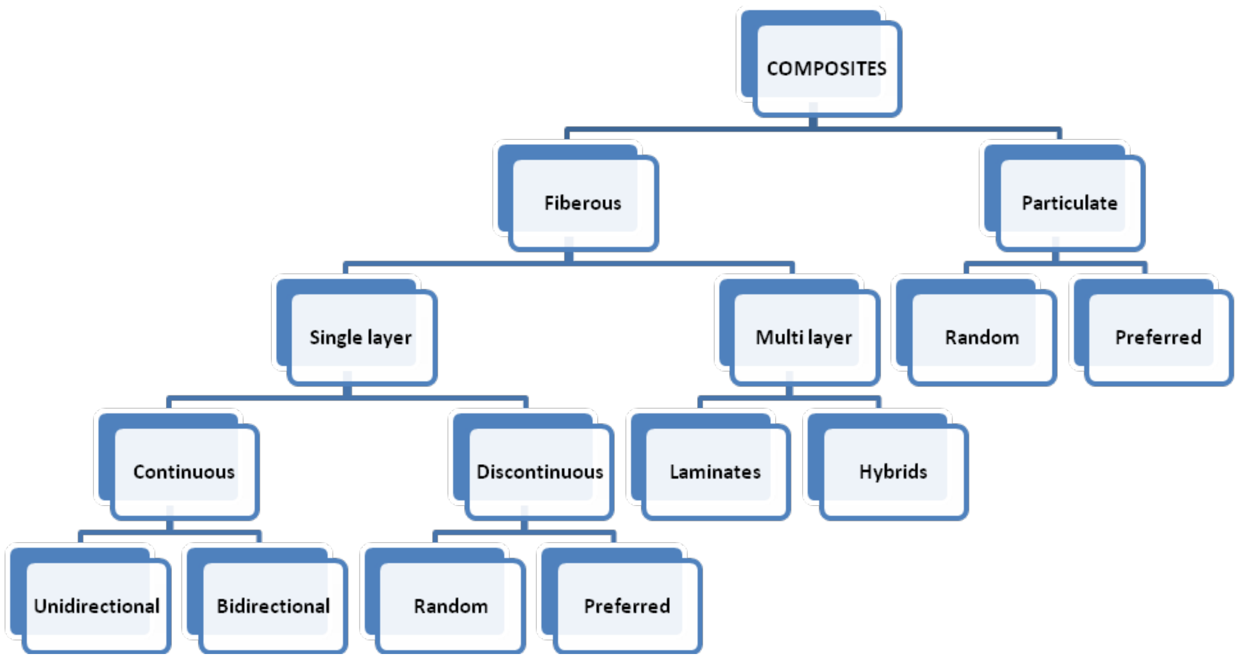

Figure 1.6 Composite material classification

The composite materials that we are discussing is mostly related to polymer composites, in which the polymer is the matrix and the fibers are reinforcements. Depending on the size of the reinforcement we can classify the composites as fibrous composites, particulate composites, powdered composites and nano composites. In fibrous composites, the reinforcements will be in the form of fibers in which the length of the fiber will be much higher than the cross sectional dimension. The cross sectional dimension will be in the order of microns and length will be in the order of millimeters, centimeters or in meters. In particulate composites the size of the reinforcement will be in the order of some millimeters and in powdered composites the size will be in microns. In nano composites one of the dimensions of the reinforcement will be in nano level.

The fibrous composites can be further classified as, single layer composites or multi layer composites depending upon the number of layers. Depending on the requirement of thickness the number of layers can be changed. Depending on the length of the fibers the composites can be classified as short fiber composites and continuous fiber composites. In short fiber composites the fibers can be mixed with the resin system and the composite product can be obtained by compression molding process. This will provide composites of fibers with random orientation. Fibers can also be allowed to flow with the resin and can be injected to a mold of different size and dimensions by which we may get composites with aligned fibers. composites of short fibers with random orientation will yield quasi-isotropic properties whereas composites of aligned short fibers will yield orthotropic properties.

When continuous fibers are used as reinforcements, the composites can be unidirectional (which makes use of unidriectional mats (ud-mats), can be bi-directional (fibers are woven in two directions and are used) or tri-directional (3-d, fabrics are used as reinforcements). The orientation of the layers will control the anisotropy of the composites.

When multilayers are used for making composites, the layers can be made of single material or from different materials. If the composites are made with layers of different materials then the composites will be called as hybrid composites. A hybrid composites will contain fibers of glass, carbon and kevlar depending on the usage.

In particulate composites the particles can be dispersed in the matrix system either in aligned form or in a random fashion. composites with aligned distribution will provide composites of orthotropic or anisotropic properties whereas random orientation will provide composites with quasi-isotropic properties.

Fibers:

A fiber is characterized by its very high length-to-diameter ratio. The strength-to-density and the stiffness-to-density ratios are generally used as indicators of the effectiveness of the fiber. Fibers are the principal constituents in a fiber - reinforced composite material. They occupy the largest volume fraction in a composite laminate and share the major portion of the load acting on the composite structure. Proper selection of the type of fiber, volume fraction of fiber, length of fiber, and orientation of fiber is very important, since these parameters influence the following characteristics of a composite laminate:

- ✓ Density
- ✓ Tensile strength and modulus
- ✓ Compressive strength and modulus
- ✓ Fatigue strength
- ✓ fatigue failure mechanisms
- ✓ Electrical and thermal conductivities
- ✓ Cost

Classification of Fibers:

Fibers can be classified based on their production, size and strength.

(i) Based on production

(a) Natural fibers

These fibers are naturally available. As such they have inferior quality than the synthetic or man-made fibers. But, natural fibers are bio-degradable and there by eco-friendly. The list of natural fibers are

- Banana
- Coir
- Jute
- Palm
- Pine apple
- Roselle
- Sisal

(b) Synthetic / Man-made fibers

These fibers are manufactured synthetically. So, they show superior qualities than the natural fibers. But, synthetic fibers are not bio-degradable and so a threat to the environment pollution. The list of man-made fibers includes

- Boron
- Carbon
- Ceramic
- Glass
- Graphite
- Kevlar
- Silica

(ii) Based on size:

Fibers are divided into three categories based on their size. They are

- Filaments
- Wires, and
- Rods

(iii) Based on strength:

Fibers are grouped into three based on their strength-wise performance. They are high, medium and low performance fibers. For example,

a) High performance
    - Boron fiber
    - Carbon fiber
    - Kevlar fiber

b) Medium performance

- Glass fiber

c) Low performance

- Natural fibers

Reinforcement Products:

There are a wide variety of fiber products available in the market. They can be classified as given below:

- ✓ One-dimensional
- ✓ Two-dimensional
    - Bidirectional fabric
    - Multidirectional fabric
    - Weft-knitted fabric
    - Warp-knitted
    - Biaxial braided fabric
    - Triaxial braided fabric
    - Continuous fiber mat (CFM)
    - Continuous strand mat (CSM)
- ✓ Three-dimensional
    - 3D
    - 2D or angle interlock
    - 3X
    - 3X with warp stuffer yarns
- ✓ Untwisted strand
    - Roving
    - Woven roving
- ✓ Twisting of strand
    - Woven fabric
- ✓ Chopped strand
    - Chopped strand mat
- ✓ Pre-forms

- ✓ Multi axially braided and woven textiles
- ✓ Knitted
- ✓ Milled fibers

What quality of fibers required for composite material:

Certain requirements are to be satisfied by fiber in order to be used as reinforcement material in composites. They are

- ✓ fibers should be extremely thin
- ✓ fibers should be one dimensional (length > cross section)
- ✓ fiber should have high modulus and high strength
- ✓ utilization of fibers should be very effective
- ✓ fiber should contribute sustainability to the improved mechanical properties of composite

Characterization of Fibers:

Fibers should possess some characteristics so that they can be used with matrix to form composite materials to give a better product.

- ✓ Fiber should be flexible
- ✓ Lateral dimension of fibers is in millimeter or micron level
- ✓ Fiber must be several times stronger than the matrix to share the high fraction of total load
- ✓ Fiber should have higher elastic properties than the matrix.
- ✓ Fiber should have high aspect ratio (length / cross-sectional area)

Types of fibers

Even though there are a variety of fibers in the market, some of the fibers widely used in the aerospace industry will be discussed here.

(i) Glass fibers:

Glass fibers are the most common fibers of all reinforcing fibers for polymeric matrix composites (PMC). The fig.1.3 shows one of the forms of glass fiber.

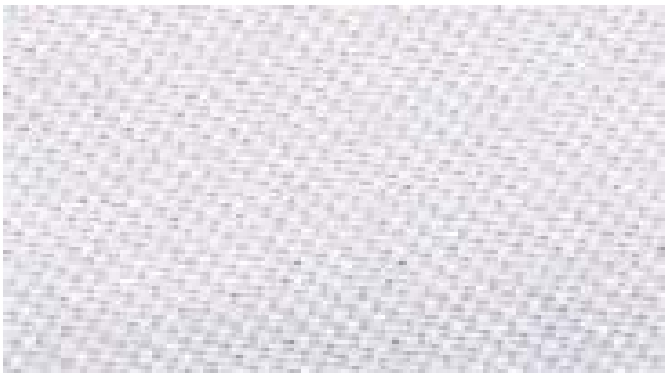

Figure 1.7 E-Glass woven fiber

The principal advantages of glass fibers are

- ✓ Low cost
- ✓ High tensile strength
- ✓ High chemical resistance
- ✓ Excellent insulating properties

The disadvantages are

- ✓ Low tensile modulus
- ✓ High density (among the commercial fibers)
- ✓ Sensitivity to abrasion during handling (which frequently decreases its tensile strength)
- ✓ Low fatigue resistance
- ✓ High hardness (which causes excessive wear on molding dies and cutting tools)

Table 1.1 Mechanical properties of glass fibers:

The table below shows the properties of E-glass and S-glass which are widely used than other types of glass fibers.

Properties		E-glass	S-glass
Specific gravity		2.60	2.50
Modulus	GPa	72	87
Strength	MPa	3450	4310
Percentage tensile elongation		4.8	5.0
Co-efficient of thermal expansion	µm/m/ºC	5.0	5.6

Types of glass fibers:

Glass fibers are available in variety of forms which cater for specific applications. The cheapest among all the glass fibers is E-glass fiber and S-glass has the highest tensile strength.

The types of glass fibers are:

- ➢ A-glass
    - o Has high alkaline content
- ➢ C-glass
    - o Used in chemical applications since having good corrosion resistance
- ➢ E-glass

- Used in electrical applications & FRP industry and low cost

- S-glass
  - Used for aircraft components and missile casings owing to having high strength

- Z-glass
  - Used for communication purposes

Table 1.2 Composition of glass fiber:

Various types of glass fibers are manufactured based on the compositions. In all of the glass fibers Silica and calcium oxide play major role. The other alloy used in glass fibers are given in the table below.

Alloy (%)	E-glass	C-glass	S-glass
SiO_2	55.2	65.0	65.0
Al_2O_3	8.0	4.0	25.0
CaO	18.7	14.0	-
MgO	4.6	3.0	10.0
Na_2O	0.3	8.5	0.3
K_2O	0.2	-	-
B_2O	7.3	5.0	-

(ii) Kevlar Fibers:

Kevlar fibers are highly crystalline aromatic polyamide fibers. They have the lowest density and the highest tensile strength-to-weight ratio. Kevlar-49 is the trade name.

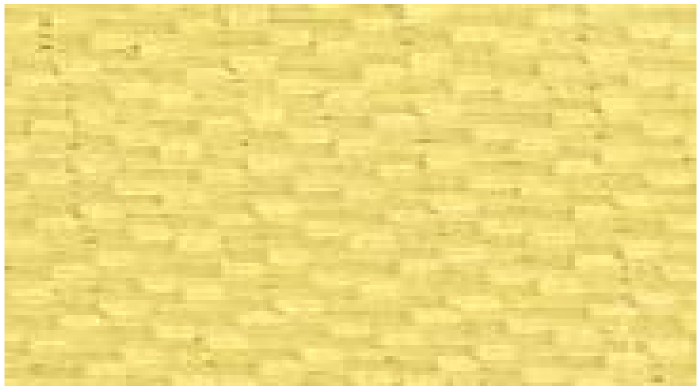

Figure 1.8 Kevlar fiber

The major benefits of Kevlar fiber are

- ✓ Lowest density
- ✓ Highest tensile strength-to-weight ratio (Aerospace applications & Ballistic applications)
- ✓ Resistance to impact damage
- ✓ Negative coefficient of thermal expansion (Used in low thermal expansion composite panels)

The disadvantages of kevlar fibers are

- ✓ Low compressive strengths
- ✓ Difficulty in cutting or machining

Kevlar fiber- reinforced composites are

- ✓ Bullet proof jackets
- ✓ Biomedical
- ✓ Armor vehicles

Table 1.3 Mechanical properties of Kevlar fibers:

Properties		**Kevlar 149**	**Kevlar 49**	**Kevlar 129**	**Kevlar 29**
Specific gravity		1.44	1.44	1.44	1.44
Modulus	GPa	186	124	96	68
Strength	MPa	3440	3700	3380	2930
Percentage tensile elongation		2.5	2.8	3.3	3.6
Co-efficient of thermal expansion	µm/m/ºC	-2.0	-2.0	-2.0	-2.0

(iii) Carbon Fibers:

Carbon fibers have carbon content of 95% and contain a blend of amorphous carbon and graphite carbon. Their high tensile modulus is due to the presence of graphite form in which carbon atoms are arranged in a crystallagraphic structure of parallel layers.

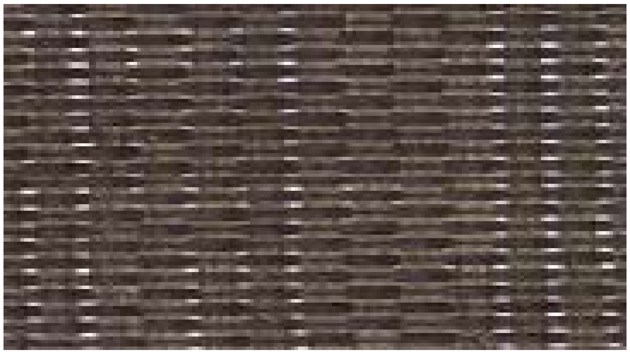

Figure 1.9 Carbon fiber

Carbon fibers are manufactured from two types of precursors:

(i) Textile precursor, PAN (Poly Acrylonitrile)

These fibers are generally categorized into high tensile strength, high modulus and ultrahigh modulus types.

(ii) Pitch, petroleum by-product

These fibers have very high modulus but their tensile strength and strain-to-failure are lower than those of PAN. They are less in cost than that of PAN.

Some advantages of carbon fibers are

- ✓ High stiffness (Due to less elongation)
- ✓ Less specific gravity
- ✓ Can withstand at high temperature
- ✓ Negative coefficient of thermal expansion
- ✓ Used for aerospace & radar applications

But carbon fibers have low strain-to-failure, low impact resistance, high electrical conductivity and high cost.

Table 1.4 Mechanical properties of carbon fibers:

Properties		Low	Intermediate	Ultra-high
Specific gravity		1.8	1.9	2.2
Modulus	GPa	230	370	900
Strength	MPa	3450	2480	3800
Percentage tensile elongation		1.1	0.5	0.4
Co-efficient of thermal expansion	µm/m/ºC	-0.4	-0.5	-0.5

(iv) Extended Chain Polyethylene Fibers

They are called by their trade name 'Spectra'. These fibers are produced by gel spinning a high-molecular-weight polyethylene. Gel spinning yields a highly oriented fibrous structure with exceptionally high crystallinity (95%–99%) relative to melt spinning used for conventional polyethylene fibers. The major advantages are

- ✓ Highest strength-to-weight ratio
- ✓ Low moisture absorption
- ✓ High abrasion resistance
- ✓ High impact resistance even at low temperature

Their drawbacks are

- ✓ Poor adhesion with resin matrices
- ✓ Low melting point, which leads to high level of creep above 100ºC

Their applications include

- ✓ Marine composites (Boat hulls & water skis)
- ✓ Ballistic composites (Armors, helmets)

Table 1.5 Mechanical properties of Spectra fibers:

Properties		Spectra 900	Spectra 1000	Spectra 2000
Specific gravity		0.97	0.97	0.97
Modulus	GPa	70	105	115
Strength	MPa	2600	3200	3400
Percentage tensile elongation		3.8	3.0	3.0
Co-efficient of thermal expansion	x10^6 µm/m/ºC	>70	>70	-

(v) Boron Fibers:

Boron fibers are manufactured by chemical vapor deposition (CVD) of boron onto a heated substrate (either a tungsten wire or a carbon monofilament). The most prominent feature of boron fibers is their extremely high tensile modulus, which is in the range of 379–414 GPa. Coupled with their relatively large diameter, boron fibers offer excellent resistance to buckling. Even though it is very costly, it has certain advantages over other fibers which include

- ✓ High tensile modulus
- ✓ High compressive strength
- ✓ Relatively large diameter

Boron fibers are used mostly in aerospace industry and also used in

- ✓ Turbine blade
- ✓ Transmission shafts

(vi) Ceramic Fibers:

Silicon carbide (SiC) and aluminum oxide (Al_2O_3) fibers are examples of ceramic fibers. They are very notable for their high-temperature applications in metal and ceramic matrix composites. The major advantages are

- ✓ Suitable for reinforcing metal matrices
- ✓ Low thermal expansion

Matrix:

The role of the matrix in composite materials are

(i) to keep the fibers in place

(ii) to transfer stresses between the fibers

(iii) to provide a barrier against an adverse environment such as chemicals and moisture

(iv) to protect the surface of the fibers from mechanical degradation e.g. by abrasion

(v) to provide lateral support against the possibility if fiber buckling under compressive loading

In addition to those roles, it has an influence on the compressive, inter-laminar shear as well as in-plane shear properties of the composite materials.

Matrix can be broadly classified as

- ✓ **Thermoset**
  - Epoxy
  - Poly ester and Vinyl ester
- ✓ **Thermoplastic**
  - Nylon
  - Polyether ether ketone (PEEK)
  - Polyphenylene sulfide (PPS)

  - Polyetherimide (PEI)
  - Polyamide-imide (PAI)
  - Poly sulfone (PSUL)
  - Lanley research centre thermo plastic imide (LARC-TPL)
- ✓ **Metallic**
  - Aluminium and its alloys
  - Titanium alloys
  - Magnesium alloys
  - Copper-based alloys
  - Nickel-based alloys
- ✓ **Ceramic**
  - Aluminium oxide (Al_2O_3)
  - Silicon carbide (SiC)
  - Silicon nitride (Si_3N_4)

Requirements of matrix:

In order to serve as a good matrix for a composite material, matrix under consideration should be

- ✓ Thermally compatible (Both fiber & matrix should have same co-efficient of thermal expansion)
- ✓ Chemically compatible (Matrix shouldn't react with fiber)
- ✓ Physical compatible

Glass Transition Temperature:

The glass transition temperature, denoted by Tg, is defined as the temperature at which the polymeric solid changes from a hard material to a soft material. But around the temperature Tg, the modulus of material is reduced by nearly the order of five times.

Heat Deflection Temperature:

Softening characteristics of various polymers are often compared on the basis of their heat deflection temperatures (HDT). Measurement of HDT is described in ASTM test method D648.

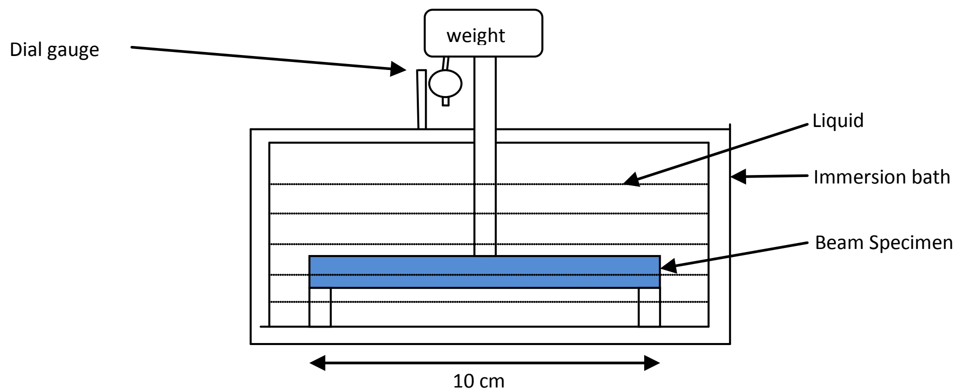

Figure 2 Heat Deflection Temperature Apparatus

In this test, a polymer bar of rectangular cross section is loaded as a simply supported beam inside a suitable non-reacting liquid medium, such as mineral oil. The load on the bar is adjusted to create a maximum fiber stress of either 1.82 MPa. The center deflection of the bar is monitored as the temperature of the liquid medium is increased at a uniform rate of 2 ± 0.2ºC/min. The temperature at which the bar deflection increases by 0.25 mm from its initial room temperature deflection is called the HDT at the specific fiber stress. It is used mostly for quality control and material development purposes. It should be pointed out that HDT is not a measure of the glass transition temperature. For glass transition temperature measurements, methods such as differential scanning calorimetry (DSC) or differential thermal analysis (DTA) are used.

Thermoset Polymer matrix:

In a thermoset polymer also called resin, the molecules are chemically joined together by cross-links. Therefore these polymers cannot be reused once cross-links are formed on curing. They are used in continuous or long fiber-reinforced composites mainly because of the ease of processing due to their low viscosity. The drawbacks that thermoset polymers suffer are limited storage life at room temperature, long fabrication time in the mould and low strain-to-failure. Thermoset polymers used in composite materials are epoxy, polyester, vinylester, phenolics, polyimides, polybenzimidazole (PBI) and polyphenylquinoxaline (PPQ)

(i) Epoxy resin:

A common starting material for the epoxy resin is diglycidyl ether of bisphenol A (DGEBA). In general, the tensile modulus, glass transition temperature, and thermal stability as well as chemical resistance are improved with increasing cross-link density, but the strain-to-failure and fracture toughness are reduced. Epoxy resin is very commonly used in aerospace structures. Some of the advantages of epoxy resin are

- ✓ Good adherence to metal and glass fibers
- ✓ Curing agents, and modifiers are available
- ✓ Absence of volatile matters during curing
- ✓ Low shrinkage during curing
- ✓ Excellent resistance to chemicals and solvents

The principal disadvantages are its relatively high cost and long curing time. To improve strain-to-failure and fracture toughness for damage-tolerant composite material, Carboxyl Terminated Butadiene Acrylonitrile (CTBN) liquid elastoner is added. But CTBN decreases T_g, modulus and tensile strength of the resin. Diamino diphenyl sulfone (DDS) is used as the curing agent.

Table 1.6 Typical Properties of Cast Epoxy Resin (@ 23ºC)

Properties		Cast Epoxy resin
Specific gravity		1.2-1.3
Strength	MPa	55-130
Modulus	GPa	2.75 – 4.10
Cure shrinkage (%)		1-5
Co-efficient of thermal expansion	µm/m/ºC	50-80

Table 1.7 Mechanical Properties of High Performance Epoxy Resins

Property		Epoxy 1	Epoxy 2	Epoxy 3
T_g	ºC	262	261	334
Flexural strength	MPa	140.7	111.7	124.1
Flexural modulus	GPa	3.854	3.378	2.965
Fracture energy	kJ/m^2	0.09	0.68	0.09
Moisture gain	%	5.7	2.6	-

Table 1.8 Effect of CTBN Addition on the Properties of Cast Epoxy Resin

Properties		0%	5%	10%	15%
Tensile strength	MPa	65.8	62.8	58.4	51.4
Tensile modulus	GPa	2.8	2.5	2.3	2.1
Failure elongation	%	4.8	4.6	6.2	8.9
Failure energy	J/m^2	1.75	26.3	33.3	47.3
HDT	ºC	80	76	74	71

(ii) Polyester resin:

As in the case of epoxy resins, the properties of polyester resins depend strongly on the cross-link density. The modulus, glass transition temperature, and thermal stability of cured polyester resins are improved by increasing the cross-link density, but the strain-to-failure and impact energy are reduced. Some of the advantages of the polyester resin are

- ✓ Low cost
- ✓ Low specific gravity
- ✓ Easy to handle
- ✓ Low viscous
- ✓ Ability to be made translucent

The disadvantages are

- ✓ High shrinkage

- ✓ Strength and modulus are lesser than epoxy

Table 1.9 Typical Properties of Cast Thermoset Polyester Resin (@ 23ºC)

Properties		Cast Polyester resin
Specific gravity		1.1-1.43
Tensile strength	MPa	34.5-103.5
Tensile modulus	GPa	2.1-3.45
Failure elongation	%	1.5
HDT	ºC	60-205
Cure shrinkage		5-12

(iii) Vinyl ester resin:

Vinyl ester resins possess good characteristics of epoxy resins, such as excellent chemical resistance and tensile strength, and of unsaturated polyester resins, such as low viscosity and fast curing. However, the volumetric shrinkage of vinyl ester resins is in the range of 5%–10%, which is higher than that of the parent epoxy resins. Some of the advantages are

- ✓ Low cost
- ✓ Excellent wet-out and good adhesion with glass fibers
- ✓ High tensile strength
- ✓ Excellent chemical resistance
- ✓ Low viscosity leads to good wetability
- ✓ Fast curing (solidification)

Table 1.10 Typical Properties of Cast Vinyl Ester Resins (@ 23 ºC)

Properties		Cast Vinyl Ester resin
Specific gravity		1.12-1.32
Tensile strength	MPa	73-81
Tensile modulus	GPa	3-3.5
Failure elongation	%	3.5-0.5
HDT	ºC	93-135
Cure shrinkage	%	5.4-10.3

(iv) Bismaleimides and other Thermoset Polyimides:

Thermoset polyimides are obtained by addition polymerization of liquid monomeric or oligomeric imides to form a cross-linked infusible structure. On curing, they not only offer high temperature resistance, but also high chemical and solvent resistance. However, these materials are inherently very brittle due to their densely cross-linked molecular structure. As a result, their composites are prone to excessive microcracking.

Due to their high temperature resistance, they are used in high temperature applications. Some of their advantages are :

- ✓ Good dimensional stability
- ✓ Good resistance to thermal stresses

The drawback is brittle in nature, resulting in micro cracks.

Table 1.11 Typical properties of Thermoset Polyimide Resins (@ 23 °C)

Property		**Without Modifier**	**With Modifier**	**PMR-15**	**ACTP**
Density	g/cm^3	-	1.28	1.32	1.34
Tensile strength	MPa	-	-	38.6	82.7
Tensile modulus	GPa	-	-	3.9	4.1
Strain-to-failure	%	-	-	1.5	1.5
Flexural strength	MPa	60	126.2	176	145
Flexural modulus	GPa	5.5	3.7	4	14.5
Fracture energy	kJ/m^2	24.5	348	275	-

Thermoplastic polymers

The molecules in these thermoplastic polymers contain rigid aromatic rings that give them a relatively high glass transition temperature and an excellent dimensional stability at elevated temperatures. Thermoplastic polymers have the following merits over their counter-part thermoset polymers. They are :

- ✓ High impact strength and fracture resistance

- ✓ Higher strain-to-failure, therefore better resistance to matrix micro-cracking
- ✓ Unlimited storage life at room temperature
- ✓ Shorter fabrication time
- ✓ Ease of joining and repair by welding, solvent bonding etc.
- ✓ Ease of handling
- ✓ Can be reprocessed and recycled

But they suffer from having lower creep resistance and lower thermal stability.

The mechanical properties of selected thermoplastic polymers that are considered suitable for high-performance composite applications are given below.

(i) Polyether ether ketone:

Polyether ether ketone (PEEK) has a glass transition temperature of 143ºC and a crystalline melting point of 335ºC. Melt processing of PEEK requires a temperature range of 370ºC–400ºC. The outstanding properties of PEEK are :

- ✓ Its high fracture toughness, which is 50–100 times higher than that of epoxies.
- ✓ PEEK has its low water absorption, which is less than 0.5% at 238ºC compared with 4%–5% for conventional aerospace epoxies.

(ii) Polyphenylene sulfide:

Polyphenylene sulfide (PPS) is consisting of aromatic rings linked with sulfides. It has a glass transition temperature of 85º C and a crystalline melting point of 285º C. It has excellent chemical resistance. PPS can be molded, extruded, or machined to high tolerances.

(iii) Polysulfone:

Polysulfone polymers are known for their toughness and stability at high temperatures. They have a glass transition temperature of 185º C and a service temperature of 160º C. The melt processing temperature is between 310º C and 410º C. It has a high tensile strain-to-failure (50%–100%) and an excellent hydrolytic stability under hot–wet conditions (e.g., in steam). Although polysulfone has good resistance to mineral acids, alkalis, and salt solutions, it will swell, stress-crack, or dissolve in polar organic solvents such as ketones, chlorinated hydrocarbons, and aromatic hydrocarbons.

(iv) Thermoplastic polyimides:

Polyetherimide (PEI) and polyamide-imide (PAI) are melt-processable thermoplastic polyimides. Both are amorphous polymers with high glass transition temperatures, 217ºC for PEI and 280º C for PAI. The processing temperature is above 350º C.

Two other thermoplastic polyimides, known as K-polymers and Langley Research Center Thermoplastic Imide (LARC-TPI), are generally available as prepolymers dissolved in suitable solvents. In this form, they have low viscosities so that the fibers can be coated with their prepolymers to produce flexible prepregs. The glass transition temperatures of K-polymers and LARC-TPI are 250º C and 265º C, respectively. Both are amorphous polymers, and offer excellent heat and solvent resistance. Since their molecules are not cross-linked, they are not as brittle as thermoset polymers.

Table 1.12 Properties of Selected Thermoplastic Matrix Resins (@ 23ºC)

Property	PEEK	PPS	PSUL	PEI	PAI	K-III	LARC-TPI
Density g/cm^3	1.31	1.36	1.24	1.27	1.40	1.31	1.37
Tensile strength MPa	100	82.5	70.3	105	185.5	102	138
Tensile modulus GPa	3.24	3.3	2.48	3.00	3.03	3.76	3.45
Elongation-at-break %	50	4	75	60	12	14	5
Poisson's ratio	0.4	-	0.37	-	-	0.365	0.36
Flexural strength MPa	4.1	3.45	2.69	3.3	4.55	-	-
Fracture energy J/m^2	6.6	-	3.4	3.7	3.9	1.9	-
HDT ºC	160	135	174	200	274	-	-
CLTE 10^{-5} /ºC	4.7	4.9	5.6	5.6	3.6	-	3.5

Fiber Reinforced Polymeric Composites

Fiber reinforced polymeric composite (FRP) is one of the widely used composite materials in the world. It consists of one or more discontinuous phases embedded in a continuous phase.

Generally, matrix is used as continuous phase. The matrix is light in weight and its specific gravity ranges between 1.2 and 1.5.

Reinforcement or reinforcing materials (Fibers) are used as discontinuous phase. These are comparably very stronger and harder than the matrix. More over they have high load carrying capacity, high modulus and stiffness, and high strength.