

CHAPTER 1

1. GENERAL INTRODUCTION

Composite materials have fully established themselves as workable engineering materials in more and more diverse fields because they combine the properties of their components and even ^{display} bring forth new or unique properties which may not present in their components. Unlike homogeneous materials, composite materials can be tailored to the suitable properties. The importance of composite materials as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 200 are composites¹.

The concept of composite material is not new. It was found at Thebes, a piece of ancient Egyptian laminated wood which belonged to 1500 B.C., now in the possession of the Metropolitan Museum of Art, New York².

In recent years plastic composite materials have been utilized to an ever increasing extent in the construction of both civil and military aircrafts, automobiles, sporting goods etc. These materials effect important weight saving in interior and exterior structures and at the same time generally offers reduced tooling and specialized fabrication cost.

The modern plastic composite industry may be said to have started in 1940 with the construction of radome structures with E-glass/phenolic composite. The era from 1940-1960 was a period when fabrication methods were the dominant consideration. The majority of present techniques were all brought to being during that period. The time from 1960-70 was perhaps the era of properties. Here the mechanics of the materials ^{were} have been carefully examined and various combinations of many new high modulus fibers, such as carbon, kevlar etc. have been tried³. The period from 1970 to the present is the era of synthesizing various unusual matrices with tailoring of properties with a view to obtain improved processability and superior thermomechanical behavior even in aggressive environments.

1.1 COMPOSITES

1.1.1 Definition

A composite may be defined as a material, consisting of a reinforcing agent embeded in a suitable matrix so as to provide useful structural properties⁴.

Composite = Reinforcement + Matrix.

Nature has provided us the first example of a composite material namely wood and bamboo in which cellulose fibers as the reinforcing agent are embeded in a lignin matrix. Man-made

composites were developed when ancient societies learned to add straw (reinforcing agent) to mud (matrix) to make stronger abode bricks. This easy technology was survived down through the centuries and is still used in many parts of the world⁵.

1.1.2 Characteristics

Properties of the composites are strongly influenced by the properties of their constituent materials, their distribution and the interaction among them. The composite properties may be the volume fraction sum of the properties of the constituents or the constituents may interact in a synergistic way so as to provide properties in the composites. The geometry (shape, size and size distribution), orientation and concentration of the reinforcing agent also affect the properties to a great extent⁶ because these determine the interfacial area, which plays an important role in determining the extent of the interaction between the reinforcement and the matrix.

1.1.3 Classification of Composites

Composite materials may be classified in different ways. Classification based on the geometry of reinforcement is convenient since the geometry of the reinforcement is largely responsible for the mechanical properties of the composites⁷. A typical classification is given in Fig. 1.1.

The three broad classes of composites are (i) dispersion strengthened composite, (ii) particle reinforced composite, and (iii) fiber-reinforced composite.

1.1.3.1 Dispersion-Strengthened Composite

The three classes of composite materials are distinguishable by their micro structures. Dispersion strengthened composite materials consist of a matrix within which fine particles having 0.01 to 0.1 μ diameter are uniformly dispersed in a volume concentration of 1 to 15%.. In this case, ^{the} matrix is the major load bearing constituent. The fine dispersion is present to impede the motion of dislocations of ^{the} matrix under load⁷. The matrix will be strengthened in proportion to the dispersion phase and the magnitude or effectiveness of dispersion. Oxide, carbides, and boride particles etc. which are insoluble with the matrix are generally used as the dispersion phase. This type of dispersion is, generally, applied in the case of metal hardening - Cu-SiO₂, Cu-Al₂O₃ etc. By this process hardness of matrix will be retained over a wide range of temperature and even nearly upto the melting point of the matrix.

1.1.3.2 Particle Reinforced Composite

The particle reinforced composite is very similar to the dispersion strengthened composite but the differences are due to the size and concentration of the dispersoid. Here dispersoid

size exceeds 1.0μ diameter and dispersoid concentration exceeds about 25%.^{7,8}

In particle reinforced composite, both the matrix and the dispersed particles share loads. In general, particles are very effective in improving fracture resistance but they enhance the stiffness of composites to a limited extent. Particle fillers are widely used to improve the properties of matrix materials such as to modify the thermal and electrical conductivities, improve performance at elevated temperatures, reduce friction, increase wear and abrasion resistance, improve machinability, increase surface hardness and reduce shrinkage.

1.1.3.3 Fiber-Reinforced Composite

A fiber is characterized by its length being much greater compared to its cross-sectional dimensions. Any material in its fiber form shows the highest strength since large flaws which are present in the bulk material, are minimised because of the small cross-sectional dimension of the fibers.^{7,8}

In fiber reinforced composites, fibers are embedded in a suitable matrix, which provide useable engineering materials. This reinforcing phase (fiber) spans the entire range of volume concentration, from a few percent to greater than 70%. The distinguishing micro-structural feature of fiber-reinforced material is that their reinforcement has one long dimension,

whereas the reinforcement particles of the other two composites do not^{7,8}.

The fibers are load carrier and the matrix serves to bind the fibers together, transfer loads to the fibers and protect them against environmental attack and damage due to handling.

The interfacial bond between fibers and matrix, % of fiber used and the geometry of fiber distribution are the major factors in determining strength of fibrous composites.

Fibers are very effective in improving the fracture resistance of the matrix since a reinforcement has a long dimension, discourages the growth of incipient cracks normal to the reinforcement that may be, otherwise lead to failure, particularly with brittle matrix. That is why, with this type of reinforcement, the highest specific strength (strength/density) is obtained. In the subsequent discussion this fiber reinforced composite is discussed in detail with specific reference to fibers and resins.

Fiber reinforced composites may be broadly classified as single-layer and multi-layer composites. Single-layer composites are actually made from several distinct layers with each layer having the same orientation and properties such that the entire laminates may be considered as a single

layer composite. The multilayer composite used in structural applications consists of several layers whose orientation is varied according to the design. These layers which may be identical to or different from, each other are bonded together. When the constituent materials in each layer are the same, they are called simply 'laminates'. If the layers are made up of different materials, they are called 'hybrid laminates'.

Reinforcing fibers in a single layer composite may be short or long compared to its overall dimension. Composites with long fibers are called continuous fiber reinforced composite and those with short fibers are called discontinuous fiber reinforced composite. Again depending on the direction of reinforcing fiber in the matrix, they are classified into unidirectional and bidirectional composite/random orientation and preferred orientation composites.

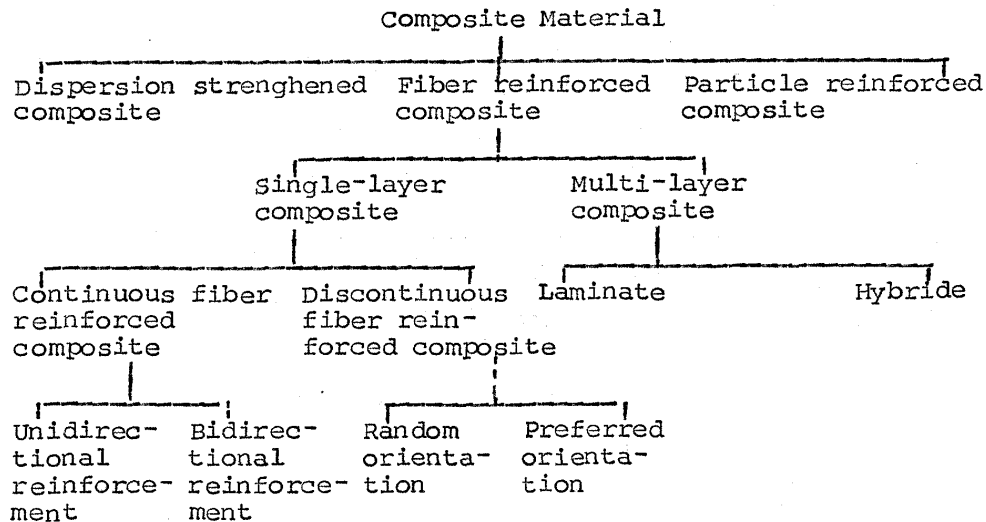


Fig. 1.1 Classification of composites.

1.2 HYBRID COMPOSITE

A hybrid composite consists of either a mixture of reinforcements and a matrix, or a mixture of different matrices and a suitable reinforcement, or both. It is the former variety which is important in view of the fact that the mechanical properties of composites are dependent to a very great extent on the nature of the reinforcement, particularly the fibrous reinforcement. No single fibrous material possesses all the desired properties and the hybridization of the fibers appears to be the only solution to obtain desired properties⁹⁻¹¹.

A fiber which has high strength and high modulus is very much in demand because the former increases the toughness and the later increases the stiffness of the composite. But unfortunately, no such single fiber exists. The blending of fibers of high strength and high modulus can solve this problem. For example, the modulus and fatigue performance of glass reinforced plastic can be improved by the inclusion of carbon fibers or toughness of carbon fiber reinforced plastic can be improved by the inclusion of glass or aramid fiber.

1.3 SOME SPECIAL COMPOSITES

According to the definition of composite, these special composites are no longer a composite at all. Their behavior and structures are very much akin to the behavior and structure

of composites. These are found particularly, in the resin matrix systems and are explained as follows.

1.3.1 Molecular Composite

Highly crystalline polymers in which crystallites are oriented in one direction, are known as molecular composite or self reinforcing material. These crystallites act as a reinforcing agent and enhances the strength along the orientation of crystallites^{12,13}.

One such self-reinforcing polymer is Xydar, trade name given by Darto Manufacturing Co., Xydar is an aromatic polyester copolymer based on bisphenol, p-hydroxy benzoic acid and terephthalic acid and has excellent strength. It shows liquid crystalline behavior in its molten state. The high strength of Xydar comes from its ability to form 'fibrous molecular structures' in molten state. It is these fibrous chains that impart exceptional strength to the solidified polymer and give rise to the self reinforcing material¹³.

1.3.2 Polymer Composite

Takayanagi et al proposed that rigid polymer molecule, instead of macroscopic fiber dispersed in a flexible polymer matrix in molecular level could provide a new type of composite names polymer composite¹⁴.

It has been used in a blend system of rigid poly(p-phenylene terephthalimide) and flexible ABC resin, ^{the} former reinforcing the later. X

1.3.3 Homo Composite

In the compression moulding of PMMA, three morphologies are produced, one of which is a strictly granular type which enhances the fracture toughness. This behavior recalls the characteristics behavior, frequently observed with particulate composite structures¹⁵. In this respect, PMMA with the above described granular structure, may be regarded as a homocomposite materials. X

1.4 FIBROUS REINFORCING MATERIALS

Many materials which can be obtained in fibrous form, can be used and are being used for reinforcing various materials (viz. plastics, metals and ceramics material). There are three important properties¹⁶ that will be required for the selection of those fibers : (i) it must have small diameters so that it can be bent to a small radius of curvature without over straining the outermost areas of that fiber, (ii) its modulus must be greater than the matrix, otherwise load will be carried by the matrix, rather than be transferred to the reinforcements, and (iii) its strength must be high as the composite strength mostly depends on the strength of the fiber.

Out of many fibers, glass, viscose, asbestos etc. have been extensively experimented and are commercially available in different forms. Besides these, carbon/graphite, boron, silica, quartz, whiskers of various materials, alumina fiber, metal coated carbon/graphite fibers etc. are also used. Now Kevlar fiber, an aromatic polyamide (aramide) fiber is competing with glass and carbon fiber both in strength (specific strength properties) and cost.

1.4.1 Glass Fiber

Fiber glass was developed in the 1930's, its utility as a structural reinforcement did not come about until after World War II. Now glass fibers are being used extensively as a reinforcing agent for plastics. Generally, glass is a mixture of alkali/or alkaline earth metal-silicates. The chemical and physical properties of glass fibers are dependent on the composition and the processes by which they are drawn. The reasons for wide application of glass fiber as a reinforcing agent are : high specific strength, moderate modulus of elasticity¹⁷, excellent dimensional stability - maximum extension of $3\frac{1}{2}\%$ to breaking point, resistance to weather, fire, chemicals and solvents, high thermal conductivity, very good electrical properties (high dielectric strength and low dielectric constant), low cost. Glass fiber may be used upto 500°C.

1.4.1.1 Types of Glasses

There are several glass formulations (Table 1.1) that have been used as fibers in plastics composites; these include A, C, D, E, M and S glass.

Table 1.1 Approximate composition (by wt.) of various glasses^{18,19}

Types of glass Constituent	C-glass	E-glass	S-glass	A-glass	D-glass	M-glass
1. SiO ₂	65	55.2	65	72	73	53.7
2. Al ₂ O ₃	4	14.8	25	2.5	#	-
3. CaO	14.4	18.3	-	9.4	#	12.9
4. MgO	3	3.3	10	0.9	#	9.0
5. B ₂ O ₃	5.5	7.3	-	0.5	23	-
6. Na ₂ O and K ₂ O	8.5	0.5	-	14.2	#	-
7. Fe ₂ O ₃	-	0.3	-	0.5	-	0.5
8. F ₂	-	0.3	-	-	-	8.0
9. BeO	-	-	-	-	-	7.9
10. TiO ₂	-	-	-	-	-	-
11. CeO ₂ , Li ₂ O and ZrO ₂	-	-	-	-	-	8.0

Total of these oxides : 4%.