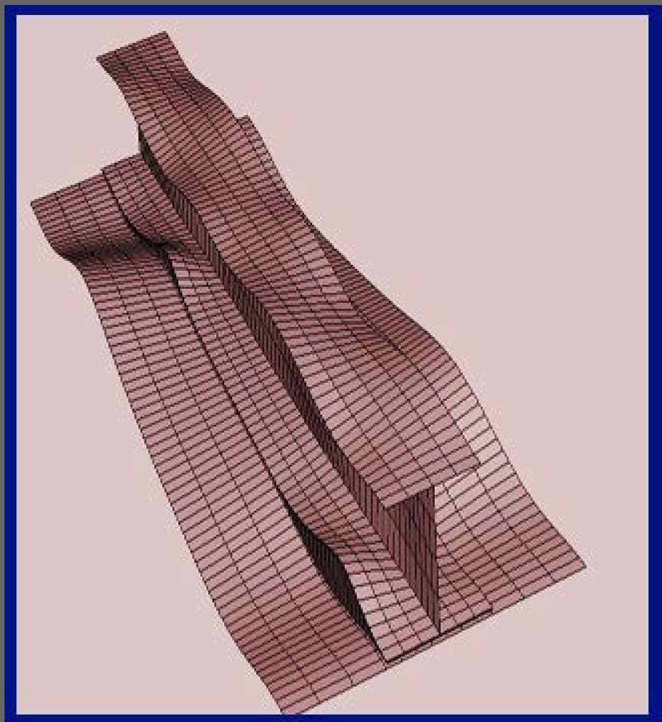

Course Name Composite Materials and Structures

Department Aerospace Engineering IIT Kanpur

Instructor Dr. P. M. Mohite

Next

Module 1: Introduction to Composites

Lecture 1: Definition and Introduction

The Lecture Contains:

Module 1: Introduction to Composites

Lecture 1: Definition and Introduction

Introduction

There is an unabated quest for new materials which will satisfy the specific requirements for various applications like structural, medical, house-hold, industrial, construction, transportation, electrical; electronics, etc. Metals are the most commonly used materials in these applications. In the yore of time, there have been specific requirements on the properties of these materials. It is impossible of any material to fulfill all these properties. Hence, newer materials are developed. In the course, we are going to learn more about composite materials. First, we will deal with primary understanding of these materials and then we will learn the mechanics of these materials.

In the following lectures, we will introduce the composite materials, their evolution; constituents; fabrication; application; properties; forms, advantages-disadvantages etc. In the present lecture we will introduce the composite materials with a formal definition, need for these materials, their constituents and forms of constituents.

Definition of a Composite Material

A composite material is defined as a material which is composed of two or more materials at a microscopic scale and has chemically distinct phases.

Thus, a composite material is heterogeneous at a microscopic scale but statistically homogeneous at macroscopic scale. The materials which form the composite are also called as *constituents* or *constituent materials*. The constituent materials of a composite have significantly different properties. Further, it should be noted that the properties of the composite formed may not be obtained from these constituents. However, a combination of two or more materials with significant properties will not suffice to be called as a composite material. In general, the following conditions must be satisfied to be called a composite material:

1. The combination of materials should result in significant property changes. One can see significant changes when one of the constituent material is in platelet or fibrous from.
2. The content of the constituents is generally more than 10% (by volume).
3. In general, property of one constituent is much greater $(\geq 5\ \text{times})$ than the corresponding property of the other constituent.

The composite materials can be natural or artificially made materials. In the following section we will see the examples of these materials.

Why we need these materials?

There is unabated thirst for new materials with improved desired properties. All the desired properties are difficult to find in a single material. For example, a material which needs high fatigue life may not be cost effective. The list of the desired properties, depending upon the requirement of the application, is given below.

1. Strength
2. Stiffness
3. Toughness
4. High corrosion resistance
5. High wear resistance

6. High chemical resistance
7. High environmental degradation resistance
8. Reduced weight
9. High fatigue life
10. Thermal insulation or conductivity
11. Electrical insulation or conductivity
12. Acoustic insulation
13. Radar transparency
14. Energy dissipation
15. Reduced cost
16. Attractiveness

The list of desired properties is in-exhaustive. It should be noted that the most important characteristics of composite materials is that their properties are *tailorable,* that is, one can design the required properties.

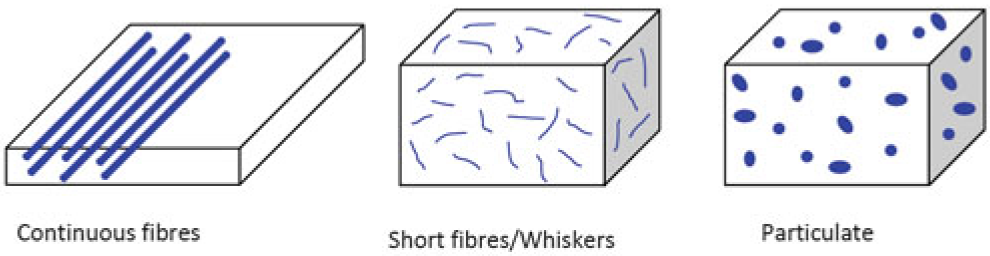

Figure 1.1 Types of reinforcement in a composite

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History of Composites

The existence of composite is not new. The word “composite” has become very popular in recent four-five decades due to the use of modern composite materials in various applications. The composites have existed from 10000 BC. For example, one can see the article by Ashby [1]. The evolution of materials and their relative importance over the years have been depicted in Figure 1 of this article. The common composite was straw bricks, used as construction material.

Then the next composite material can be seen from Egypt around 4000 BC where fibrous composite materials were used for preparing the writing material. These were the laminated writing materials fabricated from the papyrus plant. Further, Egyptians made containers from coarse fibres that were drawn from heat softened glass.

One more important application of composites can be seen around 1200 BC from Mongols. Mongols invented the so called “modern” composite bow. The history shows that the earliest proof of existence of composite bows dates back to 3000 BC - as predicted by *Angara Dating*. The bow used various materials like wood, horn, sinew (tendon), leather, bamboo and antler. The horn and antler were used to make the main body of the bow as it is very flexible and resilient. Sinews were used to join and cover the horn and antler together. Glue was prepared from the bladder of fish which is used to glue all the things in place. The string of the bow was made from sinew, horse hair and silk. The composite bow so prepared used to take almost a year for fabrication. The bows were so powerful that one could shoot the arrows almost 1.5 km away. Until the discovery of gun-powder the composite bow used to be a very lethal weapon as it was a short and handy weapon.

As said, “Need is the mother of all inventions”, the modern composites, that is, polymer composites came into existence during the Second World War. During the Second World War due to constraint impositions on various nations for crossing boundaries as well as importing and exporting the materials, there was scarcity of materials, especially in the military applications. During this period the fighter planes were the most advanced instruments of war. The light weight yet strong materials were in high demand. Further, applications like housing of electronic radar equipments require non-metallic materials. Hence, the Glass Fibre Reinforced Plastics (GFRP) were first used in these applications. Phenolic resins were used as the matrix material. The first use of composite laminates can be seen in the *Havilland Mosquito Bomber* of the British Royal Air Force.

The composites exist in day to day life applications as well. The most common existence is in the form of concrete. Concrete is a composite made from gravel, sand and cement. Further, when it is used along with steel to form structural components in construction, it forms one further form of composite. The other material is wood which is a composite made from cellulose and lignin. The advanced forms of wood composites can be ply-woods. These can be particle bonded composites or mixture of wooden planks/blocks with some binding agent. Now days, these are widely used to make furniture and as construction materials.

An excellent example of natural composite is muscles of human body. The muscles are present in a layered system consisting of fibers at different orientations and in different concentrations. These result in a very strong, efficient, versatile and adaptable structure. The muscles impart strength to bones and vice a versa. These two together form a structure that is unique. The bone itself is a composite structure. The bone contains mineral matrix material which binds the collagen fibres together.

The other examples include: wings of a bird, fins of a fish, trees and grass. A leaf of a tree is also an excellent example of composite structure. The veins in the leaf not only transport food and water, but also impart the strength to the leaf so that the leaf remains stretched with maximum surface area. This helps the plant to extract more energy from sun during photo-synthesis.

What are the constituents in a typical composite?

In a composite, typically, there are two constituents. One of the constituent acts as a reinforcement and other acts as a matrix. Sometimes, the constituents are also referred as *phases*.

What are the types of reinforcements?

The reinforcements in a composite material come in various forms. These are depicted through Figure 1.1.

1. ***Fibre***: Fibre is an individual filament of the material. A filament with length to diameter ratio above 1000 is called a fibre. The fibrous form of the reinforcement is widely used. The fibres can be in the following two forms:
    a. **Continuous fibres:** If the fibres used in a composite are very long and unbroken or cut then it forms a continuous fibre composite. A composite, thus formed using continuous fibres is called as *fibrous composite*. The fibrous composite is the most widely used form of composite.

    b. **Short/chopped fibres**: The fibres are chopped into small pieces when used in fabricating a composite. A composite with short fibres as reinforcements is called as ***short fibre composite*.**

    In the fibre reinforced composites, the fibre is the major load carrying constituent.

2. ***Particulate***: The reinforcement is in the form of particles which are of the order of a few microns in diameter. The particles are generally added to increase the modulus and decrease the ductility of the matrix materials. In this case, the load is shared by both particles and matrix materials. However, the load shared by the particles is much larger than the matrix material. For example, in an automobile application carbon black (as a particulate reinforcement) is added in rubber (as matrix material). The composite with reinforcement in particle form is called a ***particulate composite*.**

3. ***Flake***: Flake is a small, flat, thin piece or layer (or a chip) that is broken from a larger piece. Since these are two dimensional in geometry, they impart almost equal strength in all directions of their planes. Thus, these are very effective reinforcement components. The flakes can be packed more densely when they are laid parallel, even denser than unidirectional fibres and spheres. For example, aluminum flakes are used in paints. They align themselves parallel to the surface of the coating which imparts the good properties.

4. ***Whiskers***: These are nearly perfect single crystal fibres. These are short, discontinuous and polygonal in cross-section.

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The classification of composites based on the form of reinforcement is shown in Figure 1.2. The detailed classification further is given in Figure 1.3. The classification of particulate composites is depicted further in Figure 1.4. Some of the terms used in these classifications will be explained in the following paragraphs/lectures.

Figure 1.2: Classification of composites based on reinforcement type

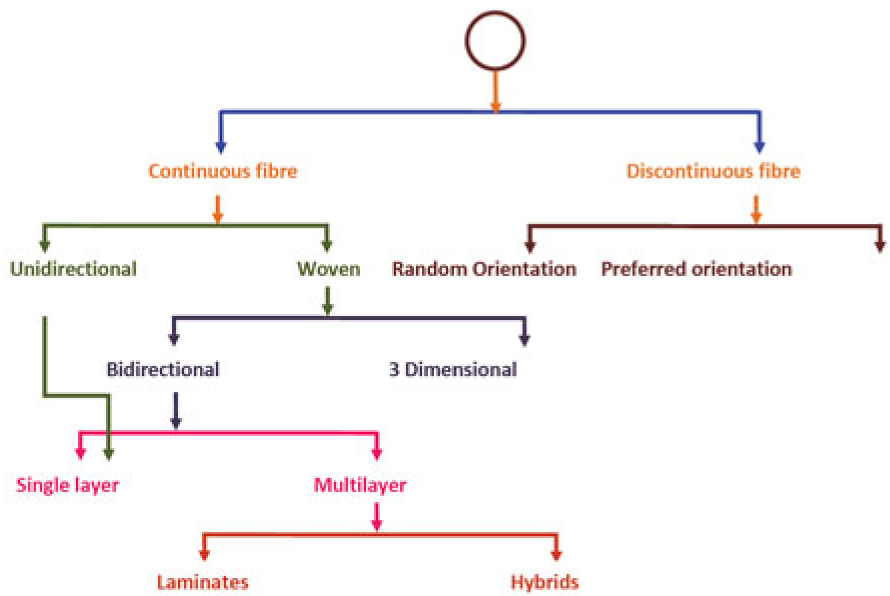

Figure 1.3: Classification of fibre composite materials

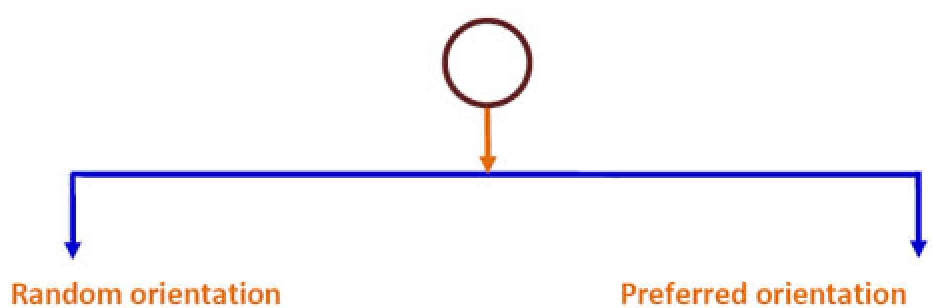

Figure 1.4: Classification of particulate composites

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Why are reinforcement made in thin fibre form?

There are various reasons because of which the reinforcement is made in thin fibre form. These reasons are given below.

a) An important experimental study by Leonardo da Vinci on the tensile strength of iron wires of various lengths (see references in [2, 3]) is well known to us. In this study it was revealed that the wires of same diameter with shorter length showed higher tensile strength than those with longer lengths. The reason for this is the fact that the number of flaws in a shorter length of wire is small as compared longer length. Further, it is well known that the strength of a bulk material is very less than the strength of the same material in wire form.

The same fact has been explored in the composites with reinforcement in fibre form. As the fibres are made of thin diameter, the inherent flaws in the material decrease. Hence, the strength of the fibre increases as the fibre diameter decreases. This kind of experimental study has revealed the similar results [2, 3]. This has been shown in Figure 1.5 qualitatively.

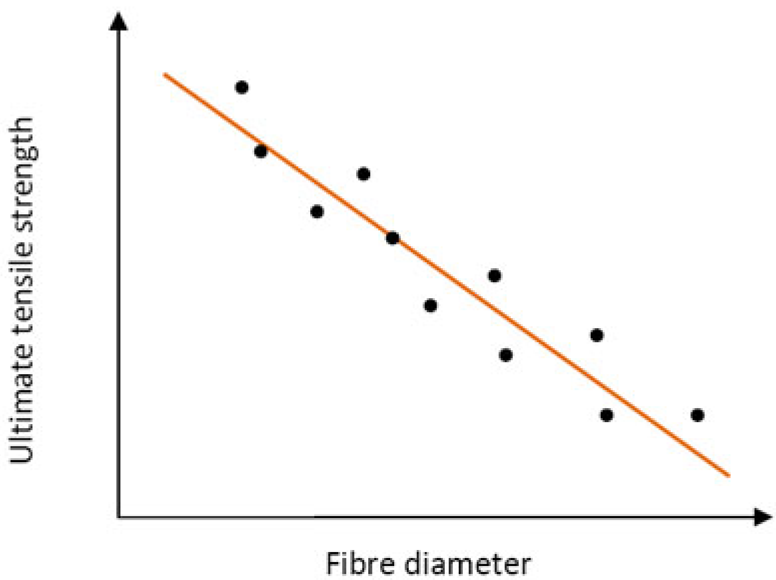

Figure 1.5: Qualitative variation of fibre tensile strength with fibre diameter

b) The quality of load transfer between fibre and matrix depends upon the surface area between fibre and matrix. If the surface area between fibre and matrix is more, better is the load transfer. It can be shown that for given volume of fibres in a composite, the surface area between fibre and matrix increases if the fibre diameter decreases.

Let D be the average diameter of the fibres, L be the length of the fibres and N be the number of fibres for a given volume of fibres in a composite. Then the surface area available for load transfer is

$$A = N\pi DL \tag{1.1}$$

The volume of these fibres in a composite is

$$V = N\pi \frac{D^2}{4} L \tag{1.2}$$

Now, let us replace the fibres with a smaller average diameter of d such that the volume of the fibres is unchanged. Then the number of fibres required to maintain the same fibre volume is

$$n = N\left(\frac{D}{d}\right)^2 \tag{1.3}$$

The new surface area between fibre and matrix is

$$A^* = n\pi \frac{D^2}{d} L = 4 \times \text{volume of the fibres} \times \frac{1}{d} \tag{1.4}$$

Thus, for a given volume of fibres in a composite, the area between fibre and matrix is inversely proportional to the average diameter of the fibres.

c) The fibres should be flexible so that they can be bent easily without breaking. This property of the fibres is very important for woven composites. In woven composites the flexibility of fibres plays an important role. Ultra thin composites are used in deployable structures.

The flexibility is simply the inverse of the bending stiffness. From mechanics of solids study the bending stiffness is *EI*, where E is Young's modulus of the material and I is the second moment of area of the cross section of the fibre. For a cylindrical fibre, the second moment of area is

$$I = \frac{\pi d^4}{64} \tag{1.5}$$

Thus,

$$\text{Flexibility} \propto \frac{1}{Ed^4} \tag{1.6}$$

Thus, from the above equation it is clear that if a fibre is thin, i.e. small in diameter, it is more flexible.

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