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A Review of Composite Materials

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Abstract

Unlike conventional materials, composites have become an optimal option for a range of modern, industrial, clinical, and sports applications. This is combined with their noteworthy physical, thermal, electrical, and mechanical properties; the key concepts of composites are its physical properties, mechanical properties, tooling, design, inspection and repair. Military vehicles, such as airplanes, helicopters, and rockets, placed a premium on high-strength, light-weight materials. This review article attempts to give an overall outline of composite materials.

Keywords: *Classification of composites, Composite materials, Matrices, Processes, Reinforcements,*

I. Introduction

In recent years, the use of composite materials has seen considerable growth in industry, especially in the fields of civil engineering, mechanics, aeronautics, aerospace, etc [1].

Composite materials are materials that combine two materials that are different in both their shape and their mechanical properties in order to increase their performance by taking advantage of each of these materials. In general, they have remarkable qualities which are based on the mechanical properties of a fiber (carbon, boron, or organic aramid) which has exceptional tensile strength and rigidity (greater than that of the best steels).

These fibers are embedded in a matrix (metallic or organic) whose complex role is to bind the fibers, keep them aligned, and transmit the loads applied to them [2]. In reality the two constituents of composite materials which are the matrix and the reinforcement combine to give a heterogeneous material often anisotropy, where the properties will be different from one direction to another.

Composite materials with an organic matrix and glass or carbon fiber are finding more and more applications in the production of structural parts of various dimensions in numerous industrial sectors such as civil engineering and biomechanics, aeronautics, automobile manufacturing, shipbuilding. These sectors have turned to this alternative given the elongation of their structure with mechanical properties equal to or superior to those of metal parts. The long-term behavior of these types of materials is a very important area in their lifetime and operation [3].

In this review we clearly present a bibliographic summary on composite materials, this summary contains definitions and the different constituents of composite materials and some areas of application.

II. What is a composite material?

A composite material can be defined as the assembly of several materials of different natures. Composites are most often made up of a matrix in which we disperse reinforcements (fibers) in a controlled or uncontrolled manner. The matrix maintains the reinforcements and ensures load transfers, while the reinforcements mainly provide their high mechanical characteristics (modules and elastic limits, mechanical resistance, etc.) [5].

The purpose of this association is to obtain a material whose specific properties are superior to those of the components taken separately. The concept of composite material, by the choice of the constituents and their respective proportions, as well as by the choice of the shape, dimensions and arrangement of the reinforcements, therefore makes it possible to design a material having the specific characteristics sought [6].

II.1. Classification of composites

Today there are a large number of composite materials that can be classified either according to the shape of the components or according to the nature of the components [5].

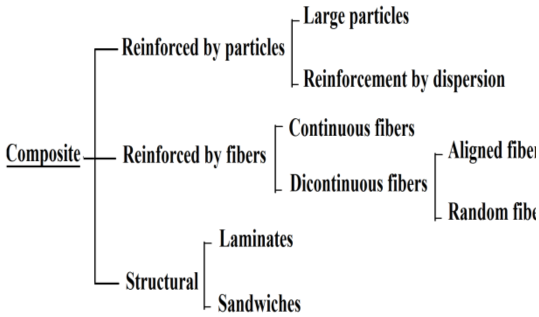

Figure1: Schematic classification of different types of composites.

II.1.1. According to geometry

a. Particle composites

A composite material is a particle composite when the reinforcement is in particle form.

A particle, as opposed to fibers, does not have a preferred dimension. Particles are generally used to improve certain properties of materials or matrices, such as rigidity, temperature resistance, abrasion resistance, reduction in shrinkage, etc.

In many cases, particles are simply used as fillers to reduce the cost of the material, without reducing its characteristics [7,8].

b. Fiber composites

A composite material is a fiber composite if the reinforcement is in the form of fibers. The fibers used are either in the form of continuous fibers or in the form of discontinuous fibers: staple fibers, short fibers. The arrangement of the fibers and their orientation make it possible to modulate the mechanical properties of the composite materials on demand. [7,8].

c. Structural composites

The manufacture of reinforcement can be done with fibers dispersed randomly or oriented in one or more directions. Axes of reinforcement can be defined by the crossing of threads (weaving). 3D structures have also been developed to improve the reinforcement of the material and provide a solution to delamination problems [7,8].

II.1.1. According to nature of the constituents

a. Organic matrix composites (OMC)

Organic Matrix Composites are, as their name suggests, composites whose matrix is mainly made up of polymer resin. This organic matrix can be either thermosetting, meaning it hardens when heated, or thermoplastic, meaning it can be softened and reformed by heat [9,10].

b. Metal matrix composite (MMC)

A metal matrix composite (MMC) is a material bringing together two elements: a metal matrix, for example aluminum, magnesium, zinc[9,10].

c. Ceramic Matrix Composite (CMC)

A Ceramic Matrix Composite (CMC) is a ceramic matrix in which ceramic fibers are incorporated. This unique combination of materials has revolutionized the aerospace industry, making components more resistant to extreme conditions and lighter compared to previous technologies [9,10].

II.2. Main constituents of a composite material

Among the main constituents of a composite material, we find:

II.2.1. Matrix

In a large number of cases, the matrix constituting the composite material is a polymer resin. Polymer matrix composites (PMC) exist in large numbers and each has a particular field of use [11]. PMCs are characterized by high matrix/filler interfacial adhesion and performance far superior to that of virgin polymers. For example, they have high stiffness, high strength along the alignment direction of fillers and good abrasion resistance. These good properties can only be achieved thanks to the role played by the polymer matrix in connecting the fibers together and allowing the transfer of stresses between them. PMCs are extensively used in a wide range of high-tech engineering products, e.g. in transportation (aircraft, boats, warship), marine structures and sports goods (rackets, rowing eights, fishing rods), and many others.. The classification of the types of matrices commonly encountered is given in Figure 2.

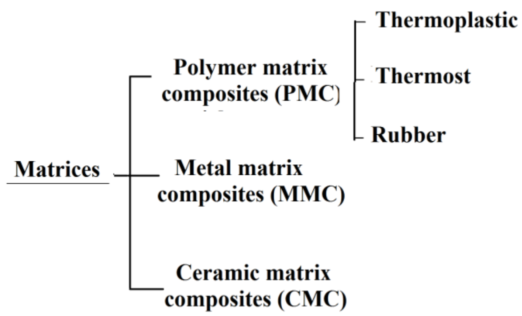

Figure 2: Classification of matrix

a. Thermoplastics

Thermoplastics are polymer chains linked together by weak bonds, they are in solid form (granules, plates, etc.) which are shaped by softening them by heating, then solidifying them by cooling.

They represent 80% of plastic materials consumed, the most common are; poly (vinyl chloride) which is used in the manufacture of pipes, poly (vinyl acetate) which is found in glues and adhesives, polyethylene which is used to make toys, bottles or bags from supermarkets, polypropylene for food boxes or floor coverings, polystyrene which is used in the composition of food containers, etc.

Their recyclability and thermo-reversibility constitute one of the great advantages which are becoming more and more important nowadays [12].

b. Thermosets

Thermosets are polymers that can only be shaped once but have high mechanical and thermomechanical properties compared to thermoplastics. They are in viscous liquid form and are shaped by triggering a chemical polymerization reaction by adding a hardener, which results in solidification.

The best known are unsaturated polyesters (vinyl ester, allelic derivatives, condensed polyesters, etc.), epoxy resins, condensation resins (phenolic, aminoplasts, etc.) They offer many important fundamental advantages over thermoplastics such as fatigue and impact resistance, longevity and corrosion resistance [12].

c. Elastomers

Elastomers are extremely flexible and elastic polymer materials, widely used in many industries for their unique properties. Their name derives from their main characteristics: elasticity and reversible deformation. These materials are essential in the manufacturing of products ranging from tires to pharmaceuticals to sports equipment [12].

d. Metal resins

Metal matrix composites are materials that combine the hardness of metals and the rigidity of ceramics. This type of resin is used as a binder in applications requiring a material with good specific properties and good temperature resistance. At present, these applications remain few in number and are limited to high-tech sectors because of the cost of implementation and the complexity of impregnation [12].

e. Ceramic resins

Ceramic matrices are composed of one or more metals combined with an element, the most common of which is oxygen, such as AL_2O_3 (Alumina), SiO_2 (Silica), MgO. (Magnesia).

Much less widespread than their organic matrix counterparts due to high cost, CMCs are intended for applications at very high temperatures. They are mainly used in the space industry and military aeronautics, as well as for the design of high-end components such as brake discs or pads.

Ceramics have many advantages for such applications: they can withstand very high temperatures, are lighter than many metals, and have good chemical stability. Unfortunately, their great fragility strongly limits their range of use [12].

II.2.2. Reinforcement

Often in the form of fibres, the purpose of reinforcements in composite materials is essentially to increase their mechanical properties (rigidity, breaking strength, hardness, etc.) and to improve physical properties, such as behavior in fire and abrasion, temperature resistance or electrical properties. The characteristics sought in the reinforcements are low density, compatibility with the matrices and ease of implementation [13,14].

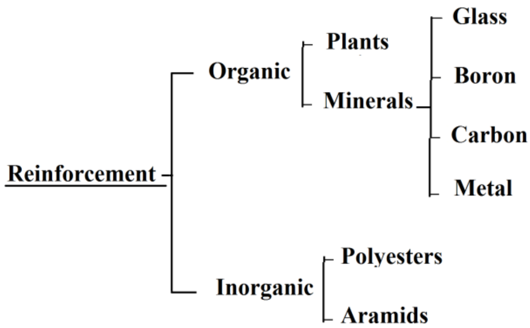

Figure 3: Types of reinforcement

a. Aramid fibers

Aromatic polyamides which contain aromatic groups more than 85% are called aramids, the known aramid fibers are Kevlar. They have high tensile mechanical properties like carbons but their compressive strength is low. The poor mechanical strength in compression is generally attributed to poor adhesion of the fibers to the matrix in the composite material.

To remedy this, fiber enzymes can be used. The use of hybrid fiber composites also allows remedying the weaknesses of aramid fiber composites [15]. Hybrid reinforcements such as glass – Kevlar or carbon – Kevlar are widely used in the leisure sector (skiing, tennis rackets, etc.).

b. Ceramic fibers

Ceramic-type composite materials are often made up of ceramic reinforcements and matrix. The fibers are produced by chemical vapour deposition on a support wire. These fibers have applications where the temperature is very high between 500°C and 2000°C. These materials are used in particular in the hot parts of aircraft engines [12].

c. Carbon fibers

Carbon fibers are thin filaments made of elemental carbon with structures that change from those of amorphous carbon to those of crystalline graphite. These fibers are made from a base polymer called a precursor; the chemical and physical properties of the final carbon fibers strongly depend on the qualities of the precursor [12].

d. Glass fibers

Glass fibers have an excellent performance-price ratio which places them by far at the forefront of reinforcements currently used in the construction of composite structures. The latter have a low tensile modulus, but an interesting tensile strength [15]. They are made of silicates and considered anisotropic materials.

e. Other types of fibers

This part brings together all the fibers that remain, generally these fibers are used for specific applications (special papers, for good electrical conductivity). They have relatively low elastic moduli compared to the other fibers already mentioned. The fibers concerned are:

- Fibers of plant origin (cellulose, flax, hemp, etc.);
- Fibers of mineral origin (asbestos, silica);
- synthetic Fibers (tergal, nylon, etc.) from polyesters, polypropylene or polyethylene;

II.2.3. Fillers and Additives

The fillers, generally in the form of fragmentary elements, powders or liquids, are incorporated into the resin to reinforce the mechanical properties. They can be mineral, organic (vegetable or synthetic) or metallic, and are generally used in the same way as in "traditional" plastics. Non reinforcing fillers can be also used to reduce the cost of dies. Additives, such as coloring or mold release agents, are widely used when designing structures made of composite materials [12].

III. Processes for implementation composite materials

The aim of this paragraph is not to detail the different techniques for developing composite materials but to present them in their entirety and to specify in which cases they are used. There are several methods for developing and formatting composites which can be grouped into categories [16]:

- By extrusion; widely used with thermoplastics;
- By impregnation; often used with fabrics and threads;
- By deposit; for sandwich composites.

These techniques are often followed by molding which defines the shapes of the material. Molding can be done in several ways:

- By compression; (cold or hot, by resin injection): this is a method used for composites with a high reinforcement rate to obtain parts with deep and delicate shapes.
- Under pressure; (contact, simultaneous injection): this is the simplest method allowing parts to be obtained in large series and at low prices. The reinforcement rate is however limited.
- Vacuum, for small and medium series parts
- Continuous: the parts obtained are flat or corrugated; sandwich composites are often prepared using this technique.
- By pultrusion: which usually occurs after impregnation of the fibers (yarns, laminates, fabrics), the profiles obtained are rectilinear or curved with constant section. This technique produces materials with fairly high mechanical characteristics.
- By centrifugation: technique reserved for cylindrical shapes (tubes, pipes).
- By filament winding: (circumferential, helical) allowing the design of advanced cylindrical and spherical parts. The proportion of fibers in the composite is quite high, which gives high mechanical characteristics. On the other hand, this method is very expensive [16].

IV. Conclusions

Composite materials are advanced designing materials. Composite materials are becoming an alternative to conventional materials and are used in various applications. This review article provided a general overview of composite materials constituents.

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