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1. An Introductory Approach to Composite Materials

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Abstract:

Even though people have been using composite materials for millennia, the notion of composites as a distinct material classification was not recognized until the mid-twentieth century. Composite materials are made up of two or more different material phases. The ancient Mesopotamians may have been the first to understand that bonding wood at an angle generated superior qualities to single-ply wood.[1.1]. Composites are frequently stronger, have a lower density, and are less expensive than traditional materials. Composites are typically made up of two or more separate components that constitute big enough regions to be called continua; the basic components are usually tightly fused at the interface. A composite material is a mixture of two or more materials with chemical and physical properties that differ. They are designed to work together to achieve a certain goal, such as boosting strength, reducing weight, enhancing electrical resistance, and so on. The various systems are judiciously combined to achieve a system with more useful structural or functional properties qualities that none of the constituents could achieve on its own. Low weight, corrosion resistance, good fatigue strength, and speedier assembly are just a few of the benefits. They're widely employed in airplane structures and electrical components, packaging medical devices, and from spacecraft to home construction [1].

Keywords:

Dispersed phase, Matrix phase, corrosion resistance, Mechanical strength

1.1 Introduction:

Composites are made up of different materials with different compositions, yet the individual constituents retain their identities. These individual constituents work together to provide the composite item with the required mechanical strength or stiffness. A composite material is made up of two or more separate phases (matrix and dispersion) and has bulk properties that are notably different from those of the constituents. The fundamental phase with a continuous feature is the matrix phase. The matrix phase is typically more ductile and less rigid. It is responsible for holding the scattered phase and sharing a burden with it. In a discontinuous form, the dispersed (reinforcing) phase is embedded in the matrix. This secondary phase is called the dispersed phase. Because the dispersed phase is frequently stronger than the matrix, it is occasionally used.

composition materials" or simply "composites" as the most commonly used word are materials made up of two or more components that have significantly different physical and/or chemical properties. When two or more fundamental components are combined, a new substance emerges with properties distinct from the individual constituents. Composites must be distinguished from material mixtures and solids solutions because the individual components stay unique and independent within the final material structure.

Individual basic ingredients, referred to as constituent materials, are used to make composite materials. The matrix and the reinforcement are the two primary types of component materials. To make a composite, at least one representative from each category is required. By retaining the reinforcements' relative placements, the matrix phase embeds, surrounds, and supports them. The reinforcements offer their unique physical and mechanical qualities to the matrix, improving its properties.

The acquired synergism between the two phases creates material qualities not seen in the individual constituent materials, while the designer can construct ideal combinations of binders and reinforcements, resulting in tailor-made composites [2]. Composite materials have swooped in and shown enormous potential in integrating a variety of industrial and manufacturing industries. A matrix is a mesh made up of readily available materials such as glass fiber, carbon fiber, and polymers. Other materials, such as nanoparticles and graphene, are also commonly employed in matrices. [1.2]

The following are some well-known composite materials:

a. In sludge, lignocellulosic (straw)
b. The material is wood (cellulose fibers embedded in hemicellulose and the binder lignin)
c. skeletons (soft protein collagen combined with the hard mineral apatite)
d. [3, 4] Pearlite (ferrite and cementite mixed)

1.2 The Fundamentals of Composites:

By definition, composite materials are made up of at least two different materials. Each takes on a different phase in a combination, such as a matrix phase or the dispersion phase.

1.2.1 Matrix Phase:

The matrix is the basic phase having a continuous character. It maintains the scattered phase together by sharing a load with it. In many cases, the matrix is more malleable and ductile. Matrix is the fundamental phase, which has a continuous character. The matrix phase is typically more ductile and less rigid. It is responsible for holding the scattered phase and sharing a burden with it.

1.2.2 Dispersion Phase:(Reinforcing):

The dispersed phase is a second phase that is embedded in the matrix in a discontinuous form. It is known as the reinforcing phase because it is often stronger than the matrix. [1.2]

The second phase (or phases) is a discontinuous shape incorporated into the matrix. The dispersed phase is usually stronger than the matrix, it is also known as the reinforcing phase.

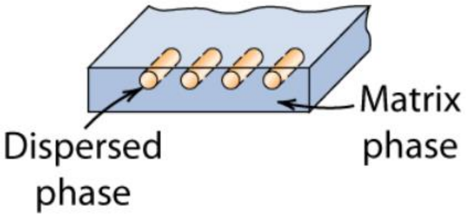

Figure 1.1: Different Phases of Composites

Composite materials are divided into two classification systems. One is based on the matrix material (metal, ceramic, or polymer), while the other is based on material structure:

1.3 Composites I: Classification (Based on Matrix Material):

a. Metal Matrix Composites (MMC):

Metal matrix composites (MMCs) are composites in which the matrix phase is a metal, such as aluminum, magnesium, titanium, or other metals. Because of the high density of metals, metal matrix composites are less popular than polymer matrix composites (PMC). Metals, on the other hand, have greater strength and stiffness than polymeric materials and can resist higher temperatures. A scattered ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase is mixed with a metallic matrix. For structural applications, a lighter metal such as aluminum, magnesium, or titanium is preferred. This gives the reinforcement and the structure as a whole supple support. [1.2]

b. Ceramic Matrix Composites (CMC):

Ceramic Matrix Composites are made up of a ceramic matrix with other ceramic fibers implanted in it (dispersed phase). Ceramic is a key ingredient of ceramic matrix composites where metal or other inorganic materials are employed as reinforcement. Ceramics have a high melting point temperature, great compressive strength, good strength at high temperatures, and good oxidation resistance. Ceramics, on the other hand, have low tensile and impact strength, both of which can be enhanced by using appropriate reinforcing elements.

Ceramic fibers are incorporated in a ceramic matrix phase in this type of composite. This sort of structure solves the problem of low crack resistance that plagues traditional ceramic structures. Carbon, Silicon Carbide, Alumina, and other materials are excellent choices for both the matrix and scattered phases. The shaft sleeves for large pumps shown below were made utilizing SiC-fibre reinforced SiC material and chemical vapor infiltration. [1.2]

c. Polymer Matrix Composites (PMC):

Polymer is employed as the matrix phase in polymer matrix composites, whereas organic, inorganic, or hybrid materials are used as the reinforcing phase. Polymer matrix composites provide several advantages over metal and ceramic matrix composites, including low density, high extensibility, high shock absorption capability, inexpensive fabrication costs, and so on. As a result, polymer matrix composites outnumber metal and ceramic matrix composites in popularity. Metal matrix composites, on the other hand, are commonly utilized over PMC when high service temperatures and strength are required. Currently, fiber-reinforced polymer composites account for more than 90% of all composites.

Glass, carbon, steel, or Kevlar fibers are incorporated in a thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC), Polyvinylchloride, Nylon, Polystyrene) matrix (dispersed phase). Polymer matrices glue together various short or continuous fibers in this form of composite. The most common matrices are thermoset resin systems such as epoxies, phenolics, and polyamides. The lightweight, high rigidity, and high strength of PMCs are well-known. [1.2]. These polymers are good matrix materials since they're easy to work with, have a low density, and have desirable mechanical properties. As a result, high-temperature-resistant polymeric resins are commonly employed in the aerospace industry [6].

Thermosets and thermoplastics are two forms of polymers that are commonly used. Thermosets have a well-bonded 3D-molecular structure that develops after curing. At high temperatures, these materials disintegrate rather than melt. To adjust the curing conditions and decide on other qualities, simply changing the resin's fundamental composition is sufficient. They can also be kept partially cured for long periods. Furthermore, thermosets have a great degree of flexibility. As a result, they're ideal as a matrix basis for FRC in advanced applications. Thermosets are commonly employed to make chopped fiber composites, particularly when starting with a premixed or molded compound containing fibers of a given quality and aspect ratio, as is the case with epoxy, polymer, and phenolic polyamide resins. Thermoplastics are materials with a one- or two-dimensional molecular structure that melt at high temperatures and have exaggerated melting points. Additionally, their softening at high temperatures is reversible; hence, their original properties may be recovered by cooling, making it easier to apply proven compression procedures to make molded composites.

Figure 1.2: Polymer Matrix Composites

1.4 Composite Material Classification II (Based on Reinforcing Material Structure):

Fibrous, particulate, and laminate composites are the three types of composites based on reinforcement.

a. Composites of Particulate Matter:

Particulate composites are made up of flakes or powdered particles that are spread or implanted in a binding matrix. Concrete and wood particle boards are well-known examples of this type [5].

Particulate Composites are made up of a matrix that is reinforced by a dispersed phase that takes the shape of particles. Particle-reinforced composites. Particulate Composites are made up of a matrix that is reinforced by a dispersed phase that takes the shape of particles. Particles are randomly oriented in composites. These materials' dispersed phase is made up of two-dimensional flat platelets (flakes) that are laid parallel to one other.

- Particle-reinforced composites are composites that have been reinforced with particles.
- Due to their ease of availability and low cost, these are one of the most extensively utilized types of composite constructions. They can be further divided into two types based on the process of strengthening: particulate and dispersion-strengthened.
- The particles in this scenario are much smaller, ranging from 0.01 to 0.1 um in size. Similar to precipitation hardening in metals, the strengthening happens at the atomic and molecule level.
- Examples: High-temperature strength is provided by Thoria (ThO_2) distributed Nickel alloys. Sintered Aluminium Powder (SAP) is a type of alumina powder that is distributed on an aluminum matrix.

This type of composite comprises a high proportion of coarse particles. Rather than necessarily improving qualities, they are frequently meant to develop unique combinations of them. They work with all three types of matrices: MMC, CMC, and PMC.

Examples: Power-cutting tools are made from tungsten carbide or titanium carbide embedded with cobalt or nickel.

b. Fiber-Reinforced Composites:

Fibrous Composites with a dispersed phase of fibers improve strength, stiffness, and fracture resistance. The material's toughness prevents crack propagation in directions parallel to the fiber. When fibers are placed in a specific direction (preferred orientation) and force is applied in the same direction, the strength increase becomes considerably more significant.

Long-fiber (continuous-fiber) reinforced composites have a stronger effect than short-fiber (discontinuous-fiber) reinforced composites. Short-fiber reinforced composites have a restricted ability to transfer load since they are made up of a matrix reinforced with a dispersed phase in the form of discontinuous fibers.

The dispersed phase - fibers - carries the majority of the load imparted to a long-fiber reinforced composite. In such materials, the matrix only acts as a binder for the fibers, holding them in place and protecting them from mechanical and chemical harm.

The mechanical qualities of fiber-reinforced composites, such as strength and strength-to-weight ratio, are increased. It is made up of strong, stiff, but brittle fibers that are embedded in a softer, ductile matrix. The matrix serves as a conduit for the load to be transferred to the fibers that do the majority of the heavy lifting.

- They're further divided into two types: continuous and discontinuous fibers.
- The length of the fibers in continuous fiber composites can range from a few feet to several thousand feet. Important design requirements can be strengthened and adjusted by enabling a uniform orientation of the raw composite fiber.
- Continuous fiber composites are generally more expensive than their discontinuous fiber counterparts. However, it compensates for this by greatly improving performance.
- Fiber-reinforced composites with discontinuous fibers
- This composites sub-division is further subdivided into two sub-sub-divisions. Discontinuous aligned fibers and discontinuous randomly oriented fibers are the two types of fibers.
- Shorter lengths of extremely condensed fibers aligned in one definite orientation in a matrix make up discontinuous aligned fiber composites. They have mechanical properties that are comparable to those of continuous fiber composites that are unidirectional. However, the shorter fibers reduce the composite's ductility, making it excellent for high-strength, low-ductility applications.

Short, condensed fibers implanted in all directions of a matrix make up discontinuous randomly-aligned fiber composites. Aligned fiber composites offer improved mechanical properties solely in the reinforcement direction. By randomly embedding the fibers in all directions of the matrix, this anisotropy can be avoided. While this may result in a reduction in peak strength, it does so at a lower cost by increasing formability.

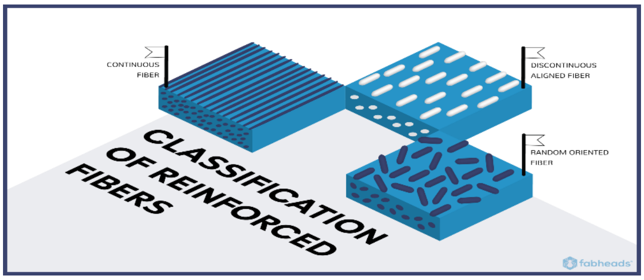

Figure 1.3: Alignment of Reinforced Fibers

c. Composite Laminates:

Laminar composites and sandwich composites are two types of structural composites that are commonly employed. Structural composites are a subset of composites. Their qualities are influenced by the geometrical design of various structural elements as well as the constituents' properties. Two-dimensional sheets/layers with a chosen strength direction make up laminar composites. These layers are stacked and bonded together based on specific requirements. In a plastic matrix, materials such as metal sheets, cotton, paper, and woven glass or carbon fibers are incorporated. Layers with varied anisotropic orientations or a matrix reinforced with a dispersed phase in the form of sheets make up laminate composites. In two directions, laminate composites provide improved mechanical strength, but only in one direction, perpendicular to the desired orientations of the fibers or sheet, the material's mechanical characteristics are low. Laminar composites include thin coatings, heavier protective coatings, claddings, bimetallic, and laminate. Sandwich structures are made up of thin layers of face material that are linked to a lightweight filler core. The core separates the faces and provides shear rigidity along planes perpendicular to the faces, resisting deformations.

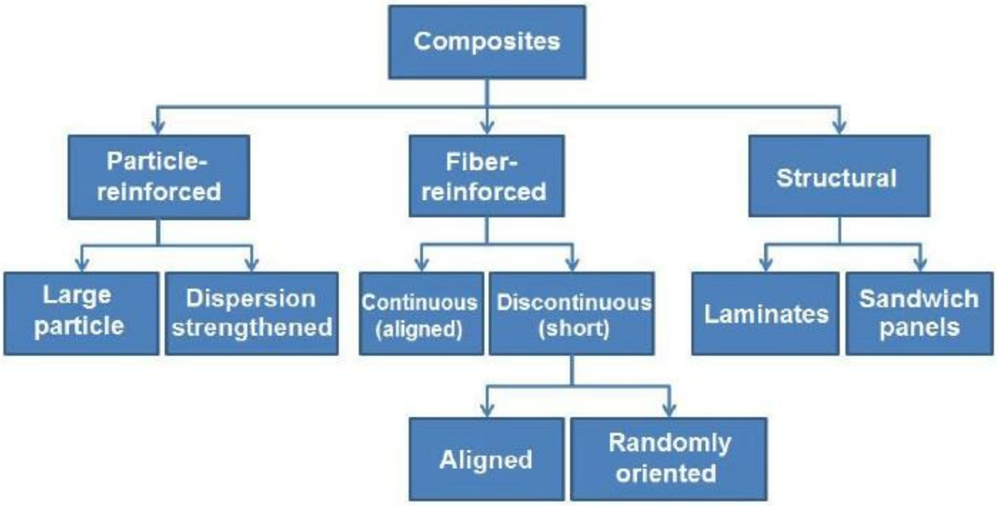

Figure 1.4: Classification of Composites Based on Fiber Reinforcement

1.5 Characteristics of Composites:

We already know that there are many different types of composites based on the classification of these materials. It's a well-known fact that different types of composites operate differently. Composites, on the other hand, share some features. Polymer matrix composites have emerged as the most rapidly emerging and widely used composites due to their inherent advantageous properties. In comparison to well-known materials such as metals, polymer matrix composites have the following characteristics:

1.5.1 Specific Strength and Modulus Are Both High:

The high specific strength and specific modulus of polymer matrix composites are the most essential advantages. The ratio of strength to density is defined as a specific strength, while the ratio of modulus to density is defined as a specific modulus; in both situations, length is the appropriate dimension/unit. These metrics, which are particularly important for aerospace structural materials, are tools to quantify the material's bearing capacity and stiffness capabilities under the premise of equal mass.

The great performance and low density of reinforcing fibers can explain composites' high specific strength and specific modulus. The specific modulus of glass fiber resin matrix composites is slightly lower than that of metallic materials due to the low modulus and high density of glass fibers.

1.5.2 Good Damping Characteristics:

The natural vibration frequency of forced structures is proportional to the square root of the specific modulus of structural materials and is related to the geometry of the structure. As a result, composites have a high inherent frequency, making resonance creation difficult in general. Simultaneously, the fiber/matrix interface in composites absorbs vibrational energy very quickly, resulting in significant vibration damping of these materials. Vibrations can be quickly stopped if they occur [10].

1.5.3 Composites – Fabrication:

Wetting and mixing the reinforcement with the matrix is a common step in the fabrication of composite materials. After that, a heat or chemical process binds them together forming a hard structure. Preset molds are created based on a variety of factors such as the materials used, the order and method of material introduction, the required elements, and so on.

It can be accomplished using a variety of methods including

- Spray Lay-Up
- Wet/Hand Lay-up
- Vacuum Bagging
- Filament Winding
- Pultrusion
- Resin Transfer Moulding (RTM)

- Autoclave Curing
- Resin Film Infusion (RFI)
- Chemical vapor deposition
- Centrifugal Casting

1.6 Applications of Composites:

Resins bonded with thermoplastics are currently a rapidly growing class of composites. Many research and development efforts in this area are now focused on enhancing the fundamental properties of resins and deriving the maximum potential functional advantages from them for specific applications.

This includes efforts to use precarious metals as a substitute in die-casting operations. The previous few decades have seen a significant shift in how people think about technology. With each passing day, the number of applications appears to grow exponentially.

The number of uses for composites has increased as the market and manufacturing methods have advanced. Aerospace, drones, construction, corrosion-resistant equipment, consumer products, antenna structures, radar, rocket engines, satellite structures, solar reflectors, and other spacecraft and other industries are among them.

- **Aircraft:**

Rotor shafts in helicopters, compressor blades, engine bay doors, fan blades, flywheels, helicopter transmission structures, jet engines, turbine blades, turbine shafts, wing box structures, and so on.

- **Aerospace:**

If one wishes to dominate the aerospace business, the lightweight and high specific strength is a big asset. Composite materials fit like a glove when it comes to properties like fatigue and corrosion resistance, a higher degree of optimization, and the possibility of cost savings.

The graphic above shows the overall material composition of a standard Airbus 350. Composite materials account for 53% of the total materials used.

- **Drones:**

Drones have found applications in everything from surveillance to food delivery, photography, and surveillance in just a few years. The drone's cargo has a significant impact on flight time and battery consumption. Composite materials play an important part in the design and manufacture of drones to reduce their weight. They can replace traditional materials such as aluminum, which is a good option for drone production but adds to the total weight.

Figure 1.5: Applications of Composites

- **Automobiles:**

Abrasive materials, bearing materials, electrical machinery, engine parts such as bearing materials, connecting rods, crankshafts, cylinders, pistons, and so on, pressure containers, truss members, cutting tools, electrical brushes, and so forth.

Wind turbine blades: carbon-wood epoxy composite wind turbine blades.

Tungsten carbide (WC), titanium carbide (TiC), and chromium carbide are the most common cemented carbides (Cr_3C_2) that can be used.

Cutting tools are the most common application for tungsten carbide cermets and other applications include powder metallurgy dies, indenters for hardness testers, wire drawing dies, rock drilling bits, and other mining tools.

Titanium carbide cermets (Ni-binder) are used in high-temperature applications such as gas turbine nozzle vanes, steel cutting tools, valve seats, thermocouple protection tubes, and torch tips.

- **Construction:**

For a long time, composite materials have found a place in the civil and construction industries. Cladding, drywalls, furnishings, building cores, and foundations have all benefited from composite material's adaptability. High tensile strength, fatigue resistance, low bulk, and other properties of fiber-reinforced plastic composites are suitable for civil engineers. Floors, bearing pads, concrete structures infused with steel plates or bars in a sandwich structure, beams and bars, and wood panels are only a few examples of composite use in construction.

- **Sports:**

In the future, the composites have infiltrated almost every facet of life. Sports and recreation are intriguing areas where it has made a stronghold. From racing helmets to safety gear to tennis rackets and hockey sticks, there's something for everyone.

- **Consumer Appliances:**

Phones, home appliances, insulator boards, component systems, circuit breakers, lighting devices, insulated cables, and other electronic equipment all use composite materials in some way.

1.7 Conclusion:

This article provides a basic explanation of composite materials and the various types of composite materials that are categorized based on the specific features and characteristics of composite materials required in the end-use. The importance of composite materials and their use since ancient times underscores their value.

The composite sector is becoming increasingly profitable with each passing day. The worldwide composite market is growing at a rate of 5% per year, while carbon fiber demand is increasing at a rate of 12% per year. Composites have taken over the world, with uses ranging from aerospace and automotive to healthcare and electronics.

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