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Fundamentals of Materials Science and Engineering: An integrated Abordem

By

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Abstract

Materials Science and Engineering is a multidimensional area that studies the relationship between the structure, processing, and properties of materials, with the aim of developing materials with specific properties for different applications. It studies both material properties and applications. Materials science and engineering play a key role in a variety of areas, driving innovations and technological advancements. The study of the structure, properties and behavior of materials allows optimizing the performance of products and developing solutions to technological challenges. This area is essential for the creation of more efficient, durable, and sustainable materials, directly impacting industry, health, and the environment. The present research follows the general purpose of understanding the relationship between structure, property, processing and performance of materials. In fact, the study aims to answer the following starting question: What is the relationship between the Structure-Property-Processing-Performance of materials? Thus, a systematic review was involved in which, based on the search for keywords, exclusion criteria were applied, resulting in articles on materials science and engineering. The results indicate that materials science and engineering is the relationship between the structure of a material, its properties, the processing used to obtain it and its performance in an application. The structure of a material (from the atomic scale to the microstructure) directly influences its properties. Processing, in turn, affects the structure of the material. Finally, the performance of the material in an application is a direct consequence of its properties.

Keywords: *Materials science and engineering, structure, property, processing, performance.*

1. INTRODUCTION

Materials Science is a multidisciplinary field that studies the relationship between the structure, processing, and properties of materials. It provides the scientific basis for the selection and development of materials, understanding the properties of matter and their applications in various areas of science and engineering.

Callister (2011) understands that Materials Science comprises the investigation of the relationships or correlations that exist between structures and properties. It seeks to understand nature, that is, structure, composition, chemical, physical and biological properties. Materials Science pursues the purpose of studying the internal structure, properties, and processing of materials. After that, Materials Engineering follows.

The present research presents the general objective of understanding the relationship between structure, property, processing and performance of metallic, polymeric, ceramic and composite materials. In fact, the study follows the central purpose of answering the following starting question: What is the relationship between the structure-property-processing-performance of materials?

Thus, a systematic review was involved in which, based on the search for keywords, exclusion criteria were applied, resulting in articles on materials science and engineering. The keywords used in the literature search were, namely, materials science and engineering, structure, property, processing, performance.

2. Analysis and Discussion of Results

Materials Science and Engineering is a multidisciplinary field of knowledge that investigates and analyzes the manipulation of the composition and structure of materials, with the aim of controlling their properties through synthesis and processing

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for the production of goods for use and consumption (Smith & Rosa, 1998, cited in Souza, undated).

This science is dedicated to the application of this knowledge in order to transform materials into useful and/or necessary products for society. Despite the link between Materials Science and Engineering, it is believed that there is no strictly defined line separating these two branches.

In Materials Science and Engineering, the term "composition" refers to the chemical constitution of the material, that is, the atoms, molecules, or ions that make up that material. The term "structure" refers to the way these atoms, molecules or ions organize (arrange) themselves for the formation of the material.

Materials science and engineering is an interdisciplinary field of knowledge that deals with the study and manipulation of the composition and structure of materials, in order to control their properties through synthesis and processing for the production of goods for use and consumption

From Materials Science and Engineering, it is possible to understand the nature of materials and apply fundamental and empirical concepts that make it possible to relate the structure of materials, their various properties and their behavior to the transformation of these materials into utility products.

Tetrahedron of Materials

The tetrahedron of materials is an instrument used in Materials Science and Engineering to exhibit the interconnection between the processing, structure, properties, and performance of a material. This concept, therefore, emphasizes how these elements are intrinsically linked and how the alteration of one of them can affect the others. It is the definition of the scope of materials science and engineering. The four tetrahedral elements are:

- Performance and Cost Properties
- Composition
- Processing
- Structure (from nano to macro)

Processing and Performance

The most different materials, because they have different characteristics, properties and structures, must be analyzed for their best performance for certain applications.

We cannot always have in a material the essential properties for its use, nor can a certain property be present next to another in the same material, so it is essential to know how to evaluate the system.

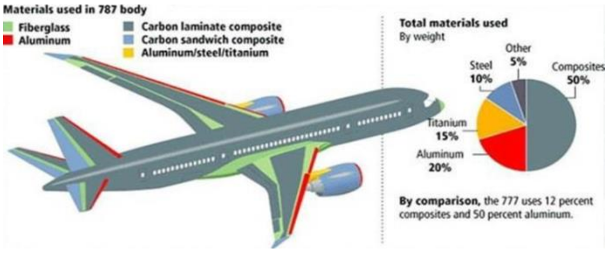
The more familiar an engineer or scientist is with various characteristics and structure-property relationships, as well as with material processing techniques, the more skilled and confident he or she will be to make thoughtful material choices based on these criteria. In conceptual terms:

- Processing: a set of techniques for obtaining materials with specific shapes and properties.
- Performance: response of the material to an external stimulus, present in real conditions of use.

General Applications

In the opinion of Tcchiptschin (undated), there is an immeasurable range of material applications, however, the following stand out:

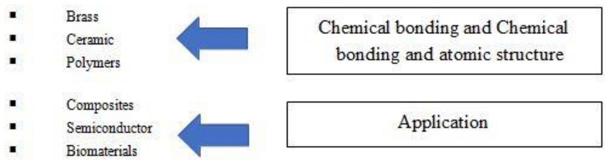
- Transportation (car, plane, space shuttle, trains, ships, bicycles, F-1 cars)
- construction (houses, buildings, viaducts, tunnels)
- Apparel (waterproof fabrics, high-performance sports fabrics, footwear)
- Communication (TV, telephone, mobile phone, microcomputer, optical fiber, copper wires, CD, walkman)
- Food (packaging, food storage tanks, food processing systems).



Classification of Materials

For convenience, most engineering materials are divided into three main basic categories: metallic materials, polymeric materials, and ceramic materials. Materials, for reasons of conformity, are separated into classes based on their constitution, arrangement of their atoms, and their properties, according to Askeland and Wright (2015). The classes/classes are divided into:

Materials can be classified into:



2.1. Metals

Metals are conceived as inorganic substances, composed of one or more metallic elements, and may also contain some non-metallic elements (sometimes impurities). Normally, metals have a crystal structure in which atoms are arranged in an orderly manner.

Metallic materials are, in general, good thermal and electrical conductors. Many of them are relatively resistant and ductile at room temperature, and several remain quite resistant even at high temperatures (thermoresistant).

It is important to note that metals and their alloys are commonly divided into two classes: ferrous alloys and metals, which contain a large percentage of iron, such as steels and cast irons, and non- ferrous alloys and metals, which do not contain iron or contain only a small amount.

Examples of non-ferrous metals are, among others, aluminium, copper, zinc, titanium and nickel. The distinction

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between ferrous and non-ferrous alloys is due to the fact that steels and cast irons are produced in much larger quantities and are used much more than other alloys. Metals, in their pure form or in alloys, are used in various branches of industry, including aerospace, biomedical, semiconductors, electronics, energy, building and construction, and transportation.

Internationally, specifically in the United States, the production of major metals, such as aluminum, copper, zinc and magnesium, closely follows the growth of the economy. Meanwhile, iron and steel production has been lower than expected due to competition in the global market and economic reasons, which are always pressing.

Engineers and materials researchers are continually trying to improve the properties of existing alloys or to design and produce new alloys that are more resistant, even at high temperatures, and with better creep and fatigue properties.

Certainly, existing alloys can be improved by improving their chemistry, by controlling the composition and by processing techniques. By 1961, for example, new or improved nickel- or iron-nickel-cobalt-based superalloys were available for use in the high-pressure vanes of aircraft gas turbines. The term superalloy was coined in view of the superior performance of these alloys at elevated temperatures, approximately 540 ºC (1,000 ºF), and under high stress levels.

Therefore, the metals used in the internal parts of the turbine must be able to withstand high temperatures and pressures during its operation. By the 1980s, improved smelting techniques had made it possible to produce directionally solidified columnar grains and single-crystal nickel-based cast alloys.

Another perspective is found in Askeland and Wright (2015), which mentions that materials belonging to the class of metals are inorganic substances, consisting of one or more metallic chemical elements, and may contain non-metallic elements in their composition. Among the most common metallic materials are, namely, Iron Steel, Magnesium, Copper, Aluminum, Silver, Bronze, Titanium, Gold, etc. In addition, within the class of metallic materials there are also metal alloys, which are formed by mixing a metal with one or more metals or non-metals, some examples of non-metallic materials that can be present in metal alloys are: Carbon, Nitrogen and Oxygen

Classification of metals Ferrous Leagues

Ferrous metal alloys have iron, element atomic number 26, as a nuclear element. These alloys are mainly applied in the materials industry and materials engineering (Pedrolo, 2014).

These alloys are produced on a large scale and their wide use is due to the fact that iron is an element that is very easy to find in nature and does not have such a high cost compared to other metals. The disadvantage of these alloys is that they are quite susceptible to the corrosion process. They are:

- Low, medium and high carbon steels
- Stainless steels (chromium alloy)
- Alloy Steel

Cast irons

Cast iron is a metal alloy, with a carbon content between 2% and 4%, which is characterized by its high compressive strength and good ability to absorb vibrations. It is used in various industries, such as automotive, aeronautics, and construction, due to its versatility and strength. There are different types of cast iron, such as gray, nodular, white, and malleable, each with specific properties and applications.

Cast iron is very resistant to pressure and deformation, which makes it suitable for applications that require withstanding high loads. The cast iron structure helps dissipate vibrations, which is useful in machine and vehicle components. Cast iron has a lower melting point than steel, which facilitates the casting and molding process. Cast iron is a recyclable material, which contributes to more sustainable manufacturing practices.

Non-ferrous alloys

Non-ferrous metal alloys are those that have the minimum or no percentage of iron in their compositions. Hence, they have high resistance to corrosion, even under the action of the sea air or harsh atmosphere. In addition, they are usually good electrical conductors, light and literally recyclable.

Numerous alloys of aluminum, copper, tin, lead and much more, are part of the requested non- ferrous metal alloys. That is why non-ferrous metal alloys are the most recommended to serve the aeronautical and nautical industry. Despite having aspects in common, non-ferrous metal alloys have several differentials and, of course, different applications.

However, these leagues also have some limitations. The following can be mentioned:

- Relatively high density;
- Comparatively low electrical conductivity;
- Susceptibility (except in stainless steels) to corrosion in some usual environments.

2.2. Ceramics

The word ceramics, in everyday language, has a different meaning than it has in Materials Sciences. In popular language, ceramics are objects made of porcelain or crockery; in the field of Materials Sciences, the word "ceramics" has a wider scope.

Generically, Gouvea (2018) argues, ceramics are made up of metallic and non-metallic chemical elements that are linked through covalent and ionic bonds. Aluminum oxide, or alumina, is an example of a ceramic material composed of aluminum, which is a metal, along with oxygen, a nonmetal, whose chemical formula is Al_2O_3.

Other examples of common ceramic materials are: a) silicon dioxide (or silica, SiO_2), b) zirconium dioxide (or zirconia, ZrO_2), c) silicon carbide (SiC), and d) silicon nitride (Si_3N_4).

It is also important to state that ceramic materials are inorganic materials made up of chemically bonded metallic and non-metallic elements. Ceramic materials can be

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crystalline, non-crystalline, or a mixture of both. Most of them have high mechanical strength at high temperatures, but tend to be brittle (little or no deformation precedes failure).

The advantages of ceramic materials for engineering applications involve low weight, high strength and hardness, good heat and wear resistance, reduced friction and insulating properties. The insulating properties combined with high resistance to heat and corrosion make them suitable for insulation of heat treatment furnaces and smelting metals such as steel.

In the United States, the historical growth rate of traditional ceramic materials, such as ceramics, glass, and stone, has been 3.6% per year (1966 to 1980). The expected rate of growth of these materials from 1982 to 1995 followed the growth of the American economy. In recent decades, an entirely new family of ceramic oxide, nitride, and carbide materials, with enhanced properties, have been manufactured.

From generation to generation, it means, from technology to technology and in this the idea is proven that the new generation of ceramic materials, called engineering ceramics, structural ceramics or advanced ceramics, has greater mechanical resistance, as well as greater resistance to wear, corrosion (even at high temperatures) and thermal shocks (arising from sudden exposure to very high or very low temperatures). We highlight the following advanced ceramic materials: Alumina (oxide); Silicon nitride (nitride) and Silicon carbide (carbide).

An important aerospace application of advanced ceramic materials is the use of ceramic plates for space shuttle coating. Ceramic plates are made of silicon carbide because of their ability to act as heat shielding and to quickly return to the usual temperature when the heat source is removed.

It is critical to note that ceramic materials thermally protect the spacecraft's internal aluminum substructure during ascent and during re-entry into the Earth's atmosphere. Another no less important application of advanced ceramic materials, and which highlights the versatility, importance and future growth of this class of materials, is their use in the manufacture of cutting tools.

For example, silicon nitride is an excellent material for cutting tool manufacturing because of its high resistance to thermal shock and fracture. The applications of ceramic materials are truly limitless, as they can be used: in aerospace, metal manufacturing, biomedicine, the automotive industry and many other areas.

Note that the two main disadvantages of these materials refer to the fact that they are:

- Difficult to be transformed into finished products, and therefore expensive,
- The fact that they are brittle.

Composition of ceramic materials

The composition of ceramic materials varies depending on the type of ceramic and can be divided into traditional ceramics and advanced ceramics. Traditional pottery, with a long history of use, is composed of clay, feldspar, silica, calcite, nepheline, among others. Advanced ceramics, with more specialized applications, include oxides, carbides, and nitrides from elements such as silicon, aluminum, and tungsten. Briefly:

- Composition:
- Combination of metallic and non-metallic elements (oxides, carbides and nitrides)
- Types of connections:
- Mixed, ionic-covalent character.

Types of ceramic materials:

- Traditional ceramics.
- High-performance ceramics.
- Glass and glass-ceramics
- Cements

Ceramic materials are generally classified into traditional and advanced, based on their applications and properties. Traditional ceramics, such as red ceramics and white ceramics, are used in construction and kitchen products. Advanced ceramics, such as oxides and nitrides, are used in high-tech applications, such as electronics and medicine. We can also classify materials into the following dimensions**:**

- Glasses
- Clay-based products
- Refractory
- Cements

2.3. Polymers

Polymers are macromolecules formed by the union of smaller molecules, called monomers, through chemical reactions. The word "polymer" comes from the Greek "poly" (many) and "mere" (parts), indicating that they are molecules composed of many parts.

Polymeric materials are very common in everyday life and most consist of long chains or molecular networks that are usually based on organic materials (precursors that contain carbon). Structurally, most polymeric materials are non-crystalline, but some have a mixture of crystalline and non-crystalline regions. The strength and ductility of polymeric materials vary greatly.

Due to the nature of their internal structure, these materials are predominantly poor conductors of electricity. Some of them are good insulators, used in electrical insulation applications.

One of the most recent applications of polymeric materials is in the production of digital video discs (DVDs). In general, these materials have a low density and decompose or soften at relatively low temperatures.

In economically developed countries such as the United States of America, plastic materials have shown the highest growth among basic materials, with an annual rate of 9% by weight. However, the growth rate of plastics in 1995 fell to less than 5%, a significant decrease.

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Such a drop was, however, expected, as plastics had already replaced metals, glass and paper in most of the high-volume markets in which they currently find application, such as packaging and construction. Polymers are macromolecules made up of repetitive units, linked through covalent bonds. And, how much classification:

- Nature
- Natural (Wood, rubber, proteins)
- Synthetics PVC, polystyrene, polypropylene

Materials obtained directly from nature are called natural materials, polymers that can be extracted directly in nature are also called natural polymers. Example of natural polymers: latex extracted from the tree. Many polymers such as casein, cellulose ethanoate and cellulose nitrate are semi- synthetic or artificial because, as with other artificial materials, they are obtained through the manufacture of natural substances. Os polímeros semi-sintéticos são obtidos por reações químicas a partir de polímeros naturais (Pouzada, 1983).

Composition

Composite polymers are usually organic based on carbon, hydrogen, and other non-metallic elements. They are made up of very large molecules (macromolecules) and large molecules (macromolecules). Typically, these materials have a low density and can be extremely flexible. Polymeric materials include plastics and rubbers.

The polymer class is a branch of organic chemistry products, formed mainly by carbon and hydrogen, and may contain other non-metallic elements. The process of producing polymers is known as polymerization. Polymerization consists of the union of molecules of a given compound (monomer) to form a new compound called a polymer, whose molecular weight is an integer multiple of the starting product.

Polymers are long-chain molecules, formed by the union of several smaller (poly) units (meros). Polyethylene (C2H4)n is an example of a polymer formed only by carbon and hydrogen, by the union of 100 to 1000 molecules of ethylene (C2H4). However, in addition to carbon and hydrogen, polymers can contain oxygen, such as acrylic, nitrogen, polyamides or nylons, fluorine, fluoro- carbons, silicon and silicones (Souza, undated).

Polymeric materials

As mentioned earlier, polymeric materials are made up of the repetition of several (poly)molecules or repetitive units, called monomers. Thus, the properties exhibited by the material depend on the type of monomer, the amount in which it repeats, whether there are branches in these chains, and their orientation. As for its classification, the following dimensions are listed:

- Regarding the type of chemical structure
- Fuse characteristics
- Mechanical behavior Manufacturing scale
- As for the scale of manufacture
- The type of application

Plastics

Plastics, common materials, are synthetic polymeric organics, of macrocellular constitution, endowed with great malleability, easily transformable through the use of heat and pressure, and which serves as raw material for the manufacture of the most varied objects. The raw material for plastics is usually petroleum. This is formed by a complex mixture of compounds.

A no less important perspective is that plastics for engineering use, such as nylon, must remain competitive against metals. Polymer supplier industries are increasingly focusing on the development of polymer-polymer blends, also called polymer alloys or blends, targeting specific applications for which no single polymer is appropriate.

Finally, plastic is a synthetic material derived from polymers that can be molded into various shapes, being widely used in various applications due to its versatility, durability, and low cost. The term "plastic" comes from the Greek "plastikos", which means "fit to be molded

Characteristics of two Polymers

Polymers are macromolecules composed of repeating units, linked by covalent bonds, which confer a wide variety of properties and applications. They can be natural, such as cellulose and silk, or synthetic, such as plastic and polyester. The main characteristics of polymers include:

- They are long organic molecules, composed of repeating monomers.
- They are moldable by compression, transfer, air injection and extrusion processes, always applying heat and pressure, together or independently.

Structural Classification

- Linear:

Linear polymers: the units are joined in single chains. Ex. PVC, nylon

- Branched

Cross-linked polymers are polymers where adjacent chains are joined to each other through covalent bonds.

- Lattice (cross-links)

Networked polymers: These are polymers that have many cross-links forming three-dimensional networks. Ex. epoxy.

Classification for stiffness

- Thermoplastic:

These are polymers that can be repeatedly processed under heating. They have linear and branching chains, with relatively weak interaction forces. Ex: polyethylene, PVC, poly (methyl methacrylate), also widely known as acrylic.

- *Thermosets:*

These cannot be softened by heating, but will remain permanently rigid with increasing temperature. Chains with high cross-link density. Ex: Epoxy resins, polyester resins. Practically non-recyclable.

- Elastomers:

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Elastomers are understood as rubbers and have great elasticity, returning to their previous shape after stretching. They are elastic because they have a small amount of cross-links. Ex: natural rubber, polybutadiene, silicone.

Vulcanization

Vulcanization, of rubber for example, is the addition of sulfur under heating and in the presence of catalysts. During this process, sulfur atoms break the double bonds and form bonds joining the rubber molecules, which are polyisoprenes. Vulcanization consists of the formation of cross-links through chemical bonds.

Polymer Applications

Plastics

From a chemical point of view they are: Inert, mechanically resistant, insulating, transparent, translucent or opaque, coatings, toys, lenses, seals, gears, insulators, bottles.

Linear polymers

Linear polymers are:

- The linear chains are grouped in parallel, which enables a great intermolecular interaction, giving rise to a rigid high-density material, used in the manufacture of bottles, toys and other objects.
- Polyethylene is the most commonly used. Its technical acronym is HDPE or HDPE and its identification in recycling processes is given by the symbol.

Applications of branched polymers

- The branches of the chains make interactions difficult, giving rise to a soft and flexible material, known as low-density polyethylene. Its acronym is LDPE or LDPE and its identification in recycling processes is given by the symbol.
- It is used to produce plastic bags
- Coating of wires and malleable packaging.

Polypropylene (PP)

- It is obtained by polymerizing propylene (propylene).
- It is used to produce molded objects, fibers for clothes, ropes, carpets, sealant material, trays, shelves and bumpers of automobiles, among others.

Polystyrene (PS)

It is obtained by the successive addition of vinyl-benzene (styrene).

- It is used in the production of moldable objects such as plates, cups, cups, syringes, laboratory supplies, and other transparent rigid materials.
- When it undergoes expansion caused by gases, it originates a material known as Styrofoam, which is used as a thermal, acoustic and electrical insulator.

Polyvinyl chloride (PVC)

Polyvinyl chloride (PVC) is obtained from successive additions of vinyl chloride (chloroethene). mole, and it is usually used to produce pipes, phonograph records, floors and raincoats.

Synthetic leather, which imitates and replaces leather of animal origin, is polyvinyl chloride mixed with dyes and other substances that increase its elasticity. One of its main characteristics is the fact that it prevents the spread of flames, being used as an electrical insulator.

PVC is the only plastic material that is not entirely sourced from petroleum. It contains, by weight, 57% chlorine, a derivative of sodium chloride (table salt), and 43% ethylene, derived from petroleum. Therefore, the main raw material for PVC is sea salt, a renewable natural resource available in abundance in nature.

Teflon (PTFE)

It is the product of the polymerization of tetrafluoroethene or tetrafluoroethylene. Tefion is an exceptionally inert, non-combustible, and very tough polymer. It is used to produce sealing tapes, non-stick coatings for pots and pans, electrical insulation, pipes and equipment for the chemical industry (valves and registers), among others

Polyacrylonitrile

It is the product obtained by the polymerization of acrylonitrile or vinyl cyanide. It is not used in recycling processes. They can undergo wiring processes. This is one of the few polymers that can be obtained in aqueous solution. If polyacrylonitrile is added to an appropriate solvent, it can be easily stretched, allowing the production of fibers marketed under the name of orlon or acrylon.

Polyvinyl Acetate (PVA)

It is the product obtained by the polymerization of vinyl acetate. Much of the PVA currently produced is used for the production of paints, adhesives, and chewing gum.

Methyl polymetaacrylate (PMMA)

It is the product of the polymerization of methyl meta-acrylate. In production, the reaction causes the formation of a pasty mass, which is poured into a mold or between two vertical sheets of glass, where the end of polymerization occurs.

The parts are colorless, presenting great transparency, so this polymer is used to produce contact lenses, transparent panels, car lanterns, advertising panels, traffic lights, etc.

Polyacetylene

It is the first polymer to conduct electric current. It has a low density, "does not rust" and can form thin blades. The electrical conduction capacity is due to the presence of double alternating bonds in its structure, which allows the electrons to be delocalized along the chain.

Synthetic Drunks

The most common raw materials for the production of synthetic rubbers are:

- Buta – 1, 3 – dieno (Eritreno)
- 2 – Clorobuta – 1, 3 – dieno (Cloropreno)

Synthetic rubbers, when compared to natural rubbers, are more resistant to temperature variations and chemical attack, being used for the production of hoses, belts and sealing articles.

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There are other types of synthetic rubbers formed by adding two different types of monomers. These rubbers are classified as copolymers. Copolymers are polymers that are made up of more than one type of monomer.

The most important of these rubbers is formed by the copolymerization of erythrene with styrene, which is known by the acronyms GRS (government rubber styrene) or SBR (styrene butadiene rubber), whose main application is the manufacture of tires.

2.4. Composites

The term composite a prior suggests the joining of more than one type of materials. Therefore, they are materials formed by the union of other materials in order to obtain a higher quality product. Composites are formed by the combination of materials from the classes presented above (metals, ceramics and polymers). This bond leads to a material with properties superior to those of the components separately. They are materials formed by combining two or more materials with different properties, resulting in a material with properties superior to those of its individual components

There are several types of composites formed by different combinations of metals, ceramics and polymers, most of them are man-made; However, some naturally occurring materials are also considered composites, such as bone and wood.

One of the most well-known composites is fiberglass, which consists of small glass fibers embedded inside a polymeric matrix. The union of glass fibers, a resistant and rigid (but fragile) material, with the polymeric matrix, a ductile and flexible (but weak) material, results in a flexible, ductile, resistant and relatively rigid composite material (Callister & Rethwisch, 2013, cited in Souza, undated).

A composite material can be defined as two or more materials (phases or constituents) integrated to form a new material. The constituents retain their properties, but the resulting composite will have different properties from these.

Most composite materials consist of an appropriate filler or reinforcement material and a suitable binding resin in order to achieve the specific characteristics and desired properties. Normally, the components do not dissolve into each other, and can be physically identified by an interface between them.

Composites can be of various types. Some of the predominant types are fibrous materials (composed of fibers in a matrix) and particulate materials (composed of particles in a matrix) (Callister & Rethwisch, 2013, cited in Souza, undated).

Still in the context of the authors cited above, many different combinations of reinforcing materials and the matrix are used to manufacture composites. To take an example, the matrix material can be a metal such as aluminum, or a ceramic such as alumina, or even a polymer such as epoxy.

Depending on the type of matrix used, composites can be classified into metal-based composites (MMC), ceramic matrix composite (CMC), and polymer matrix composite (PMC).

Fibrous or particulate materials can also be selected from any of these three main categories of materials, examples of which are carbon, glass, aramid, silicon carbide, and others. The combinations of materials used in composite design depend primarily on the type of application and the environment in which the material will be used

With technological advancement, composite materials have replaced metal components mainly in aerospace, avionics, automotive, construction, and the sports equipment industry. An average annual increase of approximately 5% in the future use of these materials is expected.

Many researchers corroborate that one of the reasons for this is its high strength and its stiffness- to-weight ratio. Some advanced composites have similar stiffness and strength to metals, but with significantly lower density and therefore lower net weight. These characteristics make them extremely attractive in situations where the weight of the product is a crucial factor.

In general, similar to ceramic materials, the main disadvantage of most composites is their fragility and low fracture resistance. Some of these deficiencies can be mitigated, in certain situations, by the appropriate choice of matrix material.

Two prominent types of modern composite materials used in engineering applications are fiberglass reinforcements in a polyester or epoxy matrix and carbon fibers in an epoxy matrix. Since the beginning of the construction of these aircraft, new procedures and modifications aimed at reducing costs have been implemented.

Características

At the beginning of this theme we discussed that composite materials are characterized by the combination of two or more materials with different properties, aiming to obtain a material with superior characteristics than the individual components. This combination results in lighter, stronger, more durable materials with greater adaptability to various applications. These materials are made up of more than one type of material:

- Matrix
- Replenisher

Designed to present the best characteristics of each of the materials involved.

Examples:

- Products made of "fiberglass" → are made up of fibers of a ceramic material (glass) reinforcing a polymer material matrix

The composite materials are:

- Composite materials are made up of more than one type of material that is insoluble from each other.
- Composites are "designed" to present the combination of the best characteristics of each constituent material;
- Many of the recent materials are developed into materials that involve composite materials;

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- A classic example is the polymer matrix composite with fiberglass. The composite material has the strength of fiberglass associated with the flexibility of polymer.

Natural composites

Natural composites are multiphase materials of natural origin, usually formed by combining different organic components, such as fibers and resins, that come together to create materials with specific properties. They are obtained from natural sources such as plants, trees, and animals.

Wood is a natural composite:

- Flexible and resistant cellulose fiber
- Lignin, a stiffer resin that holds the fibers together

Examples

- Polymer with glass fiber, carbon fiber, natural fiber and others
- Reinforced cement, cermet
- Steel tread tires

Composites with fibers

Fiber-reinforced composites are materials that combine a matrix (usually a polymer, metal, or ceramic) with fibers (such as glass, carbon, aramid, or natural fibers) to improve their mechanical properties, such as tensile strength, stiffness, and impact resistance. The choice of fiber and matrix depends on the desired application and the required performance properties. Generally, the most used fibers are:

- Glass fibers
- Carbon fibers
- Boron Fibers
- Boron Fibers
- Polymer fibers (PE, PET, Kevlar)

3. Conclusions

The present investigation followed the purpose of understanding the relationship between structure, property, processing and performance of metallic, polymeric, ceramic and composite materials. It intended to answer the following starting question: *What is the relationship between the structure-property-processing-performance of materials?*

As is customary in the systematic review, keywords were searched for keywords and exclusion criteria resulting in articles on materials science and engineering. The keywords used in the literature search were, namely, materials science and engineering, structure, property, processing, performance.

The main results indicate that materials science and engineering is the relationship between the structure of a material, its properties, the processing used to obtain it and its performance in an application. The structure of a material (from the atomic scale to the microstructure) directly influences its properties. Processing, in turn, affects the structure of the material. Finally, the performance of the material in an application is a direct consequence of its properties.

In short, material science and engineering is fundamental for students and professionals in this area of knowledge that aims to study and develop structures and materials to produce products with the appropriate performance and expected durability.

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