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NANOCOMPOSITES MATERIALS DEFINITIONS, TYPES AND SOME OF THEIR APPLICATIONS: A REVIEW

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Abstract:
Nowadays it is difficult to imagine life without nano-technologies, more specific: nanomaterials. The purpose of this review article is to highlight the definition, types and the application of both nano-materials and nano-composites. Different types of nanocomposites materials with different application are exist based on their matrix and nano material phases. Also, there are different types of reinforcements (particles, fibers, and sheets) each type has its properties and application. These materials are used in a lot of application from easy application to advanced once.

Keywords: Nanotechnology, Nanocomposites, MMC, CMC, PMC.

1.INTRODUCTION

Nanotechnology is the science of finer particle size of materials at dimensions of approximately 1 to 100 nanometers that provide unique properties of materials used for specific applications. At the nanoscale the biological, chemical and physical properties of materials differ from the properties of individual atoms and molecules or of bulk matter. These unique properties of materials emerge that enable novel applications [1]. Nanotechnology is a term encompassing nanoscale engineering, technology, and science which focused on controlling, exploiting and understanding the unique properties of matter that can emerge at nano scales. It's believed that substantial societal and economic benefits are offered with these properties [2]. Some of the properties of nanoscale materials (e.g., high surface area-to-volume ratio and small sizes) that have raised hopes for beneficial applications have also raised concerns about their potential negative effects on the human health and environment, so the major problem is how to provide the best protect for the environment and human health when using nano materials [2]. A nanometer (nm) is a length of 10^{-9} meters (one billionth of a meter) in the SI (System International Units). You're talking about atoms and molecules at this scale [3]. Nanocomposites (NC) are multiphase materials with nanoscale additions in one of the phases. They are predicted to exhibit unexpected features as a result of the merging of each component. The three types of nanocomposites based on their matrix are ceramic matrix nanocomposite CMNC, polymer matrix nanocomposites PMNC and metal matrix nanocomposites MMNC. In comparison to pure or traditional composite materials, NC have garnered attention in recent years due to their excellent thermal, mechanical, fire-retardant, and solvent resistance properties [4]. It is well recognized that the particle size and its distribution, surface characteristics, geometric shape, dispersion state all can have a significant impact on the properties of composite. As a result of the current commercial availability of nanoparticles, polymer nanocomposites are becoming more popular. Mechanical properties such as modulus and strength, water, gases, and hydrocarbon permeability, dimensional and thermal stability, chemical resistance, flame retardancy, and optical properties, dielectric, magnetic, electrical properties are all significantly improved in these composites [5].

In terms of mechanical, thermal, electrical, and barrier properties, nanocomposites outperform conventional composites. They can also greatly reduce flammability while maintaining the polymer matrix's transparency. These attractive properties lead to a wide range of potential industrial uses for polymer nanocomposites [6]:

1. Automobile (exterior and interior panels, gas tanks, bumpers)
2. Development (structural panels and building sections)
3. The aerospace industry (high-performance components and flame-retardant panels)
4. Electrical and electronic engineering (printed circuit boards and electrical components)
5. Packaging for food (wrapping films and containers) [6], [7], Injection molded items, fire retardants, coatings, adhesives, optical integrated circuits, microelectronic packaging, medical devices, medication delivery, membranes, consumer goods and sensors and can all benefit from polymer nanocomposite [8].

Polymer nanocomposites PNC are polymers (elastomers, thermosets, or thermoplastics) reinforced with nano-sized particles with high aspect ratios (L/h > 300) in modest amounts (less than 5% by weight)[6].

2. NANOCOMPOSITES CLASSIFICATION

Nanocomposite materials can be divided into three groups, similar to micro composites, based on their matrix materials [9]: Metal, Polymer and Ceramic Matrix Nanocomposites (MMNC, PMNC and CMNC).

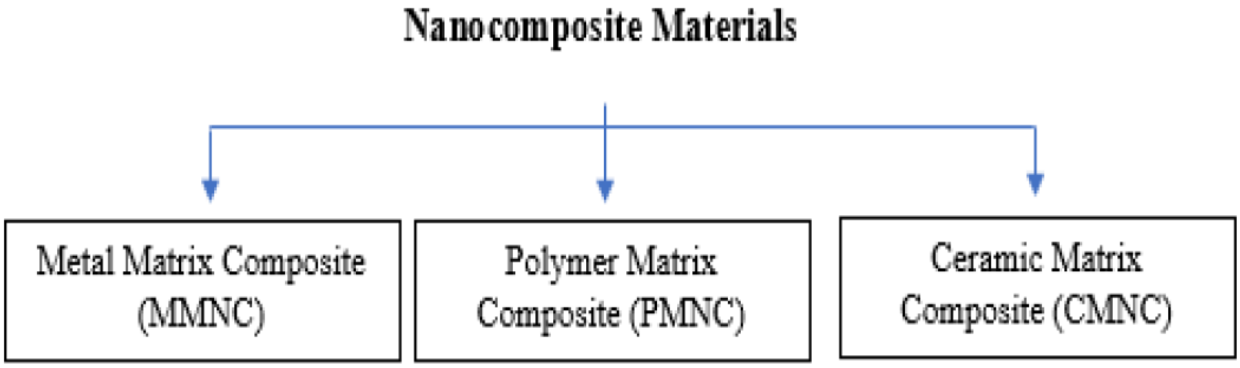

Figure 1: Types of nanocomposites according matrix.

2.1. Metal Matrix Nanocomposites MMNC

Metal matrix composites (MMCs), like other composites, are made up of at least two physically and chemically different phases that are dispersed in such a way that they provide properties that neither of the separate phases can provide. In general, there are two phases spread in a metallic matrix: a fibrous or particulate phase. In power transmission lines a composite made from Al matrix reinforced with a continuous $A1_2O_3$ fiber, the cutting tools and oil drilling inserts are made up from cobalt (Co) particulate and tungsten carbide (WC), and a composite made by reinforcing A1 matrix with SiC particle used in automotive, thermal management and aerospace applications are just a few examples. These nano composite MMNC are made up of a ductile alloy or metal matrix with nanosized reinforcing material. These materials have ceramic and metal properties, such as toughness and ductility, as well as high modulus and strength [9], [10].

As a result, these nanocomposites are highly suited for the creation of materials with high service temperatures and shear/compression strengths. They offer significant potential for usage in a multitude of disciplines, including the automotive and aerospace industries, as well as structural material manufacture [9].

2.2. Polymer Matrix Nanocomposites PMNC

The most common type of nanocomposite is PMNC, which consist of isolated nano scale particles evenly distributed in a polymer in an ideal situation. The polymer matrix is used to disperse agglomerated nanoparticles in reality. Functional nanocomposites with better physical properties open up new possibilities in micro-optics, electronics, energy conversion, and storage. In the majority of cases, the filler load correlates with the change in the sought characteristic. Due to shape or molding constraints, large solid loading is limited by composite flow characteristics, as a result a property modification. Before the forming process of composites the rheological properties (flow properties) should be measured using different tests to estimate the correct shear rate and temperature. Their rheological behavior is determined by the surface area and the ensuing large polymer-filler interfacial layer [11]. polymer nanocomposites have opened a new horizon for a potential class of hybrid materials by introducing particle nanofiller into polymer matrices to improve the properties of neat polymers [12]. During the last decade, polymer nanocomposites have gained a lot of attention and curiosity all around the world. The sol–gel process looks to be the most promising among the fabrication methods for polymer nanocomposites. At the molecular or near molecular level, the nanoparticles were dispersed before being combined with the polymer gel [13].

2.3. Ceramic Matrix Nanocomposites CMNC

Ceramic matrix nanocomposites (CMNC), particularly the aluminum oxide (Al_2O_3)/silicon carbide (SiC) system, have a lot of potential. All the investigation has proven that the addition of low volume fraction (~10%) of SiC with a specific size for Al_2O_3 matrix gives good improvement in the properties of matrix. The crack-bridging role of nanosized reinforcements has been used in certain research to explain this toughening mechanism. As a result of incorporating high-strength nanofibers into ceramic matrices, innovative nanocomposites with superior failure and high toughness characteristics have been developed in comparison to rapid failures of ceramic materials. The preparation of ceramic matrix nanocomposites has been described using a variety of approaches. Conventional powder method; Vapor techniques (CVD and PVD); Spray pyrolysis; Polymer precursor route; and Chemical methods, which include the colloidal and precipitation procedures, template synthesis, and sol-gel process are the most prevalent methodology utilized for micro composites. The sol-gel process can be affected by a wide range of factors which permit control of the structure and chemical properties of the final material, such as solvent type, time, pH, water/metal ratio, precursor, and so on [8].

3. COMPOSITE NANOPARTICLES

Surface modified nanoparticle and core/shell nanoparticles are a special form of nanocomposites. Hybrid nanoparticles are defined as nanoparticles that have an organic shell (polymerized polymer, detergent, surfactant, other organic molecules) and an inorganic core (metal oxide or metal). Vollath described this kind of particles which consisting of a polymerizable organic shell and metal oxide, generated using gas phase synthesis in a microwave plasma reactor in the 1990s. This idea enables for the creation of new functional materials with unique biological, optical, magnetic or electrical capabilities. Core/shell nanoparticles have recently piqued interest for use as anode materials in lithium-ion batteries. The organic molecule is primarily carbon in the form of graphite, amorphous carbon, or graphene [11].

4. MICROSPHERE COMPOSITE NANOPARTICLES-

Larger spheres, which are themselves made of a nanocomposite, distinguish this specific sort of composite. Several writers have written on microsphere composites; however, they are much less common than core/shell nanoparticles. In most cases, the ceramic component is magnetic (either Fe2O3 or Fe3O4) and has a biological or magnetic resonance application [11].

5. TYPES OF NANOSCALE FILLERS

Nanoscale fillers come in a variety of forms and sizes, and when coupled to polymer matrices, they generate ultra large interfacial regions as shown in figure 1.

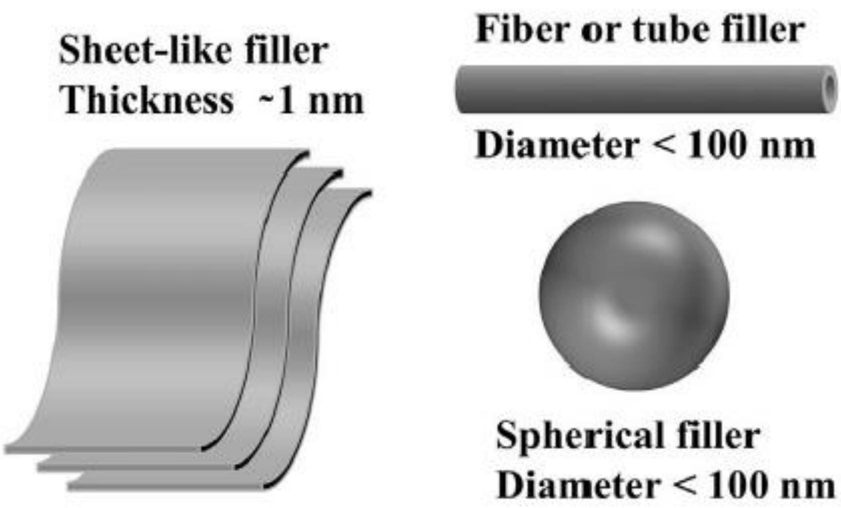

Figure 2: various types of nanofillers.

5.1. Sheet-like nanoscale fillers

Layered silicates, which belong to the 2:1 phyllosilicate structural family, are the first example of this type of nano-fillers that commonly employed in polymer nanocomposites. The structure of the often-utilized layered silicates, such as montmorillonite, hectorite, and saponite, is shown in Figure 3. Two-dimensional layers make up their crystal lattice. Two outer silica tetrahedrons are fused to a core alumina or magnesia octahedral sheet, with the octahedral sheet's oxygen ions belonging to the tetrahedral sheets. The layers are approximately nm thick, and their lateral dimensions range from a few 10^{ths} of nm to several μm or more. Between the "interlayers" or "inter-galleries," these sheets will stacks having Vander Waals spaces among them. This type of clay has a moderate positive exchange capacity, and because the charges of the layers vary, an average value measured over the entire crystal must be used [14]–[16]

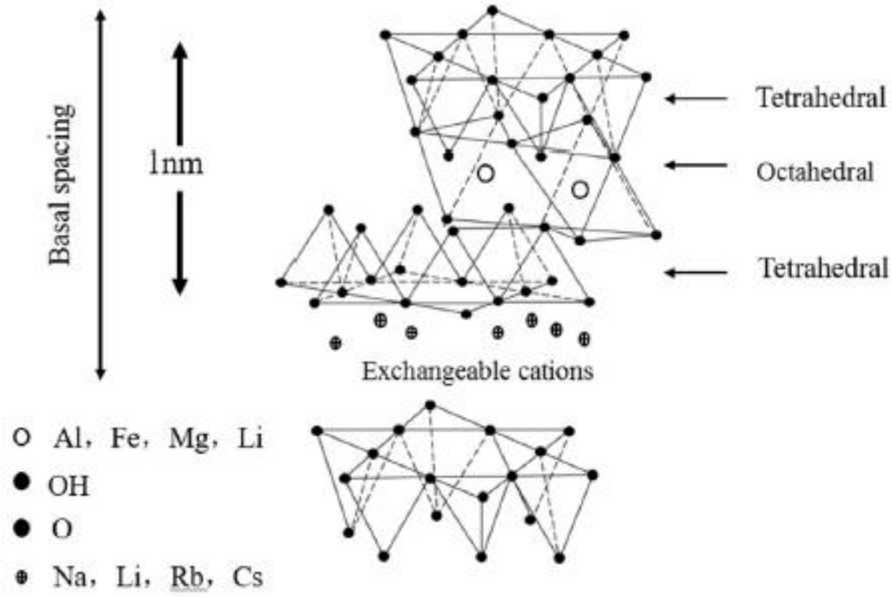

Figure 3: The most commonly used silicate structure.

5.2. Nanotubes and nanofibers

Carbon nanotubes are fullerenes with hexagonal graphite walls and typically capped ends that are slender and long. Multi walled carbon nanotubes (MWCNTs) are made by stacking and arranging a number of graphitic shells (2 for simplicity) to form a cylindrical tube, whereas single-walled carbon nanotubes (SWCNTs) are formed by a graphene sheet rolling alone. as in figure 4. Covalently bound carbon atoms form a hollow structure in a single-walled carbon nanotube. Multiwalled nanotubes (MWNTs) come in a variety of shapes and sizes, depending on how they are made. Approximately 0.34 nanometers is the distance between neighboring graphene layers. The geometry and size of carbon nanotubes determine their mechanical and physical properties [17]–[20].

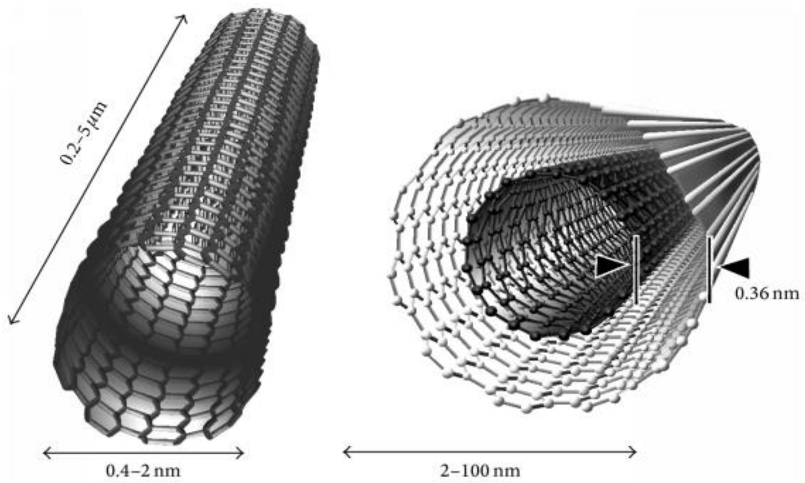

Figure 4: single wall SWCNTs (left) and Multiwall MWCNTs (right) carbon nanotubes.

5.3. Nanoscale spherical fillers

Pyrolysis has made carbon black available in a variety of surface areas, and spherical nanoparticles have existed since the 1900s. Particles with a surface area range from 20-500 m^2g^{-1} have a size from 20-300 nm. To make silica accessible, researchers have utilized the wet chemical technique, the Ludox process (Dupont commercial procedure), and the flame process. For a long time, flame methods have been used to produce ultrafine powders, and they are still used today. The goal of several research projects is the creating of spherical nanoparticles with variable diameters. Particle size is influenced by the nanoparticle manufacturing process. This interest stems mostly from the impact of particle size on their properties. Nanoscale fillers when mixed with polymers it can give the ability to use these polymers in new applications due to the properties that nanoscale fillers. The fillers on nano scale can adds properties to polymer matrices that micro fillers or other fillers can't[21].

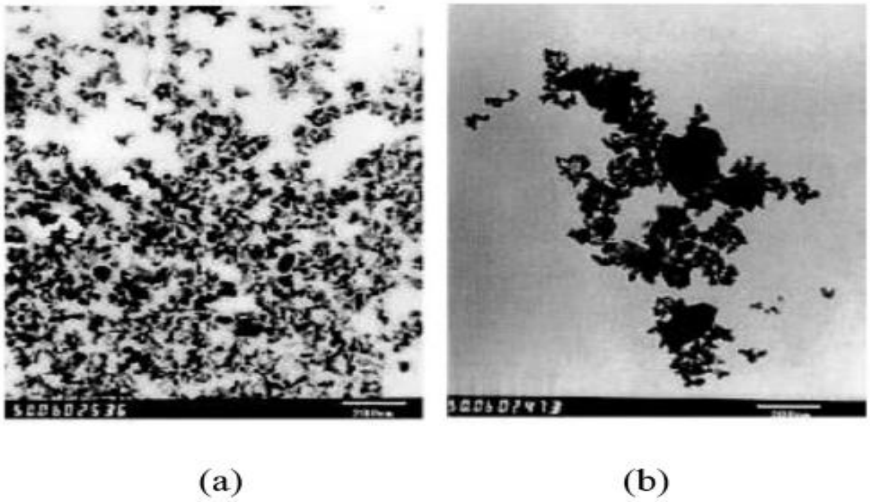

Figure 5: ZnO nanoparticles in water TEM images.

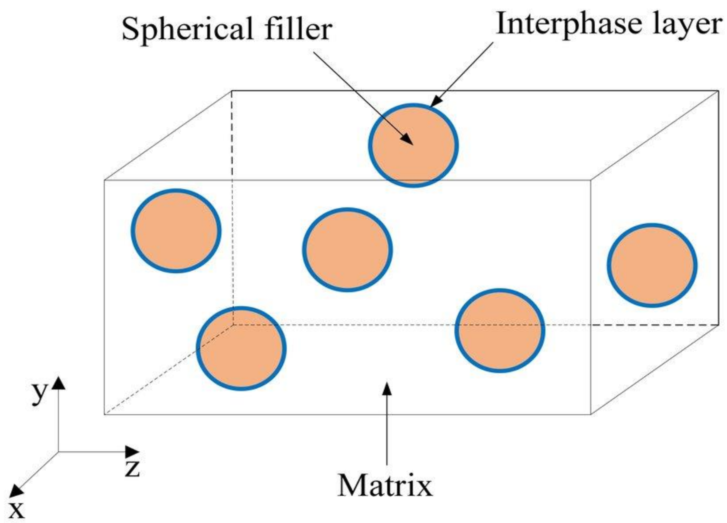

Figure 6: 3D shape of spherical fillers dispersed in matrix.

6.APPLICATION OF NANOPARTICLES

Nanoparticles can be used in many different ways. Here are a few of the most significant.

6.1. Medical and drug Applications

Simple and complex inorganic nanoparticles have unique chemical and physical properties that make them an important component in the creation of innovative nanodevices for a variety of applications such as pharmacological, medical, biological, and physical applications. NPs have grabbed the interest of researchers across the medical field due to their ability to deliver medications in the right dosage range. As a result, therapeutic efficacy has increased, side effects have decreased and patient compliance has improved. NPs are used for their optical properties in biological and cell imaging applications, as well as photothermal therapeutic applications, to produce efficient contrast. Both the discrete dipole approximation approach and Mie theory could be used for the most common classes of NPs to evaluate the scattering and the absorption efficiency, as well as optical resonance wavelength [22].

6.2. Manufacturing Applications

Nanocrystalline materials are intriguing to examine because their characteristics differ in size from those of the bulk material. Manufacturing NPs have unique mechanical, electrical, optical and imaging characteristics in commercial, medical and environmental applications because of their physicochemical properties. The benefits of nanotechnology have been documented by many companies, and commercial products are now being mass-produced in fields like aerospace, microelectronics, and pharmaceuticals. Packaging and food processing industries have heralded nanotechnology as the next great thing [22],[23].

6.3. Mechanical Industries Applications

NPs can be used in a variety of mechanical applications, such as adhesives, coatings and lubricants, as evidenced by their mechanical properties, which include outstanding stress, strain and young modulus properties.

Also, this property could be used for the manufacturing of nanodevices that are mechanically stronger for different applications. Tribological properties (surface properties) of the polymer or the metal matrixes could be enhanced by adding nanoparticles NPs to improve their mechanical strength, the added nanoparticles improve the lubrication in the contact area and reduce the wear and friction [22].

6.4. Electronic Applications

The prospect of low-cost electronics and large space for flexible screens and sensors, as opposed to typical silicon approaches, has sparked interest in printed electronic research in recent years. Printed electronics, which use a variety of functional inks containing NPs such as organic electronic molecules, metallic and ceramic NPs and carbon nanotubes CNTs, is expected to become a large-scale production technique for new types of electronic equipment in the near future. One-dimensional metals and semiconductors possess unique electrical, structural and optical properties, making them a key systemic component in a new generation of photonic, electronic and sensor materials [22].

7.CONCLUSION

This paper discussed both nanotechnology and nanocomposites materials definitions and their classifications. Nanomaterials have different types based on their shapes (particles, fibers, and sheets), also have different sizes with different nano dimensions (1D; only one dimension in nano-scale, 2D; two dimensions in nano scale, and 3D; the all three dimensions are in nano scale). Nanocomposites have three main classifications based on their matrix phase (metal matrix nanocomposite MMNC, ceramic matrix nanocomposite CMNC, and polymer matrix nanocomposite PMNC). The applications of the nanocomposite materials depend on both the matrix (metal, ceramic, and polymer) and the reinforcement types (particles, fibers or sheets).

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