Chapter

Nanocomposite Materials

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Abstract

Nanocomposites are the heterogeneous/hybrid materials that are produced by the mixtures of polymers with inorganic solids (clays to oxides) at the nanometric scale. Their structures are found to be more complicated than that of microcomposites. They are highly influenced by the structure, composition, interfacial interactions, and components of individual property. Most popularly, nanocomposites are prepared by the process within in situ growth and polymerization of biopolymer and inorganic matrix. With the rapid estimated demand of these striking potentially advanced materials, make them very much useful in various industries ranging from small scale to large to very large manufacturing units. With a great deal to mankind with environmental friendly, these offer advanced technologies in addition to the enhanced business opportunities to several industrial sectors like automobile, construction, electronics and electrical, food packaging, and technology transfer.

Keywords: nanocomposites, composites, phases, latex, disperse nanomaterials

1. Introduction

The nanoparticle includes the particles having size between 1 and 100 nm. These particles have different properties at their atomic level due to their size. This change in properties of nanoparticles is beneficial in many fields [1, 2]. Nanotechnology is one of the most interesting fields for researchers since the last century. Numbers of developments have been made since then in the field of nanotechnology. Nanoparticles can be classified as metal nanoparticles, non-metal ceramic nanoparticles, semiconductor nanoparticles, and a well-known type is carbon nanoparticles [3]. Nanoparticles have those chemical and physical properties which makes them very different from that of the corresponding bulk materials due to their small size and large surface to volume ratio. They attract much attention because of their potential applications in many fields including optics, electrics, magnetism, ceramics, and catalysis [4].

2. Composites

Composites are engineered or naturally occurring solid materials which results when two or more different constituent materials, each having its own significant characteristic (physical or chemical properties) are combined together to create a new substance with superior properties than original materials in a specific finished structure [5, 6]. They are commonly designed to offer wide range of properties and characteristics, some are as follows:

- Stiffness and strength
- Low coefficient of expansion
- Resistance against fatigue
- Ease in manufacturing complex shapes
- Simple repair of damaged structures
- Resistance to corrosion

3. Nanocomposites

Nanocomposites are those composites in which one phase has nanoscale morphology like nanoparticles, nanotubes, or lamellar nanostructure. They have multiphases, so are multiphasic materials, at least of the phases should have dimensions in the range of 10–100 nm. To overcome the limitation of different engineering materials now-a-days, nanocomposites are emerged to provide beneficial alternatives. Nanocomposites can be classified on the basis of their dispersed matrix and dispersed phase materials [7]. With the help of this rapidly expanding field, now-a-days, it has been possible to generate many exciting new materials with novel properties via innovative synthetic approaches. The properties of the so-called found not only depended on the properties of their originals, but also crucially on their interfacial and morphological characteristics. Of course, we cannot ignore the fact that sometimes it also happened that the newly generated property in the material is unknown to the parent constituent materials [8, 9]. Hence, the idea behind nanocomposite is to use building blocks with dimensions in nanometer range to design and create new materials with unprecedented flexibility and improvement in their physical properties.

4. Advantages of designing novel nanocomposites

Nanocomposites are the solid combination of a bulk matrix and nanodimensional phase(s) which differ in properties due to dissimilarities in structure and chemistry. Properties that have indicated substantial improvements:

- Mechanical properties (strength, bulk modules, withstands limit, etc.)
- Thermal stability
- Hinders flame and reduce smoke generations
- Permeability of gases, water, and solvents are reduced
- More surface appearance
- Improved electrical conductivity
- Increased chemical resistance
- Enhance optical clarity as compared to conventionally filled polymers

Among several nanocomposites, polymer-based nanomaterials are the most leading materials of current research and development. Characteristics like film forming ability, activated functionalities, and dimensional variability provide lots of benefit to polymer-based nanocomposites [10].

The potential risk of nanocomposites commonly occurs majorly in areas like

- Risk to health and environment
- Molecular manufacturing
- Societal risks
- Formation of nanocomposite materials:

Nanocomposites can be formed by blending inorganic nanoclusters, fullerenes, clays, metals, oxides, or semiconductors with numerous organic polymers or organic and organometallic compounds, biological molecules, enzymes, and sol-gel derived polymers (**Figure 1**).

Nanocomposite materials that are obtained by the combination of two or more separate building constituents in one material offers unique properties that plausibly arises from their small size, large surface area, and off course from the interfacial interaction between the phases. Their extra ordinary potential have been smoothly utilized to enhance the biological potential of many drugs, biomaterials, catalysts, and also in some high-value added materials [11].

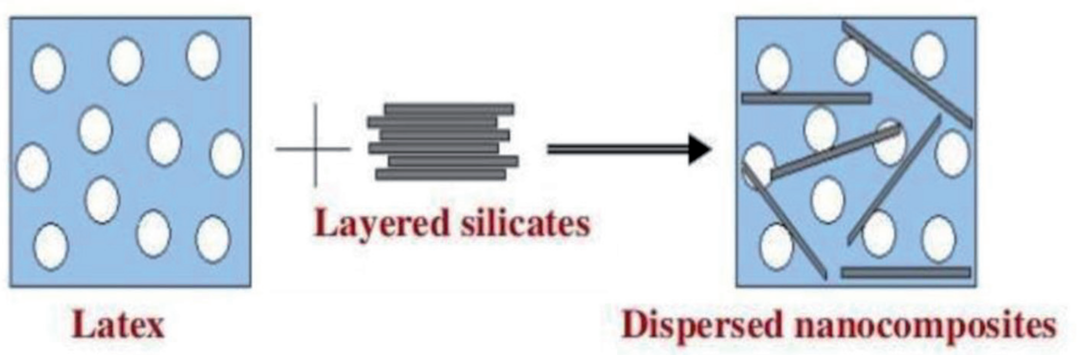

Figure 1.
Formation of nanocomposite materials.

5. Types of nanocomposites

Nanocomposite materials can be classified in the following way based on the presence or absence of polymeric material in the composite.

The nanocomposites in which the compositions do not contain any polymers or polymer-derived materials are called non-polymer-based nanocomposites (**Figure 2**). Non-polymer-based nanocomposites are also known as inorganic nanocomposites. They can be further classified into metal-based nanocomposites, ceramic-based nanocomposites, and ceramic-ceramic-based nanocomposites [12].

5.1 Non-polymer-based nanocomposites

5.1.1 Metal-based nanocomposites

Bimetallic nanoparticles being investigated in detail in the form of either of alloy or core-shell structures due to their improved catalytic properties and advancement

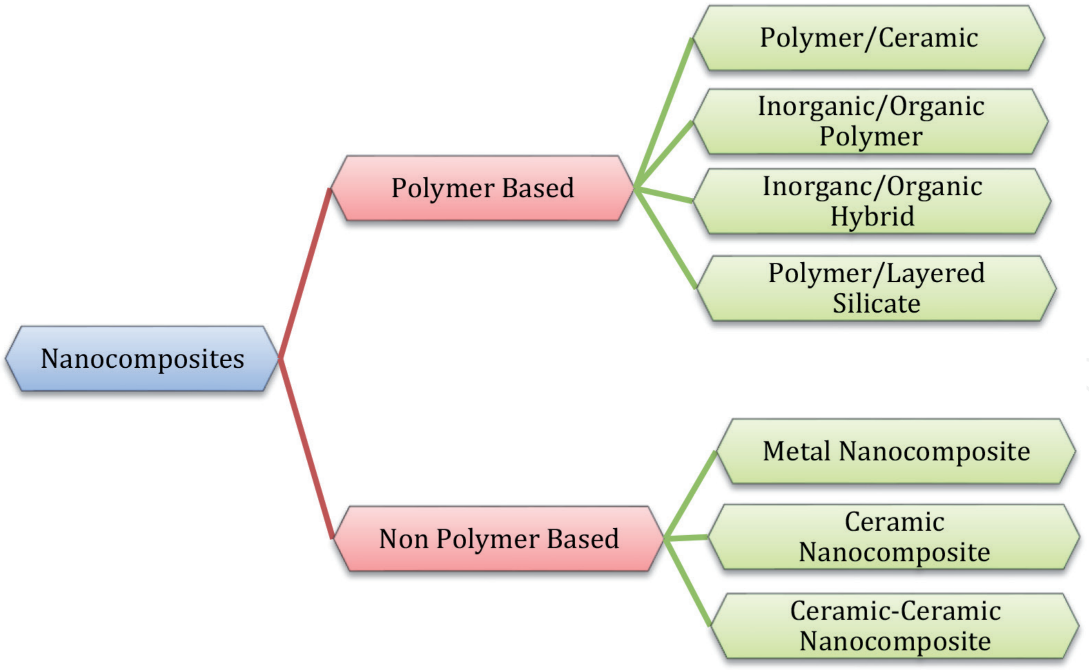

Figure 2.
Classification of polymer- and non-polymer-based nanocomposites.

in optical properties related to individual and differentiate metals [13]. They can be characterized by:

- Super plasticity,
- Lower melting points,
- Increased strength and hardness,
- Improved magnetic properties,
- Increased electrical resistivity, etc.

Non-polymer-based nanocomposites can be also classified as: metal/metal nanocomposites, for example Pt-Ru nanocomposites.

5.1.2 Ceramic-based nanocomposites

Ceramic-based nanocomposites are defined as ceramic composites with more than one solid phase, in which at least one of the phases has dimensions in the nanoscale range (<50–100 nm). In these types of composites, both the phases have combined magnetic, chemical, optical, and mechanical properties, for example hydroxyapatite/titania nanocomposites [14–16].

These can be characterized by:

- Better toughness
- Increased ductility
- Increased strength and hardness

5.1.3 Ceramic-ceramic-based nanocomposites

The non-polymer-based nanocomposites can be also classified as ceramic/ceramic nanocomposites which can be used in the area of artificial joint implants for fracture failures and it could promptly reduce the cost of surgery and would extend the mobility of the patient. The life spam would increase by 30 years, if the use of zirconia-toughened alumina nanocomposite implants is used effectively. The other example of ceramic/ceramic nanocomposites are calcium sulfate-biomimetic apatite nanocomposites [17].

The most promising prospects of both metal-based nanocomposites and ceramic-based nanocomposites are in the application of areas in dentistry in which the non-polymer-based nanocomposites or the inorganic materials that is metal or ceramics such as calcium phosphate, hydroxyapatite, and bioactive glass nanoparticles are very advantageous in alveolar bone regeneration and enamel substitution [18].

6. Polymer-based nanocomposites

The polymer or copolymer which contains nanoparticles or nanofillers dispersed in the polymer matrix is termed as poly nanocomposites. One dimension (1D) must be lying in the range of 1–50 nm and these possess several shapes like as platelets, fibers, spheroids, etc. Poly nanocomposites are in the category of multiphase systems such as, MPS namely composites, blends, and foams which can absorb about 95% of the production of plastics. So, these systems need controlled mixing, the achieved dispersion should be stable, dispersed phase should be oriented, and the compounding strategies which are involved for all MPS, which includes poly nanocomposites (PNC) is almost same [19].

Polymer nanocomposites are proposed as a class of materials with unique properties but, the most challenging property of PNCs is the complex interfacial areas in between the polymer matrices because of this small scale large specific area is created that highlight the importance of polymer-nanoparticle interactions. So, to achieve properties, such as, mechanical, thermal, optical, and electric, we need to analyze the intercalation process among the nanoparticles and polymer bases [20].

Polymer nanocomposites are known to be a class of reinforced polymer with a very low, i.e., less than about 5% of nanometric clay particles. These substances gained huge attention simultaneously from both the academic institution as well as from industrial sectors commonly in the area of nanocomposites. This is actually due to their drastically enhanced or improved thermal, mechanical as well as the barrier properties as compared to the micro- and also the conventional composites. These materials can be differentiated notably by: improved fire resistance and thermal stability, improved barrier properties, and increased recyclability [21].

However, despite of having so many advantages, it is still very much difficult to prepare a uniform dispersion between the filler and the matrix, as shown in **Figure 3**. Hence, unlikely, it reflects the lower mechanical as well as thermal properties in the produced nanocomposites.

6.1 Uses of polymer nanocomposites

Figure 4 shows the various uses of polymer nanocomposites irrespective of the nature of the field used. By the hydrolysis of tetraethyl-ortho-silicate, the hybrids made of poly rubber (dimethyl siloxane) and nanosilica can be given a specific shape like objects, such as golf balls (**Figure 5**). Many number of polymer nanocomposites for example, rubber, propylene, styrene butadiene rubber, and ethylene vinyl acetate are used in barrier applications.

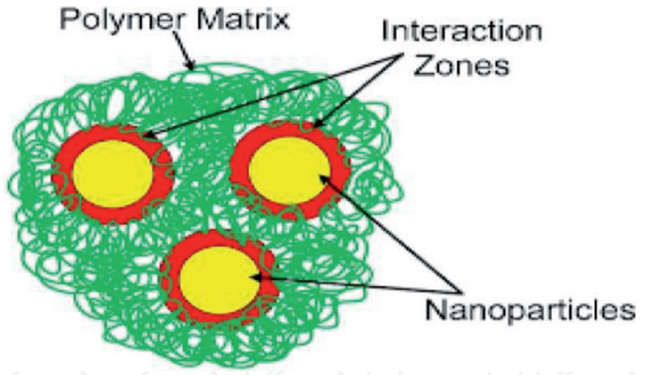

Figure 3.
Uniform dispersion between the filler and matrix in nanocomposites.

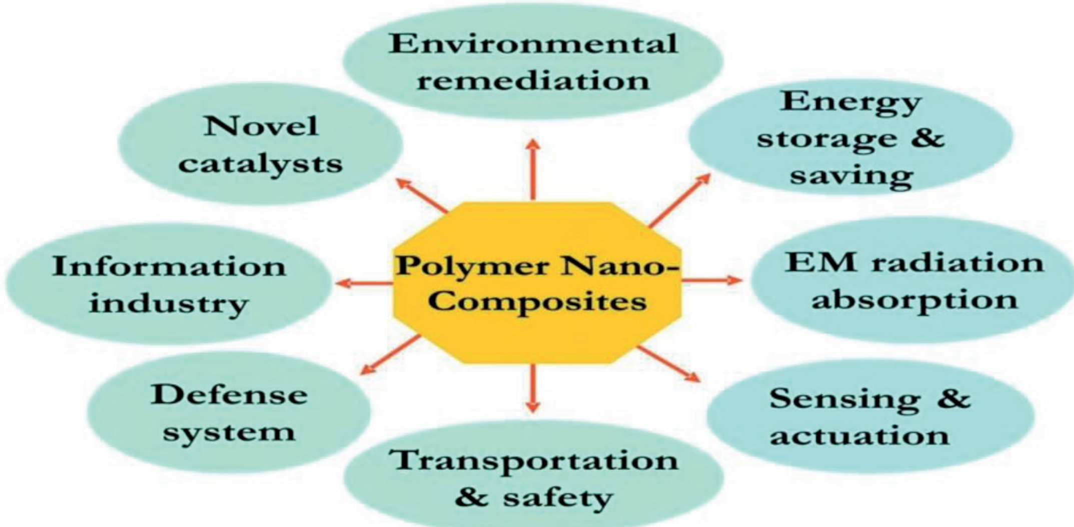

Figure 4.
Various uses of polymer nanocomposites.

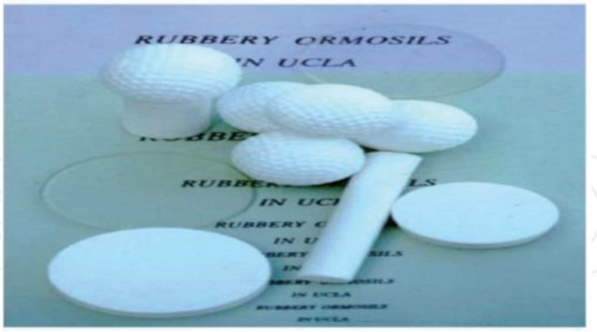

Figure 5.
Rubbery hybrids with different shapes.

They can act as a tremendous barrier for chemicals like toluene, sulfuric acid, and hydrochloric acid as well as for several gases such as, carbon dioxide, oxygen, and nitrogen [22, 23]. They are also utilized in chemical protective and surgical gloves as they have excellent solvent barrier properties in order for avoiding contamination from medicine.

Polymer nanocomposites are also used in food packaging, and the particular examples for food packaging includes processed cheese, meat, and dairy products also the medical containers for carrying blood collection tubes, baby pacifiers, and drinking water bottles. To enhance the barrier, mechanical properties and the life of the product clay-based polymer nanocomposites are been used in plastic bottles [24].

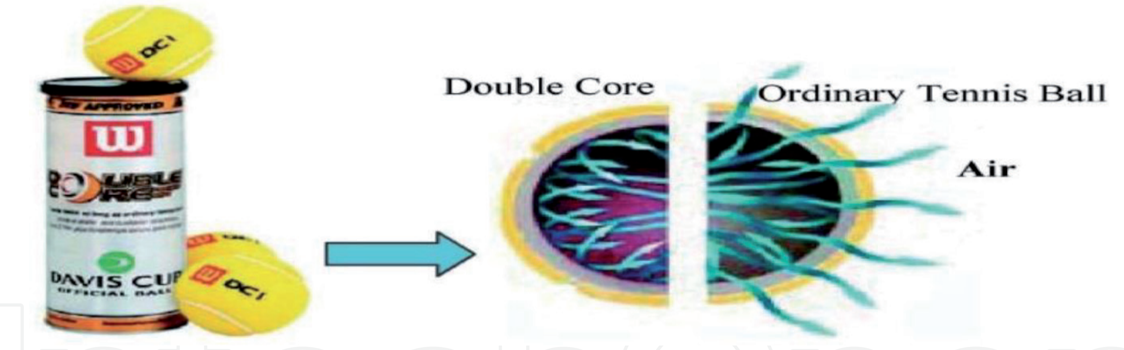

Figure 6.
The core of this Wilson tennis ball is covered by a polymer-clay nanocomposite coating.

Nanocomposites are also incorporated for beer bottle manufacture, so as to reduce many problems like biological and non-biological aspects, beer colloids instability, oxygen permeation, and change in taste due to light exposure. The double core Wilson tennis ball is the most recently commercialized sports goods (**Figure 6**), in which the coating of clay nanocomposites is done in order to maintain the internal pressure for a long period of time and also the core is coated by butyl rubber clay nanocomposite which doubled the shell life and acts a gas barrier.

6.2 Electronics and automobile sectors

In today's time, the biggest milestone is the incorporation or application of polymer/clay nanocomposites in the field of electronics and automobile sectors. Specifically to decrease the solvent transmission through polymers like elastomers, poly urethane, is the most impressive ability nanoclay incorporation. The poly nanocomposites help in the reduction of weight and processing cost so that they used by tire companies which are the major driving force for their usage. It is the naturally obtained materials which possesses low density. When the clay incorporated tires are compared with the ordinary ones then it is found that they have excellent mechanical properties and also improved gas barrier performance for tubeless tires uses [25]. Mostly for automobile tire manufacturing, styrene butadiene and natural rubber nanocomposites are preferred the most. It is due to their improved thermal properties and abrasion resistance that contribute to the long life of the tires. They have great applications in solar cells, transistors, battery manufacturing, etc.

6.3 Coatings

The most important modifying property of surfaces is coating. So, many methods and strategies are tried by the researchers to improve the surface properties of several products. The properties such as, excellent resistance for chemicals, better barrier properties, super hydrophobicity, and corrosion resistance are exhibited by nanoclay incorporated thermoset polymer nanocoatings [18]. The process parameters, such as dipping time, nature of surfactant, temperature, etc., determine the coating thickness. The thermoset polymer nanocoatings which are incorporated clay and nanosilver could improve the antibacterial properties and is used in medical sectors.

6.4 Bio-nanocomposites

The name "Bi-nanocomposites" is given as they are characterized as natural nanocomposite. To understand their essential roles in biological systems, their structures and properties are studied by biologists. Bio-nanocomposites are designed originally and are present to fulfill the needs of life and to meet surrounding environmental conditions so they can guarantee the living of the associated species. Natural materials are different in terms of structure and compositions but the design of bio-nanocomposites require biological molecules to consider them as synthetic building blocks, which is far more distant from the context of their own natural function. They are made of biopolymers and inorganic solids which has the dimension in the range of 1–100 nm. Due to their multidimensional properties such as antimicrobial activity, biocompatibility, and biodegradability they have several numbers of applications. The effective outcome of growing needs of bio-based polymers is the drastic reduction in the usage of fossil fuels. Bio-nanocomposites have easily replaced conventional non-biodegradable petroleum-based plastic as they are light weight and eco-friendly; they have become a sustainable that is future lasting material for use in high performance applications. As they are biocompatible, it makes them beneficial for biomedical applications and also makes them suitable for cosmetics and biotechnology applications. They have dominant significance in the future as green sustainable materials [26]. Bio-nanocomposites will act as substituents for the currently used petroleum-based polymers.

7. Uses of bio-nanocomposites

1. Bio-nanocomposites are used in cosmetics industries and also in the fabrication of implants, scaffolds, diagnostics, and biomedical devices.

2. They are also very beneficial as catalysts, contact lenses, and gas-separation membranes.

3. In the treatment of osteomyelitis, by the regeneration of tissue biopolymer-based nanocomposite is applicable.

4. Artificial bone implants involves nanostructured organic/inorganic nanocomposites which are useful in managing load-bearing bone grafts.

5. Using live cells of functionalized particles, controlled electrophoretic assembly of bioinorganic composite materials is done.

6. They are largely applicable in diagnostic, drug delivery, and tissue generation.

7. In industries, they are used as actuators. They are also used in the manufacturing of compostable bags as they are eco-friendly.

8. Applications of nanocomposites

Nanocomposites have been growing with a speedy rate so as their large number of applications. In the next 10 years, the worldwide production will exceed 600,000 tons in the following regions:

1. Superior strength fibers and films

2. UV protection gels

3. Drug delivery systems

4. New fire retardant materials

5. Anti-corrosion barrier coatings

6. Lubricant and stretch paints

Nanocomposites have also attracted the field of automotive and industrial applications by doing enhancements in especially the mechanical properties. They can be used or applied in the various vehicles types like engine covers, door covers, and timing belt covers. Other applications are usage as blades for vacuum cleaners, mower hood, covers for mobile phones, etc.

9. Future aspects

Modification of surface properties of nanoparticles by treating them with green agents for specific applications having specific improved microstructural properties like improved exfoliation, compatibility, and also thermal stability.

Advance optimization of the polymerization conditions during the preparation of the nanocomposites in order to get maximum output with minimal cost.

Detailed study on the effect of composition of the nanocomposites to build up the developed microstructures during the preparation activities.

Preparation of nanocomposites as well as their blends by using the materials like polymer blends along with the melt blending technologies. Hence, the advantages of the properties of the individual material as well as their coaction can be developed.

Using nanocomposites to make flexible batteries: "A nanocomposite of cellulous materials and nanotubes could be used to make a conductive paper. When this conductive paper is soaked in an electrolyte, a flexible battery is formed."

10. Conclusion

With the rapid development of nanotechnology in the past few years, the study of the nanocomposites has been increasingly become important in the development of new materials for advanced applications. To fulfill the growing needs of multifunctional materials, nanocomposites are the right choice as these are not only the versatile class of materials, but also have a high level of integrated association. It is a multidisciplinary field which includes the knowledge of scientific background as well as technological aspects to create macroscopic engineered materials obtained through nanolevel structures. These materials are suitable materials to meet the emerging demands arising from scientific and technologic advances. Outstanding potentials of nanocomposites can be exemplified by the massive investments from many companies and governments throughout the world. As a result, nanocomposites are expected to generate a great impact in world economy and business. The important aspects is that it provides plausible benefit to many of our industrial sector like electronics and electrical industry, chemical industry, transportation sectors, health care organizations, and above an all the protection of the environment. Hence, these are expected to have high impact on making the environment cleaner, greener, and safer in the coming years.

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